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VERNON MAP-AREA
BRITISH COLUMBIA

By
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Plate I. Typical view of Interior Plateau. Shuswap Lake from Blind Bay, looking west; Squilax Mountain (elevation 4,873 feet) is prominent in left background.

PREFACE

Since they were first described by G. M. Dawson in 1898, the rocks of the Shuswap terrane have been the subject of controversy. According to recent opinion they may be rocks of any age earlier than mid-Mesozoic, metamorphosed by late Mesozoic granitic intrusions. Thus they represent a condition rather than an age and have no stratigraphic significance.

The writer presents impressive evidence that, for the type locality, much of which is in Vernon map-area, this is not the case and that the original rocks, the superimposed metamorphism, and the accompanying minor granitic intrusions are all pre-Permian in age and probably Precambrian.

Shuswap rocks of the type area, except where disturbed by Mesozoic faults or folds, are generally rather barren of economic minerals. Other, similarly metamorphosed rocks are not necessarily so. This report presents criteria for distinguishing true Shuswap rocks from rocks similar in general appearance but of entirely different age and origin.

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OTTAWA, OCTOBER 1, 1956

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VERNON MAP-AREA, BRITISH COLUMBIA

CHAPTER I

INTRODUCTION

Geography

The Vernon map-area is bounded by longitudes 118 degrees and 120 degrees west and by latitudes 50 degrees and 51 degrees north, and is about 6,000 square miles in area. Geological mapping was, however, extended east of the 118th meridian and north along the shores of Adams Lake.

Several small towns are included in the map-area, mostly in the west half along the valley of Okanagan Lake and its northward extensions. The most important centres and their approximate populations are: Vernon (7,800), Revelstoke (3,000), Salmon Arm (1,200), Armstrong (1,100), Enderby (700), Falkland (400), Lumby (500), Chase (300), and Sicamous (300).

ACCESS

Access to the map-area is by both railways and roads. The main line of the Canadian Pacific Railway crosses the northern part and passes through Revelstoke, Sicamous, Salmon Arm, Chase, and Kamloops. One spur line runs south from Sicamous to Vernon and Kelowna and another south from Revelstoke to Arrowhead on the north end of Upper Arrow Lake just east of the area. A branch line of the Canadian National Railways from Kamloops passes through Falkland to Armstrong and shares the Canadian Pacific line to Vernon and Kelowna. The Trans-Canada Highway follows closely the route of the Canadian Pacific Railway across the northern part of the map-area. Provincial highway No. 5 enters the map-area from Kelowna along the Okanagan Valley and joins the Trans-Canada Highway north of Enderby. Another provincial highway runs from Kamloops through Falkland to Vernon, then continues east through Lumby, and thence passes southeast to Lower Arrow Lake and Nakusp. Secondary roads are plentiful in the west half but scarce in the east half of the area. New roads are being built at an amazing rate, into the timbered regions all over the map-area.

Although water transportation has long since yielded its standing to automobile roads and railways, intermittent tug and barge freighting is still provided on Okanagan and Shuswap Lakes as a service to comparatively isolated habitations on their shores. A Canadian Pacific paddle-wheel steamer currently gives valuable, if picturesque, service to all points on Arrow Lake between Castlegar and Arrowhead, making two complete round trips a week. Small boats, either hand or motor powered, can be hired at numerous small fishing and tourist lodges on the shores of Shuswap, Mara, Adams, Okanagan, Mabel, Sugar, and Upper Arrow Lakes.

A few trails give access to some areas not reached by road, but, in the east half, where roads are scarce and trails could be of much value to the geologist, they are practically non-existent. Most of those shown on topographic maps have almost disappeared through neglect and disuse.

PHYSIOGRAPHY

The Vernon map-area embraces parts of the Interior Plateau and Columbia Mountains (Bostock, 1948). For that reason it is partly rugged with high relief and partly lowlands with relatively low relief. The dividing line between the two divisions falls roughly along longitude 119 degrees or more exactly along the valleys occupied by Okanagan, Mara and Shuswap Lakes. The principal drainage is to the west and to the south, into the systems of Fraser and Columbia Rivers, respectively. The main parts of the Fraser system in and near the map-area are: Sugar Lake, Mabel Lake, Shuswap River, Shuswap Lake, Adams Lake, and South Thompson River. The main parts of the Columbia system are: Columbia River itself, flowing south across the northeast corner into Upper Arrow Lake, which lies just east of the map-area, and Okanagan Lake, which drains south into Okanagan River, joining Columbia River in the State of Washington.

The west half of the area lies mainly in the Interior Plateau and, although its relief is much less than that of the east half, many hills range up to 4,000 feet or more above the valleys and attain elevations of 3,000 to 6,000 feet. The valleys are broad and the hills, though they may be high, have gentle slopes and are set back from the valley bottoms giving the effect of low rolling topography (*see* Plate I). The hills are in general thickly covered with evergreens and only Mount Tod in the extreme northwest corner of the map-area reaches timber-line. Many of the hills in the west and southwest are flat-topped or mesa-like. These hills are capped by flat-lying, plateau-type Tertiary lavas which once covered most or all of the west half of the area and are the remnants left after erosion and downcutting by the main streams.

The large lakes, such as Okanagan, Shuswap, Adams, Mara, and Mabel, are essentially water-filled parts of long, inter-linked valleys. The longest and most important of these valleys is that occupied by Okanagan and Mara Lakes and extends north to Sicamous where it merges with the reticulating valleys occupied by Shuswap Lake. Okanagan Valley is joined in the vicinity of Vernon by other broad valleys that pass south from Falkland and Salmon Arm, and west from Lumby. The valleys are all at about the same elevation, 1,100 to 1,500 feet above sea-level. They are mostly cleared of timber and support important orchard farming, truck farming, and dairy farming.

In contrast to the west half, the east half of the area is mountainous with valleys that are narrow and deep. Summit elevations range up to nearly 10,000 feet and base elevations range between 1,400 and 2,000 feet. Most of the mountains extend well above timber-line, which is at an elevation of approximately 6,500 feet, and the higher parts are consequently open and meadowed or rugged and rocky (*see* Plate II A). Many glaciers and perennial snowfields cling to the peaks, especially in the Gold Range where the highest elevations are reached, and all mountain ranges bear the marks of alpine glaciation. The ranges that do not attain elevations above 7,000 feet are mostly round-topped and meadowed with flanks scalloped by many cirques made by long-extinct glaciers ('biscuit-board' topography). Ranges extending much above 7,000 feet elevation are jagged and craggy having been severely sculptured by alpine glaciation.

Most valleys, ranges, and main streams in the east half are long and trend approximately north. The main valleys are connected with poorly defined short, east-west valleys, except in the north where the pronounced valley of Eagle Pass trends approximately west from Revelstoke to Sicamous. This valley is narrow, deep, and sinuous but provides a fine low-level route through Monashee Mountains for the railway and highway.

Evergreen forests thickly cover the valleys and mountain slopes below timber-line and are the foundation of the principal industry, which is logging.

The Cordilleran ice-sheet of Pleistocene time covered all the area below 7,500 feet. Hills and ranges that do not exceed that elevation are rounded or, in the case of some hills capped by Tertiary lavas, flat-topped. The mountain ranges extending above 7,500 feet were apparently not overridden by the main ice-sheet but are considerably marked by alpine glaciation, both past and present. The main ice-sheet moved from north to south across the map-area but seems to have done little in the way of profound scouring. Relatively thin and vulnerable sheets of Tertiary basalt are striated and covered with glacial debris but are practically intact mesa-like units. The narrow, deep valleys of the east half are to some extent sculptured into U-shapes by valley glaciers fed from alpine sources but the broad valleys of the west half show few such effects. The retreating glaciers left a moderate amount of erratic boulders and till on the upland hills and filled the valleys with outwash debris. White, stratified silts and wave-cut benches up to a few hundred feet above the present valley bottoms testify to the damming and impounding of the drainage in immediate post-glacial times. The parts of valleys now occupied by long, finger-like lakes as Okanagan, Adams, Shuswap, and Mabel may have been sites of large stagnant, valley glaciers that disappeared after the other parts of the valleys had been filled with glacial outwash. Some such assumption may explain why the lakes, which are mostly quite deep, were not themselves filled. Kettles and drumlins are common in a few parts of the west half of the area.

Alpine and valley glaciation has dominated other agencies to produce the present forms in the mountainous east half of the area. Glacial cirques, arêtes, matterhorns, hanging valleys, U-shaped valleys, and terminal moraines are common features. Small glaciers still occupy cirques on the north sides of most peaks in the Gold Range and large ice-fields are found around such peaks as Blanket and Cranberry Mountains. All the glaciers are retreating rapidly.

VEGETATION

The forests in the Vernon map-area are typical of central British Columbia and are dominated by evergreens. Most particularly those in the east half of the area are of the type known as 'mixed' stands, because they contain a heterogeneous assemblage of trees including some deciduous species; pure stands of a single variety are rare.

The whole map-area is naturally forested except for the cleared land in the valley bottoms, the Okanagan dry belt, and the regions above timber-line, the latter being confined to the high mountains in the east half and Mount Tod in the northwest corner. The climatic difference between the parts of the map-area is great and is reflected in the vegetation. The low-rolling hills of the region immediately surrounding Okanagan Lake are included in the so-called 'dry belt' of central British Columbia and are devoid of timber or are sparsely dotted with the magnificent ponderosa (western yellow) pine. The low vegetation is characterized by sage-brush, chaparrals of thorny bushes, juniper, and small cactus, an assemblage typical of semi-desert conditions and hot, barren slopes. Away from this region, either to higher elevation on the west and east or along the main valleys to the north of Okanagan Lake, rainfall is heavier and timber grows more thickly and includes more and more Douglas fir, lodgepole pine, and aspen. In the moister regions ponderosa pine is absent. The high plateau regions east and west of Okanagan Lake and the moist regions around Shuswap Lake are timbered with Douglas fir, lodgepole pine, tamarack, cedar, hemlock, poplar, birch, and alder.

The vegetation in the lower valleys in the east half of the area is characteristic of temperate rain forests. Cedar, hemlock, white pine, and cottonwood dominate the forest growth in the valley bottoms, which are generally swampy and support lush jungle-like seasonal growth of swamp grass, tall ferns, skunk cabbage, and devil's club. The type of trees present on the slopes depends upon the altitude, direction of slope, and steepness. In general, cedar, hemlock, and white pine give way to Douglas fir, lodgepole pine, tamarack, and spruce as the altitude increases, and these, in turn, yield to spruce and balsam fir still higher up. At timber-line and in sheltered places above timber-line the trees are almost exclusively balsam fir, spruce, and whitebark pine. The steep, timbered mountain slopes are commonly and characteristically scored with 'green-slides', which are light green, narrow strips leading straight downhill from timber-line. These mark the routes of previous or annual snow avalanches that have swept all evergreen timber from their paths but have favoured the growth of a formidable jungle of tangled and bent mountain alder and devil's club. Devil's club grows at all altitudes to timber-line and is a considerable discomfort to the traveller. Between elevations of 5,000 and 6,000 feet a very thick underbrush (locally known as 'buckbrush') composed of willow and huckleberry is everywhere encountered and forms a shoulder-high mesh that is the despair of the exhausted climber.

BASIC INDUSTRIES

Agriculture is the principal industry in the west half of the area and is best known through the apple orchards near Vernon and Salmon Arm. Mixed farming, dairying, truck gardening, and the growing of small fruits, feeds, and cereal grains are important in the irrigated lands of the valley bottoms. The upland parts of the open 'dry belt' regions which are difficult to irrigate are used as range-land for beef-cattle. Timbered areas support a vigorous and growing logging and wood-products industry, which thrives especially in the luxurious rain forests in the east half. The only mineral production of any consequence is from the gypsum and anhydrite quarries at Falkland. Numerous small showings of metallic minerals have been explored and a few are still being worked, but no mine of any importance has as yet been developed.

Previous Geological Work

The earliest accounts of geological work done within the map-area are in the publications of G. M. Dawson and R. A. Daly. More recent work was done by C. E. Cairnes during 1930 and 1931 (1932)[1] in the southern parts of the map-area, and by S. S. Holland during 1932 in the extreme southwest corner of the map-area, unpublished manuscript, Dept. of Geology, Princeton University.

Field Work and Acknowledgments

Field work was commenced in the west half of the area by H. M. A. Rice in 1945 and continued by him in 1946. During the latter year the writer was senior assistant on his party. Mapping was continued by the writer and extended into the east half of the area during the field seasons of 1947 to 1951.

The writer is indebted to Dr. Rice for free use of his material and ideas, which included the recognition and subdivision of the Mount Ida group and, with the discovery of unconformities above the Shuswap terrane near Vernon,

[1]Dates in parentheses are those of publications listed in Bibliography at the end of this report.

the suggestion that the Shuswap is pre-Carboniferous in age. Much valuable and detailed information on the mineral deposits was derived from published reports and field notes by C. E. Cairnes.

Field work was facilitated by the capable cooperation of the following field assistants: K. Rose and H. D. Nicholson in 1945; H. D. Nicholson and W. Sparling in 1946; R. Skinner, C. A. Burns, and W. D. McCartney in 1947; R. Skinner, K. G. Hope, and R. M. Cristensen in 1948; A. N. Bahan, K. G. Hope and D. J. Laidman in 1949; W. D. McCartney, A. R. Bullis, and K. A. Buckboro in 1950; and W. W. Heywood, A. R. Bullis, and D. F. Stott in 1951.

CHAPTER II

GENERAL GEOLOGY

Most of Vernon map-area is underlain by rocks of the Shuswap terrane and the description and discussion of the age and structure of this controversial series is one of the principal contributions of this study. These rocks, rocks of the Cache Creek group of Permian and possibly Carboniferous age, Tertiary lavas, and late Mesozoic granitic intrusions underlie the entire area except for some Windermere rocks along the west boundary and two small areas of Triassic rocks in the southeast and northwest belonging to the Slocan and Nicola groups, respectively.

TABLE OF FORMATIONS

Era	Period or epoch	Formation (thickness in feet)	Lithology
Cenozoic	Pleistocene and Recent		Glacial gravels, morainal debris, silt, clay, lake and stream sediments
	Unconformity		
	Tertiary (Oligocene or Lower Miocene)	Kamloops group 500 - 3,000	Basaltic and andesitic lavas and dykes, pyroclastic breccia, tuff; sandstone, shale, conglomerate; coal
	Unconformity		
Mesozoic and (?) Cenozoic	Cretaceous and (?) Tertiary	Coast intrusions	Granite, granodiorite; aplite, pegmatite, and allied rocks; batholiths, stocks, dykes
	Intrusive contact		
Mesozoic	Triassic	Nicola group	Basaltic and andesitic lavas, flow breccia; limestone, conglomerate, slate
		Slocan group	Phyllite, slate, limestone; quartzite, gneiss, schist; minor volcanic rocks
Palæozoic	Carboniferous (?) and Permian	Cache Creek group 25,000	Argillite, andesite and basalt lava, tuff; sandstone, limestone, slate, phyllite, conglomerate
Precambrian or Palæozoic	Windermere or Lower Palæozoic	Lardeau series	Argillite, phyllite, mica schist, quartzite, and limestone
		Badshot formation 300	Limestone and marble

Era	Period or epoch	Formation (thickness in feet)	Lithology
Precambrian and (?) Palæozoic	Windermere and (?) Cambrian	Hamill series 8,000+	Quartzite, mica schist, argillite, phyllite, limestone
		Unconformity (?)	
Precambrian	Pre-Windermere?	Old Dave intrusions	Serpentinized ultramafic dykes
		Silver Star intrusions	Granite, pegmatite
		Three Valley intrusions	Gabbro or diorite
		Intrusive contact	
Precambrian	Pre-Windermere?	Shuswap terrane: Chapperon group[1] 5,000+	Argillite, chlorite schist, mica schist, quartzite, limestone
		Contact unknown	
		Shuswap terrane: Mount Ida group 60,000: Eagle Bay formation 30,000+	Chlorite schist, sericite schist, slate, limestone, quartzite, mica schist
		Shuswap terrane: Mount Ida group 60,000: Sicamous formation 7,000	Flaggy limestone, sericite schist, graphitic schist
		Shuswap terrane: Mount Ida group 60,000: Mara formation 3,000	Argillite, slate, sericite schist, chlorite schist, limestone
		Shuswap terrane: Mount Ida group 60,000: Tsalkom formation 4,000	Chlorite schist, slate, hornblende gneiss
		Shuswap terrane: Mount Ida group 60,000: Silver Creek formation 10,000	Slate, sericite schist, garnetiferous mica schist
		Shuswap terrane: Mount Ida group 60,000: Chase formation 4,000	Quartzite, calcareous quartzite, garnetiferous mica schist
		Contact unknown	
		Shuswap terrane: Monashee group 50,000+	Granitoid gneiss, mica-sillimanite-garnet schist, quartzite, hornblende gneiss, limestone, marble, dolomite, slate, phyllite

[1]Probably partly equivalent to Mount Ida group.

• SHUSWAP TERRANE

The name 'Shuswap' terrane was applied to a series of highly metamorphosed rocks near Shuswap Lake by Dawson in 1898 and was later extended by others to include a host of metamorphic rocks throughout southern British Columbia. Hypotheses applicable to these remote areas have been extended to include the type locality where, in the writer's opinion, they do not apply. In this report, therefore, the term 'Shuswap' as a stratigraphic unit is used much as Dawson intended it, but with some changes in the original mapping. The areal extent of the terrane as used here is shown on Figure 1. About two-thirds of the Vernon map-area is underlain by Shuswap rocks.

The Shuswap terrane is divided into three groups whose stratigraphic relation to one another is uncertain. Each group is comprised of sedimentary and probable volcanic rocks and each has undergone regional metamorphism. The

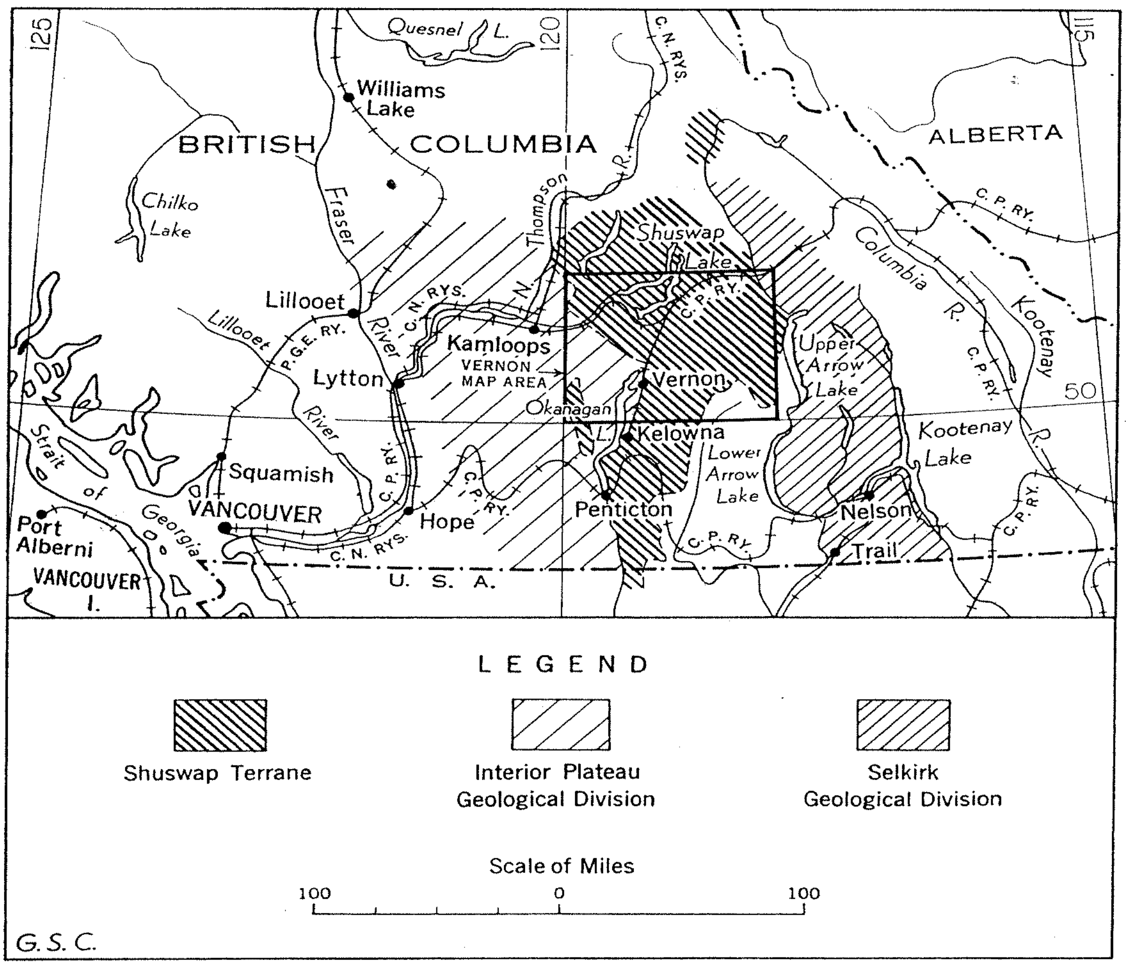


Figure 1. Distribution of Shuswap terrane.

three groups are similar in metamorphism and structure and, as a whole, are distinguished from neighbouring formations by a marked and abrupt contrast in stratigraphy, lithology, metamorphism, and structure.

MONASHEE GROUP

The Monashee group is named after the Monashee Mountains which occupy the area between the drainage system of Columbia River-Arrow Lakes in the east and that of Okanagan-Shuswap Lakes in the west. Most of the eastern half of Vernon map-area is underlain by rocks of the Monashee group.

Thickness

The total thickness of the group cannot be accurately determined because many faults interrupt the sequence and good stratigraphic markers are absent. Nevertheless, estimates can be made by determining the thickness of sections within individual fault blocks and adding those known not to repeat strata already included. The error introduced by measuring strata repeated by isoclinal folding is thought to be small, although perhaps not negligible. Folds in the Shuswap terrane are, with rare exception, small internal contortions of nearly horizontal strata. Internal isoclinal folds should have increased the thicknesses and yet the observed boudinage almost everywhere indicates thinning of the strata. The thickening due to folding may therefore have been cancelled by thinning of certain beds.

Thick sections are well exposed in the high mountains of the Gold Range where the relief is greatest and the outcrops are free of vegetation. The dip of the strata is also more regular there than elsewhere. A section of over 50,000 feet was measured in this region.

The following table gives the thickness of sections measured in the Monashee group.

Location	Thickness feet
Across Mount Thor from south of Vigue Creek to fault along Pingston Creek	50,000+
Along Eagle Pass, between Three Valley Lake and a point 3 miles west of Columbia River	15,000
Across the mountains immediately north of Greenbush Lake	12,000
Across the mountains immediately south of Greenbush Lake	12,000
Across Cranberry Mountain north of Vanwyk Creek	18,000
Across the range north of Gates Creek	21,000
In the following sections the strata are nearly horizontal and the relief small:	
Joss Mountain	6,000
Mount Griffin	5,600
Mabel and Sawtooth Ranges	7,500
Ridge east of Pingston Creek	9,500

The total thickness of the Monashee group is probably more than 50,000 feet for neither top nor bottom was observed in any section measured. No recognizable horizon markers were found, but dissimilarities in the proportions of rock types present at different places led the writer to conclude that there is little or no repetition within or between sections. For that reason and because of the great areal extent of the Monashee group the writer believes that 50,000 feet is an absolute minimum estimate of the total exposed thickness and that perhaps 60,000 feet is closer to the truth. Assuming that the rocks of the Gold Range have been brought to their present position by block-faulting, the oldest members of the group lie along the east side of the Range.

Lithology

Rocks of the Monashee group carry only a few kinds of minerals but differences in the amounts of these minerals and changes in their grain size, and differences in the texture, size, and colour of layers give an infinite variety of rocks. With a few local exceptions, the rocks exhibit metamorphism of uniformly high grade. Gneiss forms the bulk of the assemblage, but schist, quartzite, calcareous gneiss, and marble are common and are locally abundant. Continuous layers that contrast in appearance and composition evidently represent bedding and leave no doubt that the rocks are metamorphosed sediments. Metamorphic rocks that may have been derived from basic lava flows or tuffs are scarce. Contrary to popular beliefs, normal granite is not an important part of the terrane but pegmatite is. The amount of pegmatite in wisps, lenses, discontinuous layers, small sills, and dykes varies greatly from place to place. Locally it may be the dominant type of rock but the amount of pegmatite present has no direct relationship to the grade of metamorphism within the areas of generally high-grade metamorphosed strata. Where least metamorphosed, the rocks are slate, phyllite, and quartzite, and these grade through zones of increasing metamorphism into gneiss.

The simple sedimentary aspect of the rocks has been largely obscured by metamorphism. The layered character of outcrops and the textural appearance of hand specimens are to a great extent induced by deformation and recrystallization. For that reason, the description of secondary structures and lithology overlap. In detail a great variety of rock types have resulted, but in this report only the main or most distinctive will be emphasized.

High-Grade Metamorphic Rocks

Gneiss. Gneiss comprises most of the Monashee rocks except in local areas that have escaped intense metamorphism. The principal minerals are quartz, feldspars, biotite, muscovite, hornblende, pyroxene, sillimanite, and garnet. Accessory minerals or those only locally abundant are kyanite, staurolite, diopside, tourmaline, titanite, apatite, magnetite, and anthophyllite. Other minerals are so rare that they are curiosities.

In most gneiss the layers are from 1 inch to 3 feet thick and differ one from the other in the proportion of light to dark minerals. These layers may grade into one another or be sharply bounded and many are separated by thin partings or thick layers of schist. Most gneisses are even-grained rocks containing quartz and feldspar and are massive unless sufficient mica is present to produce fissility. All varieties of gneiss from quartzite and schist to granitoid gneiss exist, according to the relative proportions of quartz, mica, and feldspar present. Micas are aligned with their flat dimensions parallel with bedding except where scarce, and there they are more commonly pencil-like units or ribbons parallel with lineation. Certain gneisses nearly devoid of dark minerals closely resemble specimens of white granite. They are, however, interbedded with clearly sedimentary types and are evidently recrystallized sediments relatively free from iron.

Augen gneiss, which is widespread, is a variant of ordinary gneiss and ranges from rocks in which the feldspars are in small, parallel-oriented rhombohedrons surrounded by small grains of mica and quartz to rocks with mineral grains so large that the gneiss is a foliated or gneissic pegmatite. Lenticular concordant units of pegmatite that are a few inches to a few feet in length are common associates of all the gneisses.

The grain size of most or all the gneisses is more than 1 millimetre in diameter and commonly much more. Coarse-grained gneisses are widespread and most are mixed with abundant pegmatite. Apparently recrystallization to coarse types and the formation of pegmatites are parts of the same process.

Biotite is by far the most common dark mineral in the gneiss. Hornblende, although locally plentiful, is generally absent or in minor amounts. Biotite is disseminated through most of the gneiss, but locally may be concentrated in layers or lenses. Nearly every gneiss has thin partings, layers, or discontinuous wisps of relatively pure, black biotite lying along the foliation planes. Layers as thin as 1 millimetre may contain different proportions of dark to light minerals producing a finely layered gneiss no two layers of which are quite alike.

Garnet occurs in nearly every gneiss of the Monashee group, as an accessory mineral if not as a major constituent. The crystals are commonly subhedral and are scattered through the gneiss or crowded along certain layers. Most richly garnetiferous gneisses are recrystallized calcareous rocks. In colour the garnet varies from rust-brown and pink to deep dark red. The variety of a few of these garnets has been determined and most of them appear to be almandine.

Sillimanite is a common accessory of the gneisses although not so abundant, apparent, or widespread as garnet. Both garnet and a reddish biotite always accompany sillimanite. The sillimanite is commonly fibrous but may be in prisms up to 1 inch long and 1/8 inch thick. The fibrous type is white but where combined with biotite (as it always is) it gives the rock a distinctive pinkish tint. The coarse, prismatic type is glassy clear. Sillimanite is not distributed evenly throughout the gneiss but is concentrated along micaceous layers or fissile partings. It is consequently more common in mica-rich rocks than in massive granitoid gneiss. Lineation in sillimanite gneiss is commonly marked by the parallel arrangement of the prisms and fibres, but in some places the fibres are matted in random or radiating orientations that disregard lineation in the rock.

Augite, in small grains, is seen in thin sections from many gneisses and is accompanied by hornblende and biotite and by a plagioclase that is never less calcic than An_{50}. Augite is rarely large enough to be seen in hand specimens.

Muscovite is a common associate of biotite, particularly in those rocks that are rich in quartz, but is rarely prominent.

The composition and quantity of feldspar vary greatly from bed to bed depending on the other minerals present. Plagioclases range between An_{18} and An_{75} but most are close to An_{30}. In most sillimanitic rocks the composition of the plagioclase is in the narrow range between An_{28} and An_{35} but in some rocks of this type it may range from An_{18} to An_{45}.

Orthoclase is present in most gneisses that contain plagioclase less calcic than An_{55}. Microcline was seen only in highly quartzite gneisses or quartzite.

Hornblende is accompanied by biotite in most amphibolitic gneiss of sedimentary origin; in these rocks garnet is rare or absent. Most hornblende is in euhedral or subhedral grains scattered through the rock and exhibits colours in thin sections that range through dark brown, tan-brown, blue-green, and dark green. The composition of affiliated plagioclase has the wide range from An_{25} to An_{70}. Epidote, zoisite, pyroxene, carbonate, and quartz are common associates. In one example of boudinaged hornblende gneiss, augite appears in the scar-filling but is absent in both boudin and host.

Megascopic textures, due to reorientation by deformation, are evident in most gneisses, regardless of the mineral assemblage. Concentration and reorientation of certain minerals have produced a strong lineation in many rocks. Microscopic deformational textures are marked by the strong optical and dimensional orientation of quartz and by crushed feldspars, augen-like arrangement of feldspar rhombs, and other evidence of mineral reorientation. Nevertheless, the degree to which a deformational texture is apparent in thin section depends greatly on the mineral assemblage, no matter how evident the megascopic texture may be. For example, microscopic deformational textures are very evident in quartz-rich gneisses but in quartz-poor gneisses, especially in ones bearing hornblende, they are scarcely noticeable despite the strong development of megascopic lineation and foliation.

Schist. Schist is interbedded with gneiss throughout the Monashee group. It is, however, less abundant than gneiss and is rarely in beds more than a few feet thick. Most schist forms thin layers between thicker layers of granitoid or quartzitic gneiss; it grades into gneiss and the only real difference is that abundant mica makes the schist fissile.

Muscovite is abundant except in certain jet black biotite schists and in biotite-hornblende schists; sillimanite and garnet are plentiful in some schists. Some thinly laminated black schists, in particular, contain spectacular quantities of garnet in subhedral crystals up to 5 inches in diameter giving the rock a superficial textural resemblance to pebble conglomerate.

Most schists contain 'knots' or lenses of quartz, feldspar, and garnet, or dismembered thin beds of gneiss, and bear prominent lineation on surfaces of folia. Shearing was particularly active along the relatively weak layers of schist and imposed minor deformational structures in them. Optical and dimensional alignment is characteristic of the mineral grains in the knots and lenticular inclusions as well as in the thin, quartz-rich seams that commonly lie between the schist folia.

Quartzite. Quartzite occurs throughout the Monashee group, but the most readily traceable members are in the high mountains of the Gold Range and are shown on the map. The quartzites grade insensibly in appearance and composition into the granitoid gneisses, for most of them contain at least some feldspar and mica. Beds are commonly from 1 foot to 3 feet thick, but in some quartzites the layers may be only 1 inch thick and give a striped appearance to the outcrop. The quartzite layers are separated in some places by micaceous films, and in others by bands of schist or gneiss. Most quartzite is coarsely crystalline and translucent milky white or smoky grey in contrast to the opaque, porcelain-white appearance of layers in which feldspar is plentiful.

Thin, sharply defined layering in quartzites may be visible even in the absence of dark minerals, as layers of pure quartzite contrast distinctly with layers bearing muscovite or feldspar. Muscovite makes the rock darker in colour and the feldspar lighter.

Muscovite is the most common mica, but biotite is also common, particularly in the feldspathic quartzites. Where only a little feldspar is present it is ordinarily orthoclase or microcline, or both, but where feldspar is abundant plagioclase of composition An_{15} to An_{30} also occurs.

Of all the rocks of the group, quartzite is the most sensitive to the effects of deformation. Most of the foliation surfaces of the quartzite are scored with parallel grooves and ridges; the micas tend to be in parallel, ribbon-like units and the feldspar lies mostly in parallel, pencil-shaped structures. Quartz grains are mostly inequidimensional and are similarly oriented both dimensionally and optically. The grains are flat in the plane of foliation (parallel with bedding) and are somewhat elongated in the direction of lineation. Their cross-sectional dimensions commonly have a ratio of 6:1 or greater, and their optic axes (*c*) are remarkably well-oriented perpendicular to the lineation and parallel with the foliation. In some thin sections the optic axes give statistical concentrations of 25% when plotted on equal area stereo-nets (*see* section on Microscopic Structures, p. 119).

Marble and Calcareous Gneiss. Carbonate-bearing rocks occur in many places among the gneiss, quartzite, and schist of the Monashee group but comprise a minor proportion of the whole assemblage. Some of the largest carbonate members are shown on the map.

Pure marble is uncommon and most of the carbonate rocks contain quartz, diopside, tremolite, and feldspar, or lenses and broken pieces of gneiss and pegmatite. The bulk of the carbonate-bearing rocks contain such a large proportion of these minerals that they are best described as calcareous gneiss or calcareous quartzite. The weathered surface of the calcareous rocks is characteristically etched and pitted, the hard minerals standing out in relief as cellular, 'spongy' masses or as ribs and lenticular bosses.

Most of the weathered calcareous rocks range in colour through grey and blue-grey to buff and rust-brown but a few are sooty black. Most of these rocks effervesce vigorously with cold dilute acid but a few do not and are probably dolomitic.

Most carbonate grains are remarkably small, despite their association with coarsely crystalline rocks carrying sillimanite. The smallness of the grains is probably due to severe tectonic rock movements that ground them fine faster than they could grow under the recrystallizing effects of heat, pressure, solutions, and gases. In thin section most grains are seen to be somewhat flattened in the plane of foliation and finely twinned in two directions, one of which lies closely parallel with the foliation. In a few of the rocks, especially some of the black carbonaceous limestones, the calcite is so fine that the grains are scarcely identifiable under the microscope. Quartz grains in carbonate rock also exhibit dimensional and optical alignment except where the quartz is in scattered, isolated grains that were apparently protected by the soft matrix.

Megascopic evidence of deformation is plentiful and includes small-scale, tight, isoclinal folds, boudinage, 'pseudo-conglomerate' of quartzite beds or pegmatite dykes, and flow lines around hard lenses.

Non-carbonate minerals that occur in the calcareous rocks include the following: quartz, diopside, tremolite, orthoclase, plagioclase (An_{30} to An_{70}), titanite, biotite, muscovite, hornblende, and epidote. Of these, diopside is by far the most abundant and widespread; many rocks are formed entirely of diopside except for small amounts of calcite, quartz, and a red-brown biotite. Quartz in many of the quartz-bearing carbonate rocks appears to be a secondary mineral and to replace such minerals as tremolite. Many thinly layered hornblende gneisses of sedimentary origin contain carbonate and are interstratified with marble and other calcareous rocks. In many outcrops, thin, black layers of hornblende alternate with thin, green layers of diopside, epidote, and carbonate to produce a black and green 'ribboned' gneiss.

Intermediate-Grade Metamorphic Rocks

Gneiss. Between areas of low-grade metamorphism (*see* Map 1059A) and the main area of high-grade metamorphism lie areas of rocks that are of intermediate grade of metamorphism. The Queest Mountain block immediately east of Shuswap Lake also consists of rocks of this type, but low-grade metamorphic rocks are not known there. The gneiss of these intermediate zones resembles that of the high-grade zones except that it is finer grained, and kyanite and staurolite occur instead of sillimanite. Staurolite occurs as black, brown, and rust-red prisms ½ inch to 4 inches long, many of which have cruciform twins. Kyanite occurs as blue blades and laths ¼ to 1 inch long. Both minerals characteristically occur in the more micaceous layers and partings. The ratio of muscovite to biotite in these rocks is higher than in gneiss of the high-grade metamorphic zones. Pegmatite is rarely found with the rocks of intermediate grade.

Schist. The intermediate-grade schists contain much muscovite and biotite but are, nevertheless, dark rocks and lack the glittering lustre and white feldspar knots of the high-grade schists. Feldspar is present in these rocks but is not conspicuous in hand specimens. Garnet also is contained in many of these schists but not in conspicuous large grains as in the high-grade rocks. Kyanite and staurolite are more plentiful in the schist than in the gneiss but are not everywhere present.

Quartzite. The quartzite is fine grained and little recrystallized but most of it carries small flakes of mica.

Low-Grade Metamorphic Rocks

The low-grade metamorphic rocks are distributed as shown on Figure 2 and are the least altered members of the Monashee group. They grade in short distance into rocks of the high-grade facies.

Phyllite and Slate. Both phyllite and slate are black or dark grey and are well foliated, but phyllite is distinguished by visible mica which gives it greater schistosity. Bedding is visible in most slates and is parallel with the foliation except at, and near, the noses of recumbent folds. Many slates, particularly those on Cherry Ridge, contain small scattered pyrite cubes that weather to shapeless rusty patches forming 'spotted' slate.

Quartzite. Quartzite in the low-grade zones is a fine-grained micaceous rock similar to that in the intermediate-grade zone. It forms beds from a few inches to 5 feet thick intercalated with slate and phyllite. Most of it is grey to dark grey, the pure white variety being unknown.

Conglomerate. Only intraformational conglomerates composed of argillite pebbles in an argillaceous matrix occur in the Monashee group. They are best exposed on and near the summit of Silver Star Mountain. Few conglomerate beds are over 50 feet thick and they are intercalated with slate and quartzitic slate.

Internal Relations

The Monashee group has not been subdivided into stratigraphic units because of the complicated faulting and the uniform appearance of the strata. Stratigraphic markers have been traced within individual fault blocks but these could not be identified in other fault blocks. No unconformities are known within the group and no conglomerate, except intraformational conglomerate on Silver Star Mountain, was recognized.

Despite the stratigraphic complexity of the group it probably could be subdivided and correlated across the area by detailed mapping. The group has been considered as a granitic metamorphic complex but can be treated as a thick uniform sedimentary series with distinctive but lithologically similar strata repeated at different horizons.

Neither the bottom nor the top of the group is known but, for reasons to be given later, the youngest strata are believed to be those of the Queest Mountain block immediately east of Shuswap Lake, and the areas of low-grade metamorphism in the south. The oldest are thought to be those of the Gold Range west of Columbia River.

MOUNT IDA GROUP

The Mount Ida group is named after the prominent peak of that name immediately south of the town of Salmon Arm. Although Mount Ida itself is largely composed of Tertiary lava, it dominates, topographically a large area underlain by rocks of the group.

The Mount Ida group occupies a triangular area comprising about two-thirds of the northwest quadrant of the Vernon map-area. Along its south-western boundary the group is in fault contact with the Cache Creek group or is intruded by granitic rocks, and along its eastern boundary it is in fault contact with the Monashee group. Its northern limits beyond the map-area are not known.

The Mount Ida group consists of both sedimentary and volcanic rocks, the former predominating, but unlike the Monashee group, the group can be subdivided into lithologically distinct, mappable units.

The group as a whole has undergone low-grade metamorphism resulting in the development of chlorite and sericite schists from volcanic and certain sedimentary rocks. Locally, metamorphism combined with intense shearing has produced new mineral assemblages and rock texture and has to large extent obscured the original nature of the rocks. High-grade metamorphism has succeeded the low-grade metamorphism at a much later time and is mainly confined to the immediate vicinity of the granitic intrusions.

Thickness

Neither base nor top of the Mount Ida group has been recognized and measurements of thickness are complicated by the presence of recumbent folds and faults, and by the masking of bedding by cleavage. The recumbent folds should increase the apparent thickness but this is perhaps offset by thinning on the limbs. Estimates of thickness in the Mount Ida group are more firmly established than those in the Monashee group because the stratigraphy is better known, nevertheless, measurements differ substantially from place to place. The sum of the minimum thicknesses calculated for each formation gives a total of about 55,000 feet and the sum of the maximum thicknesses gives a total of about 75,000 feet. The writer considers 60,000 feet to be the most probable minimum thickness.

Chase Formation

The Chase formation was named by Daly after the town of that name on South Thompson River, where the smaller of two areas underlain by these rocks occurs. A third area of rocks that Daly considered to be part of the Chase formation lies near Summit (or Clanwilliam) Lake in Eagle Pass but the writer believes that these rocks belong to the Monashee group.

The full thickness of the Chase formation is not known as the base of the formation is nowhere exposed. Sections south of Little Shuswap Lake measured 3,000 feet and 6,500 feet, and another, along the valley of the Salmon River south of Salmon Arm, measured 7,000 feet in thickness. Minimum thickness of the Chase formation could be 3,000 feet but 4,000 feet is more probable and would give liberal allowance for repetition due to faulting and folding, which may account for the higher estimates.

White, grey, and blue-grey quartzite and calcareous quartzite are the diagnostic rocks of the Chase formation. They are bedded in units 1 inch to 4 inches thick that vary in shades of light grey. The weathered surface of the quartzites is generally coarsely granular or saccharoidal from the solution of calcite. Nearly all the quartzites are at least slightly calcareous and most are conspicuously so. Although no pure limestone or marble has been found, some of the rocks are quartzitic marble. Individual beds are commonly separated by thin films of sericite, and thicker, composite members by beds of muscovite-biotite schist. Mica schist comprises as much as 30 per cent of the formation but is not in as thick beds as the quartzite. Quartz, in thin sections of the quartzite, is seen to be in individual rounded grains with interstitial calcite. Diopside, muscovite, orthoclase, microcline, epidote, and apatite are common accessories. Small intrusive bodies of granite that stem from the nearby batholithic masses are numerous and are evidently responsible for much of the metamorphism.

Silver Creek Formation

The Silver Creek formation is named from a small community on Salmon River, 10 miles south of the city of Salmon Arm. A typical section of this formation is exposed opposite Silver Creek on the west flank of Mount Ida.

To some extent Daly's Salmon Arm formation is equivalent to the Silver Creek but in many places it is not. Therefore, although that name was used previously (Rice and Jones, 1948), the new name is adopted to prevent ambiguity. The Silver Creek formation lies in irregular strips and blocks mainly bounded by faults along a belt trending southeast through Little Shuswap Lake to Armstrong.

The thickness of the Silver Creek formation is difficult to measure because the bedding is relatively obscure in the schists and because the section has been expanded by sill-like intrusion of granite. Calculated thicknesses range from 10,000 feet in the Silver Creek locality to 20,000 feet at Little Shuswap Lake, but the best estimate seems to be between 10,000 and 12,000 feet.

Mica schist comprises the bulk of the Silver Creek formation but mica gneiss is also an important constituent. Muscovite is the principal mica in the schist but biotite also occurs. Other minerals are quartz, orthoclase, microcline, plagioclase (An_{20} to An_{35}), garnet, and amphibole. Some schists are nearly all muscovite and quartz and a few are mostly biotite and quartz. The quartz commonly forms thin interstitial ribs and layers between folia of schist or forms individual knots and augen sheathed by undulating folia. All stages of grain-size are found in the schists, from the finest in which delicate details of bedding are preserved to coarsely knotted schists in which all trace of bedding is destroyed. Sills that intrude the Silver Creek formation have entered along the folia of the schist largely by splitting them apart. As the separation of folia by the forceful intrusion is not regular the sills tend to pinch and swell or be somewhat lenticular. Close to the intrusive bodies much of the schist is impregnated with granitic components and has become granitoid gneiss. Besides gneiss formed in this way there are many intercalated beds of gneiss that represent sediments originally more quartzitic or feldspathic. Daly referred to the composite assemblage of schist, granite, and gneiss as a 'sill-sediment complex'.

The Silver Creek formation is a thick, unbroken succession of mica schist and gneiss conformably overlying the Chase formation. The bottom of the formation is placed at the top of the uppermost white quartzite member of the Chase formation.

Tsalkom Formation

This formation is named after Tsalkom Mountain, 5 miles north of Little Shuswap Lake. These rocks were included in the Adams Lake series by Dawson (1898) but the term embraced so many rocks now placed in other formations that Dawson's term is no longer considered suitable and a new one is proposed.

The Tsalkom formation is exposed in small blocks and irregular areas south and southwest of Adams Lake, east of Little Shuswap Lake, north of Armstrong, and south of Mara Lake.

Estimates of the thickness of the Tsalkom formation range from 4,000 feet east of Little Shuswap Lake to 15,000 feet south of Adams Lake, but the lower figure is regarded as most nearly correct. Difficulty in estimating the thickness of the Tsalkom formation mostly results from the rarity of recognizable bedding.

Most of the Tsalkom formation is lava altered to greenstone but some sericitic and chloritic sedimentary rocks are included. The original rock textures have in most places been completely destroyed through a combination of low-grade metamorphism and deformation.

The typical Tsalkom greenstone is a compactly foliated rock that can be split into tablets of any thickness but is not friable. The weathered rock is a blackish green or dark grey-green, with certain foliation planes pitted or etched by the solution of calcite. The fresh surface, a light greyish green, is flaked with chlorite and speckled with tiny black octohedrons of magnetite. The most highly sheared and altered rocks have a talcose appearance. The principal minerals are chlorite, epidote, calcite, zoisite, fibrous hornblende, albite, magnetite, and titanite. Quartz and calcite commonly occur in small veinlets. Some of the more massive types are felted uniform aggregates of chlorite but many are schistose, containing mats of aligned chlorite flakes. The schistose types are more prevalent east of Little Shuswap Lake, north of Armstrong, and southwest of Mara Lake whereas the more massive types predominate south of Adams Lake. Rarely, partly altered amphibole phenocrysts are preserved in the least altered greenstones.

Sedimentary members of the formation are sericite schist, sericitic argillite, and chloritic argillite, and some dark grey or black schist or slate. They are in relatively thin and intermittent beds intercalated with the greenstones. Many of them are tuffaceous or greywacke types which, because of metamorphism, look much like the non-bedded greenstones. Where bedding can be discerned it is mostly in tight, isoclinal, recumbent folds with cleavage parallel with the axial planes.

Although metamorphism is mostly low grade, intrusive bodies of granite have, in places, converted greenstone and schist to amphibole gneiss, amphibole-garnet-biotite schist, and mica schist. The amphibole prisms in these rocks are commonly in radiating fan-like clusters or are randomly scattered and oriented in the planes of foliation. The garnet is mostly euhedral or subhedral.

The Tsalkom formation is an uninterrupted, essentially volcanic unit lying conformably on the Silver Creek formation. The bottom is taken at the base of the lowermost volcanic member.

Mara Formation

The Mara formation was named for Mara Lake, along the west shore of which the formation is well exposed. Good exposures of the upper members are also found on the north shore of Salmon Arm in the vicinity of Canoe Point.

Much of Daly's 'sill-sediment complex' and Salmon Arm formation, and some of Dawson's Nisconlith series are now included in the Mara formation.

Measurements of the thickness of the Mara formation range from a minimum of 2,000 feet south of Notch Hill to a maximum of 4,500 feet on Salmon Arm. Repetition by folding and expansion by intrusion of granitic sills may, however, exaggerate the apparent thickness and the writer considers 2,500 to 3,000 feet to be the most probable figure.

The Mara formation consists predominantly of phyllite and mica schist, but volcanic and calcareous members are also plentiful. As the volcanic members are similar to those in the underlying Tsalkom formation and the calcareous members are similar to those in the overlying Sicamous, the formation can be regarded as an argillaceous transition between the two types of accumulation. Most of the argillaceous part has been metamorphosed to mica schist which is identical in all respects with that of the Silver Creek formation. Detailed descriptions of the rocks are unnecessary as the lithology of the components is similar to that of the respective Tsalkom, Sicamous, and Silver Creek formations.

The upper and lower limits of the Mara formation are ill-defined as the formation is conformable with, and somewhat transitional to, the adjacent formations. In practice the boundaries are drawn to include the bulk of the phyllite and mica schist and to exclude the main masses of volcanic rocks and limestone that lie below and above, respectively.

Sicamous Formation

The name Sicamous formation was given by Daly to certain characteristic limestones that occur in railway-cuts near Sicamous station, at the junction of Mara and Shuswap Lakes. Subsequent work has led to the enlargement of Daly's formation to encompass a thicker sequence, but the outcrops at Sicamous station still represent the formation. Some of the Bastion schists of Daly and the Nisconlith series of Dawson are now included in the Sicamous.

The thickness of the Sicamous has been estimated at between a minimum of 6,000 feet at Notch Hill, west of Adams Lake, and north of Canoe Point, and a maximum of 10,000 feet on the north shore of Shuswap Lake, at Blind Bay, and on Bastion Mountain. Seven thousand feet is considered a good estimate.

The rock that is characteristic of the Sicamous formation is a flaggy or platy impure limestone weathering blue-grey to blackish grey. Layers are ½ inch to 3 inches thick mostly with a parting of black graphite-sericite schist. White calcite in small veins, sill-like bodies, and lenticular knots are present almost everywhere and are diagnostic of the Sicamous limestones. Intercalated commonly with the limestone are beds of buff weathering, sericitic, calcareous schist. Graphite is a common constituent of the limestones and is occasionally found relatively pure in small pockets and lenses.

The Sicamous formation consists of three main lithological units of approximately equal thickness. The upper and lower units are predominantly platy impure limestone whereas the middle unit is predominantly sericitic, calcareous schist.

Deformation that created foliation in the schists has emphasized the platy, cleavable character of the limestones. Discontinuous bedding and thinly lenticular units are characteristic of the limestone and are marked on the surfaces of beds by slight hummocks and depressions 2 to 5 feet across. Fossils, if any were present, are not likely to have been preserved in rocks so deformed.

The bottom of the Sicamous formation is placed at the base of the lowermost large limestone stratum. Some limestone members in the Mara resemble the Sicamous but are small and scattered. The top of the Sicamous is clearly shown in road-cuts on the east shore of Blind Bay on Shuswap Lake and is sharply defined by the abrupt change from blue-grey and white limestone to chloritic, green, calcareous schist of the Eagle Bay formation. Both upper and lower contacts of the Sicamous are conformable.

Eagle Bay Formation

The name of this formation was derived from the community of Eagle Bay on the south shore of the Shuswap Lake between Blind Bay and Cinnemousun Narrows, the formation being well exposed along this shore, both on the beach and in road-cuts. The Eagle Bay formation includes much of Dawson's Adams Lake series and Daly's 'Greenstone' formation.

The main area occupied by this formation is in a broad irregular strip from Shuswap Lake northwest beyond the north boundary of the map-area to Adams Lake where one of the finest sections is exposed.

The Eagle Bay formation is divisible into three components: a thick succession of chlorite schist of volcanic and sedimentary origin at the base, followed by a band of mixed rocks, mainly limestone, named Tshinakin by Daly, followed, in turn, by more chlorite schist.

The two most complete sections of Eagle Bay formation lie along the shores of Adams Lake and between Canoe Point and Cinnemousun Narrows on the east arm of Shuswap Lake. These two sections give closely comparable figures for thickness, 25,000 feet and 23,000 feet, respectively, measured from the top of the underlying Sicamous formation to the bottom of the Tshinakin limestone. The Tshinakin is from 3,400 to 4,000 feet thick. Above the Tshinakin limestone are at least 4,000 feet of rocks that are lithologically similar to the rocks below. In all, the Eagle Bay formation is probably not less than 30,000 feet thick. Owing to the similarity of the rocks above and below the Tshinakin it was decided to combine them all into one unit. With more detailed mapping there is little doubt that they could be distinguished as separate formations.

The Eagle Bay formation consists of mixed clastic sedimentary rocks, limestone, and lava, most of which are considerably altered. At least 60 per cent of the rocks are of sedimentary origin consisting of argillite, greywacke, limestone, and quartzite, or their metamorphic derivatives. The metamorphism is generally low grade but in some small areas it is medium or high grade.

The compositions of both sedimentary and volcanic rocks are such that each has been altered to greenish chlorite-sericite schists and the rocks are not readily distinguished from each other. Both Dawson and Daly considered that most of the Eagle Bay was derived from volcanic rocks or basic intrusions rather than from sedimentary rocks.

Volcanic Rocks. The homogeneous, dark green schists that show no bedding are probably derived from lava. In their present condition they bear strong foliation of the type known as flow cleavage. Many are soft, talcy, and friable but others are cohesive and tightly banded so that they weather massively into thick tablets. Flow cleavage is, nevertheless, developed on a microscopic scale throughout these rocks, even within apparently massive tablets. The cleavage is, in places, visibly emphasized by discretely spaced layers of carbonate or quartz that have developed along the folia.

The green minerals that lend the characteristic colours to these schists are chlorite, amphibole, and epidote. Chlorite and hornblende are generally abundant but, in places, one or the other is scarce or absent. Some soft, talcy schists that appear to be composed predominantly of chlorite proved to consist mostly of fine, fibrous amphibole when seen under the microscope. Epidote is, with rare exception, a substantial component of these rocks and, in places, constitutes as much as 50 per cent of the mineral assemblage. Plagioclase is always present in greater or lesser amounts but is generally untwinned and difficult to distinguish from quartz, which is also a common constituent. The plagioclase averages An_{10} in composition but some is as calcic as An_{35}.

Two plagioclases are found in some rocks; in these calcic feldspar commonly occurs in carbonate veinlets that cut schist containing albitic feldspar. Carbonate appears mostly as veinlets along cracks and between folia or as scattered blebs and augen. Most is probably calcite although some is undoubtedly siderite. Magnetite is an abundant and conspicuous accessory in nearly all the green schists and takes the form of tiny octahedrons that are disseminated as individuals or are grouped in small lenticular patches. Biotite is not common except in small areas of superimposed, higher grade metamorphism. Where it does occur in the low-grade green schists it superficially resembles chlorite as it possesses the pleochroic colours greenish yellow and blue-green and has relatively weak birefringence.

The component minerals of the green schists are very small and are arranged in relatively uniform foliation textures. In hand specimens the component minerals can rarely be distinguished, except for magnetite and occasional large epidote or carbonate grains. In the average thin section most of the field is a mat of small, aligned chlorite and hornblende flakes, or both, studded with grains of epidote in clusters or as separate individuals. Feldspar and quartz are mostly in a very fine-grained mosaic. The whole may be homogeneous or, more commonly, divided into microscopic parallel layers within which one or other of the various minerals predominates. Commonly, flowage textures, swirl lines, tiny drag-folds around metacrysts, and augen disturb the uniform planar foliation. The augen are mainly epidote and carbonate. 'Pressure fringes' of chlorite or carbonate are commonly found on metacrysts of magnetite. Biotite, although of minor amount, appears to be late in its development with respect to most component minerals, for its platy crystals are randomly oriented and commonly cut across the pronounced foliation.

The relative proportions of the minerals range between wide limits. The green minerals, chlorite, epidote, and hornblende, ordinarily comprise 50 to 85 per cent of the total volume but vary greatly in their mutual ratio. Feldspar and quartz combined rarely exceed 30 per cent and most commonly are 15 to 20 per cent of the total. The carbonate content ranges from accessory status to 40 per cent.

Sedimentary Rocks. Texturally, the sedimentary rocks resemble those of volcanic origin. Most of them are impure argillites and quartzites that have been transformed into schists and phyllites and have lost much of the detail of their bedding in the process. Pure quartzite is not known in the Eagle Bay formation and pure argillite or slate is rare. On the other hand, both limestone and impure calcareous sedimentary rocks are abundant.

The appearance of the sedimentary schists varies greatly according to the mineral content. Many of them are green schists mineralogically similar to the volcanic rocks but are distinctly bedded on a fine scale and generally bear a higher proportion of quartz. They may have been greywacke or water-lain tuff. Others are sericitic and exhibit a silvery sheen on their folia surfaces. Still others are black, sooty, and carbonaceous. Most of the impure calcareous sedimentary rocks are highly sericitic, buff weathering, and friable. Quartz is the principal constituent of most of these rocks and is commonly accompanied by feldspar, most of which is albite but which may be as calcic as An_{35}. Chlorite, epidote, sericite, magnetite, and carbonate are common in the green rocks, and sericite, chlorite, carbonate, zoisite, and graphite are common in silvery grey, and black rocks. Biotite is rare and mostly yellow-green to dark olive-green in thin section. The grain size is generally small and relatively uniform. In thin section the rock is seen to consist of a mosaic of equant quartz through which are scattered the micaceous minerals in parallel orientation or through which pass parallel layers rich in sericite, chlorite, carbonate, coarsely crystalline quartz, or some combination of these minerals.

The limestones are massive, non-bedded to thin bedded or flaggy, impure, and schistose. The colours range from buff to blue-grey on weathered surfaces and from pure white to dark grey on fresh surfaces. Bedding is ordinarily marked by differences in colour and resistance to weathering but is sometimes obscure or lacking in massive, white, coarsely crystalline limestones. The Tshinakin limestone, for instance, contains such massive, unlayered limestone in its lower and upper divisions. The buff weathering parts of the limestones are apparently more dolomitic than the rest. Flaggy or platy limestone similar to that which characterizes the Sicamous formation is found in members stratigraphically below the Tshinakin, some of which was mapped as Sicamous by Daly. All the limestone, even the most massive looking and apparently structureless, shows microscopic evidence of deformation that is pronounced or extreme. Grains are flattened and appear elongated and parallel in cross-section; crystals are strongly twinned in at least two directions with the strongest sets oriented parallel with the long dimensions of the crystal; twin-planes are commonly spaced so closely that the optic character of the lamellæ cannot be determined with microscope and universal stage.

Conglomerate is a rare and relatively unimportant component of the Eagle Bay formation. The main occurrence is 5 miles northwest of Celista, a settlement on the north shore of Shuswap Lake, where it consists of pebbles of light grey to black quartzite that are well rounded and up to 1 inch in diameter. The pebbles are not well sorted and are closely packed in a sandy matrix. Towards the southeast this conglomerate is highly sheared and siliceous and its component pebbles are obscured.

A few scattered small areas of medium- and high-grade metamorphism are found in the Eagle Bay rocks, particularly in close proximity to intrusions of granite north of Shuswap Lake, but are too small to show on the map. These metamorphic rocks bear coarse sericite or muscovite, biotite, small garnet crystals, and black hornblende.

The basal member of the Eagle Bay formation is conformable with the underlying Sicamous formation and belongs essentially to the same phase of sedimentation as do the upper Sicamous members. The similarity lies in the calcareous thin-bedded nature of the sedimentary rocks and the dissimilarity lies in the presence of chlorite in the Eagle Bay rocks. The chlorite content may indicate the addition of tuff to the limestone being precipitated.

The calcareous chlorite schist grades upwards in a few hundred feet into white, talcy sericite schist with a peculiar pearly lustre, and thence into schist, phyllite, and impure quartzite. The lower 10,000 feet of strata is predominantly sedimentary in origin and is succeeded by about 5,000 feet of green schists of volcanic origin. These green schists vary in their appearance from place to place according to the degree to which they have been foliated and metamorphosed and, probably, also according to their original composition, but all are non-bedded rocks. Small amounts of argillaceous sedimentary rocks are, nevertheless, intercalated with them. From the top of the sequence of volcanic schists to the base of the Tshinakin limestone is an interval of about 7,000 feet containing a heterogeneous mixture of sedimentary rocks and green schist, but characterized by an abundance of small limestone members. Part of the sequence is marked as limestone on the map but includes a substantial amount of non-calcareous sedimentary rocks. Some intraformational conglomerate also appears in this sequence.

The Tshinakin is composed of three main parts. The upper and lower members are essentially identical lithologically and consist of massive white limestone that weathers buff and blue-grey and that is intercalated with minor amounts of green schist, phyllite, and calcareous sericite schist. The middle member is essentially the same rock as the beds intercalated with the limestone in the lower and upper members. Daly (1915) gives a good description of the Tshinakin limestone and the writer accepts his estimates of thickness which are: 1,600 feet for the lower member, 800 feet for the middle, and 1,500 feet for the upper, making a total of 3,900 feet.

The strata lying above the Tshinakin are poorly exposed in the map-area and can be best studied on the shores of Adams Lake. They consist of rocks that are similar in all respects to those in the Eagle Bay formation below the Tshinakin, as they include calcareous, green schist of sedimentary origin, sericite schist, black phyllite, impure quartzite, and chlorite schist of volcanic origin. The upper boundary of the Eagle Bay formation has not been drawn and the succeeding sequence of rocks is unknown. In the vicinity of Cinnemousun Narrows on Shuswap Lake the sequence of upper strata of the Eagle Bay is confused by faulting. In the vicinity of Adams Lake, north of the map-area, the upper strata are similarly complicated by faults and, also, are intruded by a granitic batholith.

CHAPPERON GROUP

The Chapperon group is named for Chapperon Creek, one of the tributaries of Nicola River that crosses the belt of these rocks near the southwest corner of the map-area. The group occupies a northward-trending belt about 30 miles long that varies between 1 mile and 6 miles in width, and over much of its length is overlain and masked by Tertiary volcanic rocks. The belt passes out of the map-area to the south, and its extent in that direction is not known. The northward extension is hidden by younger volcanic rocks.

Thickness

The thickness of the Chapperon group is difficult to determine because of severe folding and, probably, faulting. An estimate based on studies near the north end of the belt gives 5,000 feet. In so far as the section was made at one of the narrowest exposed parts of the belt one would suppose the figure to be a minimum. The base of the Chapperon group was not identified.

Lithology

The Chapperon group consists of a mixed assemblage of sedimentary and volcanic rocks that closely resemble those of the Eagle Bay formation in lithology, general mutual association, and metamorphism. Argillaceous sedimentary rocks or their metamorphic equivalents comprise the greatest part of the assemblage but rocks probably of volcanic origin are also common.

Some of the argillaceous rocks are dense, black to brownish black, and coarsely bedded, and are fairly tough and quartzitic. Calcareous intercalations up to ½ inch thick are common. Other argillaceous rocks are black, grey, or silvery grey, and thin bedded or platy. These, also, are commonly calcareous and some have intercalations of quartz. All the argillaceous rocks contain fine flakes of sericite which give a lustrous or silvery sheen to surfaces of folia.

The quartzites are generally very argillaceous. Some are thin bedded (⅛ to ¼ inch), very fine grained, light to dark grey, and interlayered with calcareous or argillaceous rock; others are thick bedded, fine grained, and colour-banded in shades of grey and blue-grey.

Calcareous rocks are abundant throughout the group but true limestone is rare. One type of limestone is white, massive, thick bedded, and blue-grey weathering, and occurs in beds as much as 5 feet thick which are sparsely distributed among argillaceous rocks and green schists. The other type has a similar occurrence and association but is grey, colour-banded, platy, buff weathering, and relatively fine grained. A bed of platy, white limestone northwest of Dome Rock Mountain shows small black marks suspected in the field of being fossils. These were examined by P. Harker of the Geological Survey of Canada but proved to be unidentifiable and dubiously of organic origin.

The green schists are evidently of both sedimentary and volcanic origin and are, in all important respects, identical to those of the Eagle Bay formation. Some are finely bedded and are intercalated on a small scale with other sedimentary rocks. Others contain no sign of bedding and occur in units of considerable thickness and compositional uniformity. Chlorite, epidote, and carbonate are among the more obvious components of the schists, just as in their counterparts in the Eagle Bay formation. The bedded green schists are the more highly calcareous, but some schists of volcanic origin also contain thin carbonate layers between foliation planes. Euhedral magnetite is a common accessory.

The Chapperon group is intruded in many places by Mesozoic granite and is, near these bodies, metamorphosed to grades higher than the prevailing regional, low-grade metamorphism. Phyllite, argillite, and impure quartzite are transformed into biotite and muscovite, garnet gneiss and schist. Chlorite schist, on the other hand, is changed to hornblende-biotite gneiss or hornblende gneiss. Coarse granulose textures, granitic sills and dykelets, and crumpled foliation attend the change in mineralogy.

Stratigraphic Relations

The Chapperon group has not been subdivided into formations because of the complexity of internal structures but is presumed to be a conformable sequence. The base of the group is not known. The top of the group is marked in two places by unconformities, one of which shows a marked angular discordance.

Salmon River Unconformity

An angular unconformity marks the western edge of the belt of Chapperon rocks at its northernmost extremity. The best exposures of the contact lie in road- and stream-cuts where the unconformity crosses Salmon River. There the Chapperon group consists of green schist, phyllite, and limestone cut by serpentinized ultramafic dykes of the Old Dave intrusions. The strata strike regularly between north 60 degrees and 70 degrees east and are vertical or dip very steeply to the northwest. The strata immediately above the unconformity consist of calcareous conglomerate and impure quartzite which grade upward, for a short distance, into argillite containing small beds of calcareous argillite, quartzite, argillaceous limestone, and intraformational conglomerate. These strata strike in directions north and northeast and dip relatively gently to the west and northwest. The angular discordance between the two stratigraphic groups ranges between 90 and 40 degrees.

The erosional surface of the older rocks is moderately irregular with angular undulations up to about 4 feet in amplitude. 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.

The serpentinized ultramafic dykes that intrude the Chapperon group are cut off at the unconformity and are therefore clearly older than the overlying strata.

No fossils have been found in the Chapperon group or in the sedimentary rocks above the unconformity. The younger rocks are, however, correlated with the Cache Creek group because of their striking similarity in lithology and because, where they extend into the adjacent Nicola map-area, they have been mapped as Cache Creek by Cockfield (1948) for lithological and stratigraphic reasons.

Dome Rock Unconformity

An unconformity marks part of the eastern margin of the Chapperon rocks where the belt crosses the southern boundary of the map-area. The contact trends almost due north from the boundary, passes for a short distance beneath the capping of Tertiary lava at Dome Rock Mountain, and is cut off to the north by a granitic batholith. The Chapperon rocks below the unconformity consist of green schist, phyllite, and small amounts of limestone which are cut by serpentinized ultramafic dykes of the Old Dave intrusions. The strata strike northwest to north and dip vertically or steeply east or west. The eroded surface of the Chapperon rocks dips vertically or steeply and trends very nearly parallel with the underlying strata but may, in places, be slightly discordant. The rocks immediately above the unconformity are calcareous conglomerates similar in all lithological respects to those at the Salmon River unconformity but have a fossiliferous matrix. Above these the rocks include argillite, quartzite, conglomerate, and andesitic lava, also similar to those above the Salmon River unconformity. They are erratic in strike and steep in dip due to folding and are also almost certainly disrupted by faults.

The fossils in the matrix of the conglomerate immediately above the unconformity were studied by P. Harker of the Geological Survey of Canada, who states that they "are believed to be of Permian age". (*See* Age and Correlation of Cache Creek group, p. 46, *F-5*.)

Correlation

The Chapperon group contains rocks that are in lithology and metamorphism similar to those of the Eagle Bay formation. The Chapperon and Mount Ida groups are therefore provisionally referred to the same series but are not necessarily stratigraphic equivalents. The evidence at the Salmon River and Dome Rock Mountain unconformities indicates that the Chapperon group is unconformably overlain by the Cache Creek group of Permian age and is therefore of pre-Permian age. Furthermore, both the regional low-grade metamorphism and the regional structure of the Chapperon group are absent in the younger strata, and must also be pre-Permian.

MUTUAL RELATIONS BETWEEN GROUPS OF THE SHUSWAP TERRANE

There is no direct evidence as to the exact mutual stratigraphic relations between groups of the Shuswap terrane, but some conclusions may be drawn from certain general facts regarding the character of the rocks concerned. These facts and conclusions are given below, but are partly drawn from data presented in the succeeding chapter on structure and metamorphism.

(1) The distinctive, thick units of the Mount Ida group that consist of schist, limestone, and basic volcanic rock are not present among the strata of the Monashee group. The Mount Ida and Monashee groups are, therefore, not stratigraphically equivalent.

(2) The rocks of the Chapperon group are similar to those of the upper part of the Mount Ida group (Eagle Bay formation). These groups may, therefore, be stratigraphically equivalent, at least in part, or may be close associates in a stratigraphic sequence.

(3) Rocks of the Monashee, Mount Ida, and Chapperon groups display unique regional metamorphism that is relatively uniform within each group, except where subjected to younger metamorphism. This metamorphism coincides with the first recognizable period of major deformation and is apparently unrelated to any large intrusive bodies. All three groups, therefore, pre-date the period of widespread syntectonic metamorphism.

(4) The regional metamorphism of the Monashee group is mostly high grade whereas that of the Mount Ida and Chapperon groups is low grade. If the grade of regional metamorphism was determined by the depth of burial, the Monashee group may be regarded as having been the most deeply buried and therefore as stratigraphically the lowest of the three groups.

(5) All three groups display structures that imply peculiar tectonic movements of regional scope, but these structures are best developed in the Monashee group. The groups appear, therefore, to have experienced the same period of deformation, but the Monashee group, possibly by virtue of its lower stratigraphic position and deeper burial, has been more profoundly and systematically altered.

In summary, the rocks of the three groups have certain characters in common leading one to suppose that they belong to a single series, the Shuswap terrane, but they show differences suggesting that the Monashee group is stratigraphically the lowest, succeeded by the Mount Ida and Chapperon groups which are partly equivalent to each other or are closely allied.

• PRE-PERMIAN INTRUSIONS

The Shuswap terrane is intruded by rocks of various types that can be subdivided according to composition, intrusive habit, and age. Most of those in Vernon map-area were intruded during late Mesozoic or early Tertiary times, or both, and therefore cut all Mesozoic and older strata. Another series of intrusions, however, is distinguished by being entirely confined to the Shuswap and is believed to be pre-Permian in age. Three distinct suites comprise these older intrusions.

THREE VALLEY INTRUSIONS

The oldest known intrusive rocks in Vernon map-area are small gabbroic or dioritic bodies found among strata of the Monashee group. These rocks are well exposed in the vicinity of Three Valley Lake, 12 miles west of Revelstoke, for which they are named, but are found in abundance elsewhere in the area, particularly in the north half of Gold Range.

Most are sills ranging in thickness from 1 foot to 15 feet, but some dykes up to 15 feet thick do occur and two have been seen to join sills as 'feeders'.

The Three Valley intrusions were emplaced before the 'Older' deformation, and their present geometry and mineralogy have been largely determined by it and the allied regional metamorphism. The sills have been dismembered, boudinaged, and converted from massive, structureless rocks to layered gneiss. Mineralogically, too, they have been altered from a rock that was probably a normal gabbro to garnetiferous hornblende-gneiss or garnet-biotite-hornblende schist which displays complex replacement textures in thin section.

The mineralogy varies from place to place within any individual sill according to the vicissitudes of metamorphism, and variation is most marked from the centre of a sill outward to the edges. Near the centre of a sill the average composition is: hornblende, 55 per cent; plagioclase (An_{55} to An_{80}), 30 per cent; garnet, 8 per cent; quartz, titanite, and apatite. Towards the edge of a sill the amount of hornblende decreases, whereas garnet increases both in size and amount; feldspar also increases in amount, and biotite becomes the chief dark component. Average composition of the rock at the edge of a sill is: biotite, 25 per cent; hornblende, 15 per cent; plagioclase (An_5 to An_{35}), 35 per cent; garnet, 15 per cent; quartz, titanite, apatite, and chlorite. Chlorite may replace garnet, biotite, and hornblende in part or entirely.

The foregoing generalization sums up the effect of at least three metamorphic processes. The first of these is a 'closed system' process that tended to break down the hornblende with concomitant development of garnet and calcic plagioclase. The second is the deformation that produced intense shearing, particularly in the outer layers of the sill and favoured the development of biotite schist at the expense of hornblende gneiss. The third is the action on the sill of hydrothermal solutions derived from, or more or less in equilibrium with, the granitoid host rock of the sills. The effects of this process were to replace the calcic feldspar by sodic feldspar and, during some late phases, to alter garnet, biotite, and hornblende to chlorite. Quartz is present as scattered grains in all these rocks but is thought to be a product of metamorphism rather than an original constituent. Titanite is an abundant accessory mineral in all phases of the sills.

Megascopically, the rocks are black and foliated with small, parallel, discontinuous streaks of white feldspar. The foliation occurs more or less throughout the sill and is concordant, but is more pronounced near the borders where the feldspar streaks are larger and more numerous and are commonly associated with biotite schist. Garnets are in anhedral grains up to 1 inch in diameter, spotted at random throughout the rock. Each garnet is surrounded by a corona of white feldspar visible both in the hand specimen and thin section. Both garnet and the feldspar of the corona have replaced hornblende, for both contain oriented remnants of hornblende grains. The plagioclase in most coronas is An_{80}, similar to that in the groundmass at the centre of some sills. Towards the sill borders, however, two feldspars are commonly present, one, the calcic plagioclase of the original rock and the other, albite formed by alteration of the first. The hornblende is light yellow-green to dark olive-green in subhedral to euhedral crystals with an extinction angle of 27 to 29 degrees. Pyroxene occurs in the central part of some sills.

SILVER STAR INTRUSIONS

The Silver Star intrusions are granitic bodies that were emplaced among the rocks of the Monashee group during the 'Older' deformation.

In contrast with the Three Valley intrusions, which were formed before the main deformation of the Shuswap (pre-tectonic), the Silver Star intrusions are considered to be related to it and mostly of the same general age (syntectonic).

The intrusions are mostly small, sill-like bodies, but many are dykes. They occur throughout most of the area occupied by the Monashee group but are particularly well exposed on the western slopes of Silver Star Mountain (shown on some maps as Aberdeen Mountain), about 15 miles northeast of Vernon.

Most of the Silver Star intrusions are pegmatite but a few, which may be locally abundant, are true granite both in texture and composition. Pre-tectonic and post-tectonic intrusions of both pegmatite and granite are known but most are syntectonic. Similarities of composition and occurrence, nevertheless, indicate a single extended period of emplacement that, in places, overlapped the period of 'Older' deformation.

Present among the rocks of the Monashee group are, however, pegmatites of two ages that differ in mineralogy and mode of occurrence. The younger group is post-tectonic and is probably allied to Mesozoic batholithic intrusions found elsewhere in the map-area and throughout the province. Most of these younger pegmatites are discordant, dyke-like bodies that follow joints or fill shatter zones near the 'younger' faults. The plagioclase in them ranges in composition from An_5 to An_{11} in contrast to the more calcic plagioclase generally contained in the Silver Star pegmatites. Black tourmaline and biotite, and occasionally rare minerals such as lepidolite, red tourmaline, green tourmaline, and beryl are found in some of the younger pegmatites, whereas the Silver Star pegmatites rarely contain any accessory mineral other than muscovite.

The Silver Star pegmatites are generally concordant sheet-like or lenticular masses that were emplaced between or scattered along the planes of foliation and bedding. In some places the pegmatite is in thick sills that exceed in amount the intruded rock and are more resistant to weathering. If, in such places outcrops are relatively few, pegmatite may be the only rock exposed, giving an erroneous impression of the amount present. Nearly all of the Monashee gneiss contains small streaks and lenses of pegmatite and, in places, sills. Many of the lenses are parts of once continuous sills that were emplaced during an early stage of the 'Older' deformation and were subsequently dismembered. Some of the thick sills, however, remain but show foliation and lineation parallel with that in the adjacent gneiss. Most bodies of pegmatite apparently developed during the 'Older' deformation as they lie along planes opened by it and yet show internal textures produced before it ceased. For example, pegmatites follow some of the axial-planar shears in the gneisses of the middle limb of the Fosthall Mountain fold and are, themselves, drag-folded and foliated, and show lineation parallel with that in the host rocks (*see* Plate II B). Pegmatite also occupies scar-fillings of boudinage.

The abundance of small scattered disconnected pegmatite bodies among the high-grade gneisses, without any visible connection to a parent source, leads one to suspect that each body was produced more or less independently by regional metamorphism rather than by intrusion from a great parent magma.

The mineralogy of the Silver Star pegmatites is simple and much the same everywhere. Orthoclase is the principal feldspar and occurs with plagioclase rarely outside the limits An_{20} and An_{30}. Quartz comprises at least 25 per cent and commonly is concentrated in layers or thin lenses along folia. Other constituent minerals, generally occurring in minor amounts, include muscovite, biotite, hornblende, and garnet.

Unlike the pegmatites, the Silver Star granites have an even grained, granitic texture, contain more accessory mica, and show definite intrusive relations.

Definitely pre-tectonic intrusions of granite are rare, but may include the pseudo-conglomerate breccia formed from small sills or dykes in limestones of the Monashee group, examples of which are exposed in road-cuts 8 miles east of Lumby. Most of the Silver Star granites are considered to be syntectonic because they bear the same types of secondary structures as the host rocks but of much less intensity, as though emplacement occurred near the end of the period of deformation.

The granites occur mostly at Silver Star Mountain, the Sawtooth Range between Tsuius and Joss Mountains, the south end of Park Range northwest of Sugar Lake, the Gold Range north of Blanket Mountain, and Ashton Creek 8 miles east of Enderby. They are medium grained (1 to 5 mm.) and are white to light grey. The principal constituents are plagioclase, orthoclase, and quartz; minor ones are biotite, muscovite, hornblende, and garnet; and accessory constituents are zircon, apatite, and titanite. Quartz comprises about 30 per cent of the rocks, and most of the remainder is divided more or less equally between plagioclase and orthoclase. The plagioclase ordinarily ranges between An_{20} and An_{30} but, in a few places, ranges to the limits An_{10} and An_{38}. Zoned crystals of plagioclase are common. The relatively undeformed granites contain biotite and hornblende but those that are strongly foliated contain muscovite and a little chlorite.

Microscopic textures of the strongly foliated granites include mortar structure, bent and broken feldspars, and interstitial streaks or 'streams' of quartz that are composed of elongated, curved grains with highly developed optical alignment. Quartz grains are never broken or crushed but are characteristically collected into 'streams' that curve around the larger feldspar fragments. Muscovite is seen occasionally to be bent or broken but ordinarily occupies shear planes in the rock, as though developed during deformation. Granites that are not so strongly foliated show relatively little microscopic evidence of cataclasis although some clusters of quartz grains in them show preferred optical orientations.

OLD DAVE INTRUSIONS

The Old Dave intrusions are serpentinized ultramafic dykes that cut rocks of the Chapperon group. They are named for Old Dave Lake in the southwest corner of the map-area, near which some of the dykes are best exposed. The dykes are difficult to outline but some are apparently up to 400 feet in width and 4 miles in length, although none has been continuously traced for that distance. The dips appear to be essentially vertical and the strikes are mostly north, parallel with the length of the belt of Chapperon rocks.

The Old Dave intrusions weather mottled buff, orange-red, purple-pink, rusty brown, dark green, and black. They are mostly composed of amorphous green serpentine that is in places mixed with an unidentified talcy mineral. Seams and veinlets of brown carbonate commonly lace the rock and give the buff or rusty colour. In some places veinlets and segregations of magnetite, chromite, and asbestos are fairly abundant but, as yet, bodies of commercial size have not been found.

The rocks are, on the whole, sheared to amorphous serpentinous masses that are segmented by interlinking sets of slickensided surfaces. In a few dykes remnants or pseudomorphs of the original minerals, which include both olivine and pyroxene, are preserved.

Intrusions of the Old Dave type cut rocks of the Chapperon and Mount Ida groups but are apparently absent from the younger formations. Small ultramafic dykes at the Salmon River unconformity intrude the Chapperon rocks but are unconformably overlain by rocks thought to belong to the Cache Creek group of Permian age. Small serpentinized ultramafic bodies also cut the Tsalkom formation on Tsalkom Mountain southeast of Adams Lake, and the Silver Creek formation on Mount Connaught, 12 miles northwest of Armstrong. The age of the Old Dave intrusions is provisionally considered to be pre-Permian.

• WINDERMERE AND EARLY PALÆOZOIC

HAMILL SERIES

The Hamill series is present only in the northeast corner of Vernon map-area but occupies much of the adjacent Lardeau map-area, east of Columbia River and Upper Arrow Lake. Much of the following description is drawn from the work of Walker and Bancroft (1929).

The Hamill series is underlain by the Horsethief Creek series but the base is not exposed in or near Vernon map-area. The upper limit of the Hamill, at the base of the Badshot formation, can however be easily recognized. The exposed thickness of the Hamill, measured in the vicinity of Mount Cartier southeast of Revelstoke, where the structures appear to be relatively simple, is between 8,000 and 10,000 feet.

The rocks of the Hamill series are predominantly sandstone more or less metamorphosed to quartzite. Low-grade metamorphic varieties are common north and west of Upper Arrow Lake, whereas medium-grade metamorphic varieties occur east of Columbia River, near Revelstoke.

Most of the low-grade metamorphic rocks are chloritic quartzite and quartz-rich chlorite schists but some slate and limestone are also present. Bedding is marked mostly by thin discontinuous films of the micaceous minerals rather than by distinct compositional differences between layers, and therefore outcrops appear relatively massive and homogeneous. The grain is universally very fine, especially in contrast with that of the Shuswap rocks. Quartz, chlorite, and sericite are the principal minerals, but biotite, amphibole, and garnet are present in some rocks that exhibit medium-grade metamorphism. The grains of biotite, amphibole, and garnet are generally poikolitic and relatively large, and are, in places, partly converted to chlorite by late processes of retrograde metamorphism. Feldspars are inconspicuous and are apparently rare in most of these rocks, but orthoclase and untwinned plagioclase ranging between albite and oligoclase have been recognized. Pyrite, magnetite, epidote, and carbonate are common to conspicuous accessories in many of the chloritic rocks. The colours of the weathered rocks are generally dark greys to greenish greys but some are so green from the abundance of chlorite, that, although of sedimentary origin, they superficially resemble greenstones or altered volcanic rocks. No rocks of volcanic origin have been recognized by the writer anywhere in the series.

Preferred optical orientation of euhedral grains is rarely apparent. Mica shows some orientation parallel with bedding, but the degree of regimentation is not high.

The medium-grade metamorphic rocks are mainly quartzite and micaceous quartzite, although muscovite gneiss and schist are characteristic. Biotite is nearly everywhere but is so dominated by coarser muscovite that most of the micaceous rocks display a silvery white sheen. Garnet and amphibole are common accessories. Blades of kyanite and prisms of staurolite occur together at one locality on the west flank of Mount Mackenzie, southeast of Revelstoke. They appear as subhedral crystals from 1/8 to 1 inch long with random orientation in layers of muscovite schist, intercalated with muscovite gneiss and quartzite. Green amphibolitic gneiss and white to dark grey marble comprise thin members that appear here and there in the stratigraphic section. The feldspars include orthoclase, microcline, and plagioclase, but are rarely abundant or conspicuous components of the rocks. The plagioclase is mostly An_{25} to An_{35}, varying, with the mineral assemblage, from stratum to stratum. More calcic plagioclases are particularly associated with the calcareous members and range in composition up to An_{75}. Except for the muscovite schists and certain gneisses in the northeast corner of the map-area and on the east side of Upper Arrow Lake, most of the medium-grade rocks are fine grained. The gneisses just mentioned are related to a swarm of sills, dykes, and small stocks of granite that intrude them, and the distinction between intrusive granite and intruded gneiss cannot always be made as the contacts are commonly blurred by granitization. They are similar to some gneisses in the Monashee group but differ in texture and structure.

The layering in the rocks is mostly directly inherited from sedimentary bedding, tectonic processes having had little or no effect. Lineation is commonly obscure and erratic in orientation. Preferred orientation of grains is generally of low order or is absent except for mica, which may be aligned parallel with bedding especially where present in high concentration, but in some rocks even mica shows random orientation. Quartz grains are generally equant with a random optical orientation except along shear planes where they are obviously deformed.

The Hamill series lies in fault contact with the Monashee group of the Shuswap terrane and the base is not exposed in Vernon map-area. The series has yielded no fossils and is generally regarded as entirely of late Proterozoic age and to be the uppermost formation of Windermere time. Nevertheless, recent mapping in the Nelson, West Half, map-area suggests that the Hamill may be partly Lower Cambrian in age (Little, 1949).

BADSHOT FORMATION

The Badshot formation is predominantly limestone and constitutes, for that reason, the best stratigraphic marker among the great thickness of non-calcareous rocks that lie above and below it. The Hamill and Lardeau series are separated by this formation. The Badshot formation appears on both limbs of the great Lardeau synclinorium and has been traced with remarkable continuity for many miles in Lardeau map-area but appears in the Vernon map-area for a short distance only, in the northeast corner near Revelstoke.

The thickness of the Badshot is reported to range from 150 feet to several hundred feet in Lardeau map-area, but is about 300 feet in and near Vernon map-area.

The limestone of the Badshot formation is mainly white or grey and relatively massive, but is commonly ribbed with siliceous layers. In many places it is recrystallized to marble. The formation includes also tabular or thin-bedded grey limestone, black carbonaceous limestone, and quartzite.

The Badshot is conformable with the Hamill and Lardeau series and is merely a calcareous phase of that sedimentation sequence. Walker and Bancroft (1929) considered it to be of Windermere age but more recent work suggests that it may be Lower Cambrian. From the eastern limb of the Lardeau synclinorium the Badshot formation can be traced south into the Nelson, East Half, map-area and thence across Kootenay Lake into the Nelson, West Half, map-area where, with some interruption, it appears to correspond with the lower Laib formation, which Little (1949) has identified as Lower Cambrian age. If the correlation of Laib with Badshot is right, the top of the Hamill series and the Badshot may be Lower Cambrian and the whole succeeding Lardeau series Cambrian or younger.

LARDEAU SERIES

Rocks of the Lardeau series occur principally within Lardeau map-area in the central trough of the great synclinorium. They appear in Vernon map-area in only two places, one east of Columbia River and the other midway along the west shore of Upper Arrow Lake.

For the most part the Lardeau series consists of slate intercalated with lesser amounts of quartzite, limestone, and conglomerate. The series is conformable with the underlying Badshot formation and is internally conformable despite the presence of intraformational conglomerate. The conglomerate contains well-rounded pebbles, mostly of quartzite and a few of vein quartz.

The age of the Lardeau series can no longer be certainly regarded as Precambrian but, for reasons advanced above, it may be correlative with post-Lower Cambrian formations in the Nelson, West Half, map-area.

• PERMIAN

CACHE CREEK GROUP

The name Cache Creek was first used for a rock unit in 1872 by Selwyn and applied to exposures at Cache Creek and Marble Canyon in Ashcroft map-area. Owing to a misidentification of some foraminifera collected in the type area the rocks were thought to be Eocene or Cretaceous. G. M. Dawson examined similar rocks at Stuart Lake in 1876 and collected supposedly Carboniferous fusulinids. He correlated the Stuart Lake rocks with Selwyn's Lower Cache Creek (Dawson, 1878, pp. 55-57). Recent re-examination of these fusulinids has shown them all to be a Permian age (Dunbar, 1932; and Thompson and Wheeler, 1942). Rocks of lithology similar to those described by Selwyn have since been recognized over wide areas in British Columbia and have been generally designated as the Cache Creek group or 'series'. No Cache Creek rocks have, however, been reported in southern British Columbia east of Columbia River and Arrow Lakes. Accounts of the present status and history of research on the group have been given by Armstrong (1949, pp. 47-51) and Thompson, Wheeler and Danner (1950, pp. 52-53).

Rocks of the Cache Creek group occur in the southwestern and southern parts of Vernon map-area, principally in a belt that enters the area at the northwest corner and extends southwestward to Vernon. Farther to the east and southeast, on line with that belt, are several disconnected areas of Cache Creek rocks. Other areas underlain by these rocks are in the southwest corner of the map-area in the vicinity of Whiterocks Mountain and along the western boundary.

In Vernon map-area, the Cache Creek group is overlain with angular unconformity by the Kamloops group of Tertiary age and by unconsolidated

Pleistocene and Recent debris. The contact between the Cache Creek and Nicola groups is not exposed in the map-area but in the adjacent Nicola map-area it is seen to be an erosional unconformity without significant angular discordance (Cockfield, 1948). The Cache Creek group is believed to rest with erosional unconformity on members of the Shuswap terrane. Two exposures of this unconformity are described above in the section on the Chapperon group and are known as the unconformities at Salmon River and Dome Rock Mountain. What is believed to be the same unconformity is exposed near Lavington 6 miles east of Vernon, near B. X. Creek 3 miles northeast of Vernon, and along a 10-mile strip trending northwest from Armstrong. The unconformity at these three localities will be described later.

The Cache Creek group appears to be an uninterrupted conformable sequence but the succession and thickness are difficult to determine due to numerous faults, absence of traceable stratigraphic markers, and the paucity of outcrop. Nevertheless, certain broad correlations and stratigraphic generalizations are possible and tentative thicknesses of the component parts have been estimated. The group can be subdivided into three units of approximately equal thickness, each containing rocks of somewhat similar lithology but in different proportions. The lowermost unit (Division A) is about 8,000 feet thick and is predominantly argillite; the middle unit (Division B) is about 8,000 feet thick and consists of andesitic lava, tuff, argillite, quartzite, and limestone; the upper unit (Division C) is at least 10,000 feet thick and consists of limestone, quartzite, argillite, and volcanic rock. A rough estimate of the minimum thickness of the whole group is 25,000 feet.

Argillite

Argillite is the principal constituent of Division A of the Cache Creek group, but is also an important component in the two other divisions. It ranges from grey and brownish grey to black but is most commonly dark grey. The state of induration can best be described as slaty although true slaty cleavage is not always present. Many of the argillites are fissile but most are massive and break with a blocky fracture, particularly those containing a high proportion of fine quartz grains. Black, lustrous slates or 'sooty' ottrelitic phyllites are common near bodies of granite and most of these have a crenulated or knotted appearance. Sedimentary banding is prominent only in argillites with a high content of sand and is shown by the alteration of grey and black. In these rocks the top of the beds may be determined by the sedimentary feature known as graded bedding. The argillites weather from light, chalky grey to dark grey, brown, and rust colours. The only fossils found in them were in extremely quartzitic, calcareous, or tuffaceous varieties.

The principal mineral content of the argillites is quartz, sericite, biotite, feldspar, chlorite, and opaque materials. Sericite commonly gives a lustrous appearance to the fresh surface of the rock in direct proportion to its abundance and grain size. Feldspar, when determinable, is about albite. Tuffaceous phases are soft and grey or greenish grey and marked by the presence of chlorite, epidote, zoisite, and actinolite and by angular fragments of quartz.

Argillite is widespread on the northeast side of the Pritchard-Falkland-Vernon fault-system where it adjoins Shuswap rocks. Again, in the southwest corner of the map-area argillites are abundant above the Salmon River and the Dome Rock unconformities. East of Vernon argillite is scarce in the Cache Creek, possibly because most of the basal division is faulted and not exposed.

Volcanic Rocks

Volcanic rocks are characteristic of Division B of the Cache Creek, but occur elsewhere in the group, particularly among the limestones of Division C. Lava is most common but tuff is locally abundant.

Attitudes of flows are not easily determined everywhere as flow contacts are rarely seen and most lavas are internally massive. The orientations of flow breccia can be used as tentative guides to attitudes but intercalated sedimentary or tuffaceous layers provide the only reliable ones. No pillow structures have been seen but nodular, bomb-like shapes are occasionally encountered. Vesicular or amygdaloidal structures are rare. All the lavas appear remarkably fresh except where in close proximity to granitic intrusions and faults.

The most typical lava is a dense, fine-grained, tough-breaking, andesitic rock ranging in colour through green, greenish grey, and grey to black. The grain size is commonly uniform and so small that individuals can scarcely be discerned with the naked eye. Hornblende or augite commonly speckles the surface as tiny black grains but are neither abundant nor conspicuous. Feldspar forms a felted mass of tiny needles.

Some lavas are lighter coloured than the typical kind and coarser grained (up to 2 millimetres). These are essentially fine-grained, grey diorites despite their extrusive nature. On the other hand, some lavas are aphanitic or almost cherty in appearance, and are green, bluish green, grey, brown, or black. These are massive rocks with a subconchoidal fracture, and are difficult to distinguish in the hand specimen from some indurated argillites or fine tuffs.

Porphyritic lavas are common and some are spectacular variants of the typical lava described, but they differ merely in the selective crystal development which gives rise to phenocrysts. Augite phenocrysts, in nearly equidimensional, euhedral black crystals up to 15 mm. in diameter, may comprise as much as 10 per cent of the rock. Feldspar, hornblende, and biotite phenocrysts are relatively rare.

Flow breccia is common and may occur in any type of lava. Most fragments are more coarsely grained and a lighter colour than the main mass in which they are embedded but otherwise the rocks differ little in composition. In places fragments of augite porphyry are embedded in a non-porphyritic matrix, in others the situation is reversed. In a few places fragments include sedimentary rocks, particularly argillite, which have broken from the walls of the lava conduit or have been rolled into the lava by the advancing front. 'Reaction rims' are common. The fragments range from ½ inch or less to 2 or 3 feet in length and, in some lavas, comprise most of the rock. Slab-like fragments are ordinarily in parallel alignment resulting in a banding or layering that can generally be regarded as concordant with the flow contacts.

Despite the fresh appearance of the Cache Creek lavas considerable alteration is disclosed in most thin sections. The finer grained parts and the feldspars have in most cases been largely converted to sericite, carbonate, zoisite, epidote, hematite, chlorite, albite, and quartz. The conversion is rarely so complete that the original minerals cannot be identified. The larger phenocrysts, particularly augite, are least affected, but may show thin layers of alteration along cleavage cracks or around the peripheries. The original feldspars vary in composition from lava to lava, but all are oligoclase or andesine between the extremes of An_{25} and An_{40}. Most are about An_{35}. Zoisite and sericite occur as thick swarms of tiny grains in the plagioclase, but albite, quartz, and calcite are mostly restricted to the surrounding groundmass. The augite is commonly free of impurities except for some of the smaller grains which may be partly or entirely changed to chlorite and epidote. The groundmass is ordinarily a confusion of secondary minerals, including hematite and other opaque materials. Some black or very dark lavas owe their colour to a copious opaque dusting of the groundmass.

Lavas of the Cache Creek, Nicola, and Kamloops groups contain many similar types and there may be some confusion in field mapping but assemblages as a whole are quite distinct. The Cache Creek lavas are relatively uniform in colour and texture, and are andesitic in composition. On the other hand, Nicola and Kamloops lavas commonly exhibit rather spectacular colours of reds, purples, greens, khaki, and browns. Furthermore, vesicular and amygdaloidal textures, that are almost characteristic of the Kamloops group at least, are practically absent from the Cache Creek rocks. In composition, too, the contrast between the basalts and trachytes of the Kamloops lavas and the rather uniform andesites of the Cache Creek group is striking.

The tuffs of the Cache Creek group are generally non-bedded, massive rocks not readily distinguished from some of the lavas or interflow sediments derived from lavas. The principal variety is mottled green to green-grey and is gritty or fragmental. The fragments in most tuffs are small and unsorted, and give a slightly powdery surface on the freshly broken rock. Water-lain tuffs range through green, grey, black, to rusty red, and, in a few localities, are in thin, sharply defined beds of greatly contrasting grain size, texture, and colour. Individual layers rarely exhibit well-developed grain gradation. Grey and green-grey argillaceous tuffs are common among the sedimentary rocks.

Like the lavas, the tuffs appear fresh in hand specimen but under the microscope are seen to be altered, much more so than the lavas. The original feldspars and mafic minerals are ordinarily altered beyond recognition and the resulting rock consists of conspicuous blebs of quartz in a nondescript groundmass of sericite, chlorite, carbonate, zoisite, albite, epidote, shreds of biotite, altered chips of feldspar and andesite, and hematite, clay, and other opaque minerals.

Most of the Cache Creek volcanic rocks lie southwest of the Pritchard-Falkland-Vernon fault-system, but many are mingled with the argillites northeast of it, especially north of South Thompson River. Tuffs occur with the lavas but are particularly well exposed on Whiskers Hill 2 miles due north of Pritchard where varicoloured, thinly bedded, water-lain tuffs occur; on the hills northwest of the north arm of Okanagan Lake; and on the north side of the valley of Coldstream Creek near Lavington.

Quartzite

Quartzite is not common in the Cache Creek group but is found particularly in Divisions B and C. Most of the quartzites are exceedingly fine grained and break with a subconchoidal, almost cherty fracture. Most are homogeneous but some contain thin beds of slightly different colours that range from medium grey to black and brown. Most are more or less argillaceous and a few are calcareous.

Limestone

Although limestone is the diagnostic rock of the upper unit (Division C) it does not form more than 40 per cent of the assemblage, which includes also lava, tuff, argillaceous tuff, argillite, and quartzite. Most of the limestone is finely crystalline, and generally white on fresh surfaces, weathering to light bluish grey or light buff-yellow. Except for relatively minor platy varieties the limestone is so massive that bedding is difficultly discernible. Some phases are flinty or siliceous and contain abundant small rounded or discoid nodules of black chert. Other types are coarsely öolitic or are composed largely of fossil fragments, most of which are crinoid stems. Argillaceous black limestone and highly calcareous tuff are common. Most of the best preserved fossils are found in these tuffaceous or argillaceous limestones.

Conglomerate

Conglomerate is rare within the Cache Creek group, but occurs as thin intraformational units bearing pebbles or fragments of argillite, slate, and volcanic rocks. The base of the group, however, is apparently marked by an unconformity overlain by a conglomerate consisting of a consolidated regolith or a water-lain accumulation of pebbles and fragments of the underlying rocks of the Shuswap terrane.

Chert

One of the characteristic rocks of the Cache Creek at its type locality and elsewhere in the province is banded chert but this rock is practically absent in Vernon map-area. Most of the chert that occurs there is in the form of nodules and lenses in the limestones and appears to be of concretionary origin.

Metamorphic Rocks

Metamorphic equivalents of the foregoing rocks include phyllite, ottrelitic phyllite, amphibolitic phyllite, hornfels, fine-grained mica schist, and chlorite schist. They occur only locally near intrusive contacts or faults. Metamorphism of the sedimentary rocks has not extended far from igneous contacts, and consists mainly of baking and the development of small mica flakes. The size of the associated intrusions is not necessarily any direct indication of the size of the metamorphic aureol for, in fact, some of the smallest plugs of granite are surrounded by relatively wide zones of phyllite or schist.

The alteration at and near the faults is principally of a hydrothermal nature and consists of bleaching or leaching, silicification, and mineralization.

Age and Correlation

Fossils have been found in Division C of the Cache Creek group at various places in Vernon map-area. Many are fragmental and too poorly preserved for accurate identification. There is, however, some general agreement, and it seems likely that Division C is of Permian age.

The collections and identifications made by different workers during the several years of geological mapping are indicated below under the applicable locality headings. The important localities are indicated on the map by the number corresponding to that in the report. All fossil localities in the Cache Creek group that are not numbered on the map yielded crinoid stems only.

FOSSIL COLLECTIONS FROM THE CACHE CREEK GROUP

F-1 *Location: Valley of Siwash Creek (west of Okanagan Lake)* 3½ *miles from mouth*

A. Collected by: C. E. Cairnes, 1930
Identified by: E. M. Kindle, 1930

Menophyllum ? sp.
Productus sp.
Athyris sp.
Spirifer sp.
Spiriferina ? sp.

"The presence of *Productus* affords evidence that this fauna is older than the Triassic. It is probably late Carboniferous age." E.M.K.

B. Collected by: H. M. A. Rice, 1946
Identified by: P. Harker, 1948

Bryozoa—*Fenestella* cf. *basleoensis* Bassler and other indeterminable genera
Foraminifera including: *Schwagerina* sp.
Parafusulina sp.

F-2 *Location: On ridge north of Siwash Creek, 1 mile north of F-1*
Collected by: H. M. A. Rice, 1946
Identified by: P. Harker, 1948

Duplophyllum sp. cf. *D. septuarugosum* Moore and Jeffords
Crinoid stems
Derbyia spp.
Meekella sp.
'*Productus*' sp.
Productus sp. cf. *P. artiensis* Tschernyschew
Linoproductus sp. cf. *L. aagardi* (Toula)
Marginifera sp.
Striatifera sp. cf. *S. compressa* (Waagen)
Rhynchopora sp. cf. *R. nikitini* Tschernyschew
Stenoscisma sp. cf. *S. venusta* (Girty)
Spiriferella sp. cf. *S. rajah* (Salter)
Spiriferella sp. cf. *S. saranae* (de Verneuil)
Martinia sp.
Ambocoelia sp.
Hemiptychina ? sp.

"Two species referable to the *Spiriferella* group are recognized in this collection. This group is very characteristic of the Permian of Eurasia and the Arctic regions where they are often associated with species of *Marginifera, Striatifera* and *Stenoscisma.*

"The species of *Meekella* and *Ambocoelia* are very similar to forms from the Permian of Texas; the species referred to *Derbyia* also have strong North American affinities.

"Typical Pennsylvanian forms are absent, with the possible exception of *Derbyia;* this genus does, however, extend into the Permian and the ranges of its species are not well defined. The fauna as a whole is considered to be Lower or Middle Permian." P.H.

F-3 Location: On the east-flowing tributary of Equesis Creek (north of Siwash Creek), 4.8 miles west of the confluence with Equesis Creek

Collected by: H. M. A. Rice, 1946
Identified by : R. T. D. Wickenden and P. Harker, 1948

Foraminifera
Corals
Meekella sp.
Small brachiopod fragments

"There are two or more genera of fusulinids in the rocks of this locality. The most common kind is a species of *Parafusulina* and some species of *Schwagerina.* The genus *Parafusulina* is most common in the middle Permian. The formation at this locality is probably of Middle Permian age." R.T.D.W.

F-4 Location: Four miles west of Falkland near Salmon River at valley level

A. Collected by: C. E. Cairnes, 1929
Identified by: E. M. Kindle, 1930

Chonetes sp.
Stropheodonta ? sp.

"The *Chonetes* which is present in such numbers as to comprise a large share of the rock does not alone offer any satisfactory evidence as to the age represented." E.M.K.

B. Collected by: H. M. A. Rice, 1946
Identified by: R. T. D. Wickenden, 1947
Foraminifera

"Although the rock is full of fusulinids most of them are too weathered to be certain of the wall structure in thin sections. There are at least two kinds both rather small. In one section part of the wall structure was preserved. This indicates a specimen belonging to the *Schwagerina* group. The genera of this group nearly all occur in the Permian although one genus, *Triticites,* is fairly common in the upper part of the Pennsylvanian as well as in the lower part of the Permian. It is possible that some of the specimens in this rock belong to this genus and at present I consider that the rock may be Lower Permian or Upper Pennsylvanian." R.T.D.W.

F-5 *Location: Two miles southwest of Whiterocks Mountain southwest corner of the map-area*

Collected by: A. G. Jones, 1947
Identified by: P. Harker, 1952

Coral fragments
Fragments of fenestellid bryozoa
Crinoid stems
Linoproductus sp.

"The fossils are scanty and badly preserved but are similar to those contained in other collections from the Cache Creek group. (They) are believed to be of Permian age." P.H.

F-6A *Location: North of Monashee Pass highway, northwest side of Kettle River, on crest of ridge, 3 miles due west of Keefer Lake*

Collected by: A. G. Jones, 1951
Identified by: P. Harker, 1951

Brachiopod fragments, indet.
Fragmentary zaphrentid coral, indet.
Brachiopod fragment, probably *Spiriferella* sp.

F-6B *Location: One-half mile south of F-6A*

Collected by: A. G. Jones, 1951
Identified by: P. Harker, 1951

Fragmentary fossils, indet.
Crinoid ossicles

F-6C *Location: One mile south of F-6B*

Collected by: A. G. Jones, 1951
Identified by: P. Harker, 1951

Fragment of *Linoproductus* sp.
Fragment of *Dictyoclostus* sp.
Other fossil fragments, indet.

"All those fossils (of F-6A, F-6B, F-6C) are stated to be from the Cache Creek group. The fossils are too fragmentary for accurate identification. They are all undoubtedly Upper Palæozoic in age and in so far as their preservation allows comparison, they are similar to those from other collections made from the Cache Creek group." P.H.

F-7 *Location: Along Monashee Pass highway, 2½ miles west of summit*

Collected by: C. E. Cairnes, 1929
Identified by: E. M. Kindle, 1930

"(This) lot shows a fossil fragment which displays parallel lath like structures. These remind me of the latteral (*sic*) ridges of *Lyttonia* but if they do represent this brachiopod the rest of the shell is absent and it is impossible to offer a definite opinion. If the problematic fossil fragment . . . is a *Lyttonia,* as I suspect, this horizon is Permian." E.M.K.

F-8 Location: Low hills immediately north of Bluenose Mountain, 1½ miles south of Lavington

Collected by: A. G. Jones, 1947
Identified by: P. Harker, 1951

Syringopora sp.
Crinoid fragments
Productid fragment—possibly *Linoproductus* sp.
Fragmentary corals: species of *Clisiophyllum.*

Lophophyllum, and *Hapsiphyllum* are represented.

"The fossils are scanty and badly preserved but are similar to those contained in other collections from the Cache Creek group. (They) are believed to be of Permian age." P.H.

Although the Permian, probably Middle Permian, age of Division C seems to be well established the ages of Divisions A and B can only be stated as Permian or ? Carboniferous or older. The entire succession seems to be conformable and the lithological components to differ in proportion only but there is little reason to suppose that the earliest part of the group may not be at least as old as Pennsylvanian.

Certain areas of rocks have been correlated with the Cache Creek group without the benefit of palæontology but on the striking similarity of lithology and stratigraphy. These rocks include those which lie above the unconformities at Lavington, B. X. Creek, and the upper Salmon River, and also those comprising a small fault-block east of Salmon Arm. The latter assemblage contains limestone that has yielded crinoid stems but no diagnostic fossils.

Lavington Unconformity

The Lavington unconformity appears on the north side of Coldstream Valley, which leads east from Vernon to Lumby, and is about 2 miles west of Lavington. More exactly, the unconformity lies on the west slope of a small valley that descends steeply into Coldstream Valley, and which is known locally as 'Keefer Gulch'. The rocks below the unconformable contact are micaceous phyllites, calcareous quartzites, mica schists, and pegmatite belonging to the Shuswap terrane. They strike northwest and dip at about 50 degrees northeast. 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 comprising a more or less flat-lying flow about 10 feet thick. This is overlain by calcareous tuffs and a layer of white, massive limestone about 20 feet thick which, in turn, is overlain by more flows of augite porphyry that contain small pods of limestone. No fossils have been found in the limestone but the lithology of the upper succession is identical with that of typical sedimentary and volcanic rocks of the Cache Creek group. Tuffs, lavas, and fossiliferous sedimentary rocks of the Cache Creek group outcrop for several miles to the east but are separated from the strata that overlie the unconformity by a fault that trends north along 'Keefer Gulch'. The rocks above the Lavington unconformity cannot positively be established as Cache Creek but their lithological similarity and proximity to known Cache Creek strata make correlation almost certain.

B. X. Creek Unconformity

The main exposure of the B. X. Creek unconformity lies 3 miles northeast of Vernon on the north side of B. X. Creek. The outcrop of the contact trends in an arcuate path around the slopes of a conical bare hill and lies in a position midway between the base and the crest at more or less a constant elevation. The rocks below the unconformity comprise the base of the conical hill. They strike northwest and dip steeply and are mica gneiss and marble of the Monashee group cut by pegmatite and granite of the Silver Star intrusions. The unconformable contact is marked by a lithified regolith of the underlying rocks that are weathered, leached, and brecciated. The rocks above the unconformity strike east and dip north at low angles and comprise the upper part of the conical hill. They are grey and green andesitic lava, grey argillaceous tuff, conglomerate containing pebbles of slate and tuff, graphitic argillite, calcareous tuff, and limestone; all of which closely resemble rocks of the Cache Creek group.

The upper assemblage of rocks contains no fossils and is separated from areas of known Cache Creek strata by older rocks and overburden. The unconformity is presumably also present to the southeast, across B. X. Creek, where identical suites of rocks occur but where the actual contact between them is not exposed.

Glenemma (?) Unconformity

Along a line leading northwest from Armstrong for a distance of about 12 miles, rocks of the Cache Creek group are believed to be in unconformable contact with members of the Mount Ida group. The contacts have, unfortunately, nowhere been seen as the region is one of grassy flats and sparsely timbered low hills where outcrop is poor. On the east end of the line of contact the underlying rocks are mainly hornblende gneisses of the Tsalkom formation but on the west end where the line ascends steeply to the Spa Hills the underlying rocks are quartz-biotite schists of the Silver Creek formation. The rocks in the zone immediately above the contact include massive to platy white limestone, conglomerate, amphibole-garnet-mica schist, sericite schist, and grey knotted phyllite schist in approximately that order of stratigraphic ascent. The conglomerate is siliceous and highly deformed. The pebbles are closely packed in a matrix of sericitic schist and are largely indistinct due to a deformation that has elongated them to several times their present diameter. They are composed of quartz, quartzite, amphibole gneiss, and, possibly, granite or biotite gneiss. Some of the largest elongated pebbles are rods 3 inches in diameter and a foot or more in length, but most pebbles are much smaller. The conglomerate has intercalations of sericite schist and amphibole-garnet gneiss some of which bear spectacular fans of radiating hornblende crystals. Knotted grey and lustrous black phyllite lies above the conglomerate zone and passes stratigraphically upward to less metamorphosed slate and 'sooty' argillite that is characteristic of Division A of the Cache Creek group. The contact is complicated and disrupted by metamorphism and faults. The western end of the contact is particularly indistinct because metamorphism has largely destroyed the original clastic textures of the rocks and has produced nearly identical schist and gneiss on both sides of the contact.

No fossils are found in the Cache Creek rocks close to the supposed Glenemma unconformity.

• TRIASSIC

NICOLA GROUP

Rocks ascribed to the Nicola group are found in a small, poorly exposed area in the valley of South Thompson River at the western edge of the map-area. They consist predominantly of lava, with some tuff, slate, and conglomerate. The lavas are mostly green andesites, many of them bearing phenocrysts of augite or exhibiting flow breccia textures. Red and purple augite porphyries are seen in lesser amounts. The lavas are massive and relatively fresh looking but, in place, are somewhat epidotized or silicified. Green tuff, green-grey argillaceous tuff, and black slate are intercalated with the lavas in small amounts. Conglomerate appears in one or two outcrops and bears angular fragments of augite porphyry, andesite, chert, quartzite, and crinoidal limestone of the types seen in the Cache Creek group.

The base of the Nicola group was not recognized in the Vernon map-area, but Daly (1915) described the contact between it and the underlying Cache Creek group from a locality just west of the map-area. In that place the basal member of the Nicola is a conglomerate up to 150 feet thick composed of fragments and pebbles derived from Cache Creek strata. The contact appears to be an erosional unconformity without significant angular discordance. The Nicola in the map-area is overlain with angular unconformity by rocks of the Kamloops group of Tertiary age.

The Nicola group has yielded no fossils in the Vernon map-area but is dated as Upper Triassic in the adjacent Nicola map-area (Cockfield, 1948).

SLOCAN GROUP

The Slocan group underlies large regions from the south end of Upper Arrow Lake eastward. In Vernon map-area, however, only a small wedge near the southeast corner is underlain by these rocks.

The group has been subdivided into groups and formations in areas to the southeast but is treated as a unit in the present report.

In Vernon map-area the Slocan group consists of argillaceous rocks, principally phyllites and slates, but also includes limestone, quartzite, gneiss, and schist. The slate and phyllite is black to grey, fissile to platy-weathering, and is commonly quartzitic or calcareous. Quartzite is intercalated with the slate in beds up to 10 feet thick. It is fine grained and grey, and weathers to rusty brown. The limestone is mostly fine grained, thin bedded or platy, and ranges between greyish white and black, depending on the argillaceous content.

Gneisses and schist characterize the southern extension of the group near West Demars and Arrow Park, at the south end of Upper Arrow Lake east of the area, where granitic intrusions are particularly abundant and have metamorphosed the host rocks. They are mostly fine-grained rocks, carrying muscovite, biotite, garnet, hornblende, microcline, plagioclase, orthoclase, and quartz. The assemblage in part superficially resembles gneisses of the Monashee group but are finer grained and lack intense deformational structures of types comparable to those of the 'Older' deformation. Furthermore the metamorphism is clearly due to nearby granitic intrusions.

The group has yielded no fossils in the immediate vicinity of Upper Arrow Lake but is dated elsewhere as Triassic in age. It may be partly equivalent to the Nicola group.

• MESOZOIC AND (?) TERTIARY INTRUSIONS

COAST INTRUSIONS

All granite bodies shown on the map accompanying this report are presumed to be of Late Mesozoic age and belong to the Coast intrusions (Rice, 1947) or are younger and belong to the group described below. Those described in earlier sections are much older and are too small to show on the map.

Most of the Coast intrusions cut rocks of the Mount Ida and Chapperon groups or younger rocks. Except for a small batholith north of Sugar Lake, the main mass of the Monashee group is relatively devoid of these rocks. In fact the scarcity of these intrusions in the Monashee group is regarded as evidence that the metamorphism in it is mostly unrelated to them.

Stocks and dykes too small to map abound in the vicinity of the batholiths, particularly in the west half of the map-area. Dykes and other small bodies of pegmatite, thought to belong to the Mesozoic suite, are also found here and there in the Monashee group.

Most contacts of the batholiths and stocks with the intruded rocks are relatively abrupt. Some thermal, hydrothermal, and dynamic metamorphism is exhibited in the intruded rocks near granites but rarely noticeable beyond a few hundred yards, or, at most, ½ mile of the contact. The granites themselves commonly contain sheeted or schlieren structures near the contact and their petrography has become complicated by the assimilation of intruded rocks. The actual beginning of the granite and ending of the intruded rocks is commonly blurred, but, no matter what the origin of the granites may have been, there can be little doubt of their mobility and intrusive nature in view of the many satellitic dykes and unassimilated xenolith inclusions. In the Mount Ida group between Salmon Arm and South Thompson River the peripheries of many large granite bodies merge with a complex of sills, schist, and gneiss. The rocks in these zones (called by Daly, 'sill-sediment complex') contain all proportions of granite to intruded rocks over rather wide areas. The intrusion borders have been arbitrarily drawn to contain approximately all areas in which granite forms one-half or more.

The dykes and sills in some places are as much as 100 feet thick but generally are in the order of 10 feet. The contacts of the dykes are particularly sharp and generally show marginal chilling of the intrusive rock and baking of the host. The sills are found mostly in the Mount Ida group where foliation planes created by the 'Older' deformation become ready loci for the sheets of granite. The contacts of the sills are not everywhere sharp but commonly grade into the gneisses and schists through a distance of a few millimetres or inches. No chilled contacts have been seen in the 'sill-sediment complex' and metamorphic effects on the intruded rocks there are much more intense and widespread than elsewhere in the peripheral zones of the large intrusions. The difference is presumably due to the greater amounts of heat and fugitive components that could be transmitted to the host rocks under such voluminous and pervasive intrusion.

Except for some granites near Okanagan Lake and in the southeast part of the map-area, all are generally of medium grain (5 to 10 millimetres). The exceptions noted contain large crystals of feldspar, particularly orthoclase, up to 4 inches in length. The granitic rocks are generally white to light grey but may be pink.

The composition of the granites varies considerably, not only between batholiths but also within batholiths. The rock types range from true granite (according to Johannsen's classification) through quartz monzonite and granodiorite to quartz-diorite. Syenites are found locally in the vicinity of Whiterocks Mountain in the southwest part of the map-area. Gabbroic or dioritic rocks are very rare in the suite. Most large granitic bodies in the northwestern part of the area contain biotite with, commonly, muscovite whereas those in the south and southwest rarely contain muscovite and generally contain hornblende or biotite or both.

Pegmatite is rarely abundant near batholiths but forms sills and dykes in some of the peripheral zones in the northwestern part of the map-area (in the 'sill-sediment complex') and also dykes in parts of the Monashee group.

The older granitic intrusions cannot be closely dated in Vernon map-area but probably are part of the Coast intrusions which elsewhere are known to be of Jurassic and Lower Cretaceous age.

CRETACEOUS OR TERTIARY GRANITIC INTRUSIONS

Two stocks, one on Whiteman Creek and one on the east shore of Okanagan Lake, and many dykes and sills are distinctly different from the intrusion described above and are believed to be younger. The stocks are medium- and coarse-grained, even textured, pink rocks that in the hand specimen resemble syenites. The dykes and sills vary widely in colour but are nearly all feldspar porphyries in which quartz is inconspicuous. Pink orthoclase is a conspicuous component of the granitic rocks but in thin section both it and white plagioclase are seen to be intergrown with abundant quartz.

Beyond the fact that these late intrusions are younger than the normal granitic rocks there is no evidence as to their age in Vernon map-area, but they closely resemble members of the Otter and Coryell intrusions of Princeton map-area (Rice, 1947) and West Kootenay district, respectively, which are believed to be of late Cretaceous or early Tertiary age.

• TERTIARY

KAMLOOPS GROUP

Rocks of the Kamloops group underlie nearly one-third of the west half of the map-area and are particularly abundant in the regions west and northwest of Okanagan Lake. The group is composed predominantly of volcanic rock and is disposed in the form of a great, dissected, horizontal sheet that lies on an erosional surface of early Tertiary age.

The thickness of the dissected sheet of Kamloops strata varies greatly from place to place according to the vagaries of the original accumulation and of the extent of subsequent erosion. On the average, the sheet is about 500 feet thick but is locally 3,000 feet or more thick. One of the thickest sections is exposed on Estekwalan Mountain west of Falkland.

The lavas, which form the bulk of the Kamloops group, flowed out over an irregular land surface upon which were accumulated lake and stream sediments, weathered detritus, sliderock or talus breccia, sand and gravel of alluvial fans, and debris of plants. These accumulations now form the basal member for the Kamloops group. They are poorly cemented and the organic debris has become lignitic coal. The thickness of the basal member varies from a few inches to several hundred feet. Some intraformational conglomerates are found between flows within the Kamloops group and the pebbles of these contain parts of the Kamloops lavas as well as of the older rocks.

The lavas are largely black, chocolate-brown, and dark grey basalts that weather to maroon, rusty red, terra-cotta brown, khaki-brown, and light buff. Some, especially as components of the thickest accumulations, are andesitic, trachytic, or even rhyolitic and range from light grey and white to light pink, green, and brown. Porphyritic textures are common with small phenocrysts of augite, hornblende, and olivine in the darker basalts, and feldspars, quartz, and biotite in the light coloured, rhyolitic lavas. Many of the lavas are vesicular or amygdaloidal. Zeolites, chalcedony, opal, carbonate, and epidote are common in amygdules. Pyroclastic breccia is common in the thick accumulations and contains fragments derived mostly from the light coloured lavas.

Dykes of basalt cut the granites and older rocks throughout the map-area but are noticeably fewer towards the east boundary. Dykes of the rhyolitic rocks are rare. Apparently the widespread, basalt flows were fed by quiet extrusion from numerous dykes whereas the relatively local, thicker accumulations, which include trachytic or rhyolitic lavas and pyroclastic breccias, were formed by explosive extrusion through a few widely separated, pipe-like conduits.

In the Vernon map-area no diagnostic fossils were found in the Kamloops group. Similar formations in the adjoining Princeton and Nicola map-area, have, however, been established as of Oligocene or early Miocene age.

CHAPTER III

STRUCTURAL GEOLOGY

The key to many problems of the Shuswap terrane lies in the study of its structure. A detailed account of certain basic structures such as folds, faults, lineation, and foliation is not only of academic value but is of considerable broad application in understanding the Shuswap rocks as a whole and in determining their role in Cordilleran geology. An understanding of the structural types requires a preliminary outline of the structural geology as a whole so that a co-ordinated picture may be presented although such a preview may be somewhat oversimplified and misleading.

The rocks of the Shuswap terrane are provisionally divided into two groups by the irregular line of the Vernon-Sicamous fault system. West of this line is the Mount Ida group and east of the line the Monashee group. The Mount Ida group has been subdivided into lithologically distinct formations each of which has, on the whole, undergone severe low-grade metamorphism. The Monashee group has not so far been satisfactorily subdivided and has been subjected to severe high-grade metamorphism. In other structural respects the two groups are very similar.

A third group in the southwest corner of the map-area, known as the Chapperon group, is also correlated with the Shuswap terrane. It may be partly equivalent to the Mount Ida group but is isolated by areas of younger rocks. The structures of the Chapperon rocks have not been studied in detail and they are, therefore, largely disregarded in the following discussion. What is known of the Chapperon structures may be summed up as follows: The bedding dips steeply in most places and strikes parallel with the length of the belt; no large folds or faults have been recognized; and foliation, small folds, and lineation are abundant.

The Mount Ida group is apparently not equivalent to any part of the Monashee group and, as it has suffered less metamorphism, it is presumed to stand higher in the stratigraphic column. In both groups the strata were essentially horizontal when deformation started, and yielded by isoclinal, recumbent folding, by shearing, and by overthrusting during a period of regional metamorphism which permitted recrystallization to keep pace with crushing. The strata as a whole remained nearly horizontal except for those parts in the noses of folds. Parts of some beds were, however, completely overturned. Severe shearing occurred along planes parallel with the axial planes of isoclinal, recumbent folds to give foliation parallel with bedding on the limbs and discordant to bedding in and near fold noses. The physical nature of the rocks and their environment is reflected in the preponderance of folding over shearing. Some shearing also took place along thrust faults that closely parallel the bedding. The direction and amount of rock movement are to some extent disclosed by strata or dyke-like bodies that have been pulled into disconnected blocks forming boudinage. Fold axes and lineation are parallel and indicate the direction of movement; they trend preponderantly northeast or southwest in the Shuswap terrane.

Folds larger than those seen in single outcrops are probably not common and only two have been definitely recognized. Small folds are regarded as minor features in most other areas but are considered important by the writer in the Shuswap terrane. The strata are deformed almost everywhere, but despite the abundance of these small folds, they are not considered to be drag-folds on limbs of larger folds. Rather, they are believed to be primary structures of the first order developed by a regional, rather simple, slipping of the strata over each other without attendant larger folds. Detailed attention is therefore given to the small folds for they are considered to be the main structural features of the Shuswap terrane, and are important tools in deciphering its structural history.

Two main periods of deformation are recorded in the Shuswap rocks, differing in nature, geometry, and tectonic orientation. The effects of the younger are superimposed on those of the older. Although the deformation succeeding the older consists of several stages or possibly separate periods, these cannot be specifically identified or correlated and are, therefore, treated as a single unit. For convenience of discussion the terms 'Older' deformation and 'Older' structures will hereafter be used for the first tectonic period in the Shuswap terrane typified by extensive isoclinal, recumbent folding and intense shearing. Similarly, 'Younger' deformation and 'Younger' structures will be applied to the cause and effects of tectonic activity succeeding the Older.

The Younger deformation had, on the whole, much less effect on the rock fabric than the Older deformation although here and there it has obliterated all visible trace of the Older structures. Structures resulting from the Younger deformation consist of faulting, gentle warping, and folding that is generally irregular but upright in contrast with the regular recumbent folding, and attendant minor structures of the Older deformation. The most noticeable feature of the Younger structures is the network of block faults, resulting from the last deformation. Normal upright folds large enough to be shown on the map are rare and the dip of strata is fairly constant in each fault block. The regional tectonic axis of Younger deformation is neither so well defined nor so consistent as that of the Older deformation but generally trends northwest, parallel with the trend of the Cordillera in general.

• PLANAR STRUCTURES

The Shuswap metamorphic rocks are, on the whole, layered on both a small and a large scale. Much of the layering is undoubtedly inherited from bedding, either directly due to sedimentation effects or indirectly as a result of shearing that has developed along the bedding. Other layering has, however, developed at an angle to bedding or in massive rocks. The origin of some layering cannot be determined and several types may be present in one outcrop. No single term describes all planar or layered structures in rocks irrespective of nature and origin although such a term would be desirable, especially in instances of metamorphic rocks where different types merge and are indistinguishable.

Planar structures in the Shuswap rocks were referred to by both Dawson and Daly as being of special interest in these metamorphic rocks. Each reported that the schistosity was parallel with bedding and decided that special conditions were required for it to develop. It is fairly certain that by 'schistosity' they meant the parallel arrangement of mica flakes and hornblende in gneiss as well as schist. Daly referred to the structure as 'secondary planes', 'schistosity', and 'micaceous fissility'. Neither geologist recognized any dynamic metamorphism to which he could attribute the parallelism of 'schistosity' with bedding and, consequently, both believed that the structure arose through a stable static condition of high stress perpendicular to the earth's surface. The recent mapping has, nevertheless, established that secondary planar structures were produced by strong deformation, either by emphasizing the bedding or by creating new layers across folded bedding and in massive rock.

Planar structures may be primary or secondary in origin and may result from the following:

(1) *Orientation of mineral grains.* In mica-schist or mica-hornblende gneiss the inequidimensional minerals are aligned with their platy or long dimensions disposed in planar parallelism. Certain of the so-called equidimensional minerals, such as calcite and quartz, may also show parallel orientation. Grains of both calcite and quartz are commonly seen under the microscope to be tablet-shaped and packed so that a remarkable physical as well as optical anisotropism is given to the rock.

(2) *Fractures as planes of weakness or splitting.* Some granitic dykes and quartz veins in the Monashee group are compositionally homogeneous, but readily break along definite parallel planes. These planes are spaced a few millimetres apart and the surface of most is wrinkled by subparallel, bifurcating furrows and ridges superficially resembling slickensides. This structure is particularly a characteristic of structurally homogeneous rocks without original planes of weakness. Slip cleavage in argillaceous rocks is a related structure.

(3) *Layering by colour, mineralogical, or textural contrast.* In a mica gneiss adjacent layers may differ in the relative proportion of dark to light coloured minerals. This is the most obvious layered structure in the rocks of high metamorphic grade in the Shuswap and, without doubt, is mostly inherited from sedimentary bedding.

(4) *Orientation of lenses and streaks of mineral aggregates.* Parallel streaks of feldspar in otherwise homogeneous quartzite or lenses of white quartz in mica gneiss are examples of this type of planar structure. They differ from type (1) in the units of orientation being multi-crystalline and from type (3) in the layers being discontinuous.

The manner in which the various subdivisions of planar structures are related is presented in Figure 3.

PLANAR STRUCTURES IN THE MONASHEE GROUP

The Older deformation in the Monashee group everywhere folded primary layered structures and created new ones. The Younger deformation had a less far-reaching influence and its effects were confined mainly to producing folds and faults rather than new foliation.

Older Planar Structures

In the Monashee group, layering by grain orientation and compositional layering is rarely absent. Ordinarily, the layers on fresh surfaces show alternations of light and dark grey or white, and on the weathered surface alternations of rust or rusty grey, depending on the iron content of the minerals. Most layers are of biotite gneiss alternating with pegmatite, but many are of black hornblendite, hornblende-biotite gneiss, white and grey quartzite, mica schist, buff weathering limestone, and green lime-silicate minerals (*see* Plate III A). Streaks and lenses of quartz, carbonate, garnet, lime-silicate minerals, pegmatite, or gneiss may produce or contribute to layering (*see* Plates III B and IV A). The layers range in thickness from a fraction of an inch to a few feet and most correspond to beds. Relatively common, however, is a pronounced layering that is not due to bedding or is of uncertain origin. In some places pegmatitic material following shear planes has impregnated or replaced the adjacent rock, in others, mineral segregation has resulted from metamorphic differentiation in and near shear planes, in still others small discordant igneous bodies, such as granite dykes, are layered parallel with the foliation of the wall-rock.

Foliation generally occurs with lineation and drag-folds and is also related to them in origin. Almost all foliation planes bear lineation as either elongated biotite flakes, oriented sillimanite, ridges of quartz, or trains of minerals. Small, recumbent drag-folds are plentiful throughout the Shuswap terrane. They

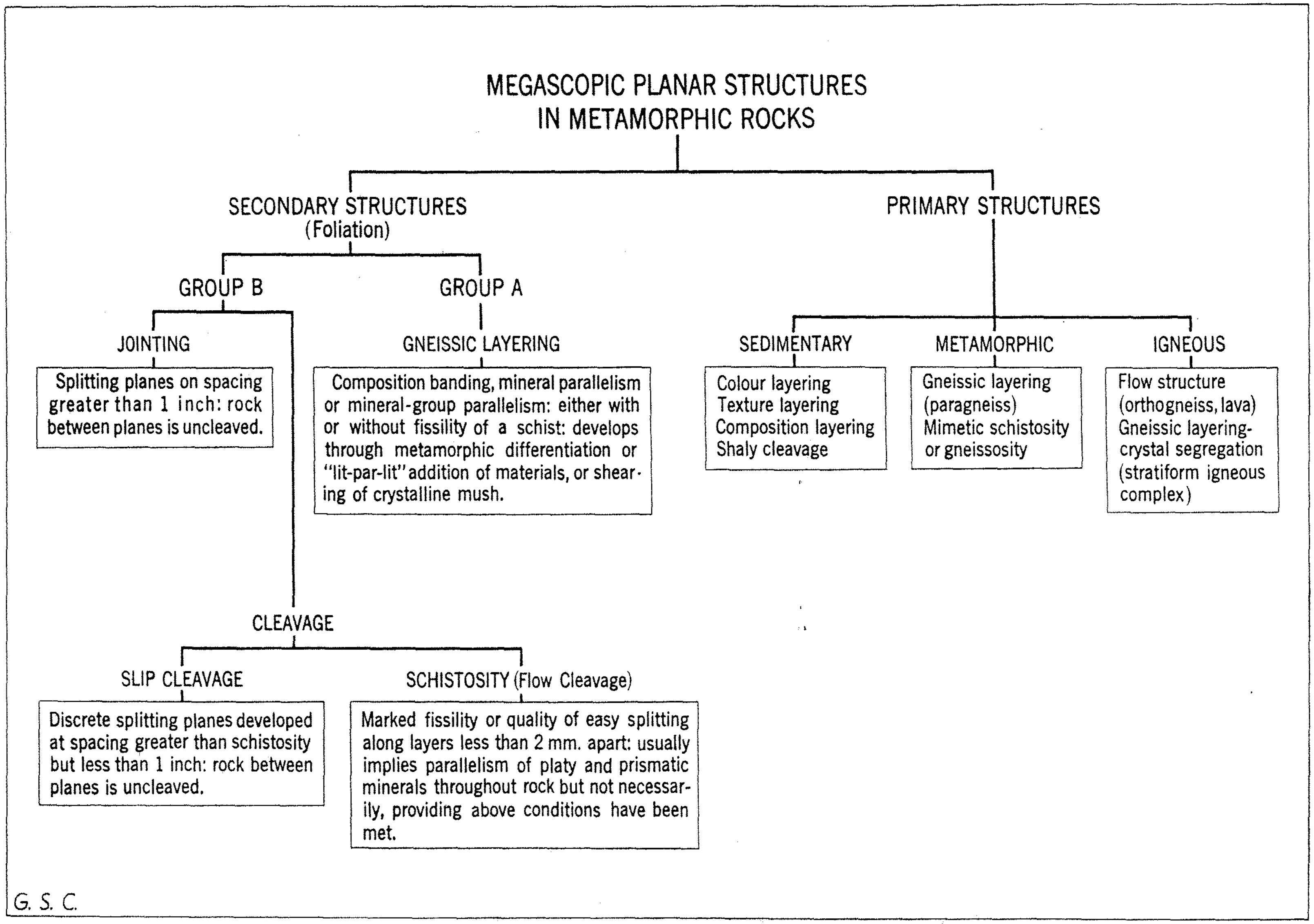


Figure 3. *A classification of planar structures in metamorphic rocks.*

assume the typical form of true drag-folds with axial planes nearly parallel with the planar structures and bedding, and they are commonly compressed and attenuated until the limbs are parallel. The folded layers represent bedding in nearly every case. In gneiss poor in mica the mica plates remain parallel with composition layers around fold crests except where these are sharp and tightly compressed. In the sharp crests of folds the mica tends to be parallel with the axial plane or be ribbon-like bands parallel with fold axes. Highly micaceous layers may exhibit axial planar orientation of grains in the crests of less extreme folds.

The role of shearing in the development of foliation is conclusively manifested by the genetic association of foliation with lineation and recumbent folds. The directions of both lineation and drag-folds indicate that the shearing was parallel with the main strata. The distribution of foliation shows that the shearing was not confined to certain relatively narrow zones but was apportioned among all the strata, although not necessarily equally. Some beds of augen gneiss are evidently zones that supported a large share of the movement and that have lost the details of internal bedding and folding.

To distinguish between axial-planar foliation and bedding is one of the greatest problems in the geological mapping of Shuswap gneisses but the task is somewhat facilitated where folds or parts of folds are preserved. Foliation in places marks small faults cutting across folded bedding. The faults are parallel with axial planes of the folds and can be identified only where the bedding is distinctly discordant to them, or where they are filled with quartz or pegmatite.

Foliation in less metamorphosed members of the Monashee group is represented by slaty or phyllitic cleavage, and this cleavage obscures or destroys the bedding in most places so that folds cannot be seen. Nevertheless, numerous field observations have shown that the cleavage in these rocks is essentially similar in origin and relation to other structures to the cleavage in the rocks of the Mount Ida group. It is nearly horizontal or dips at low angles, or, where steeply dipping, it was probably tilted after it was formed.

Zones of strong faulting during the Older deformation in highly metamorphosed rocks are commonly represented by coarse-grained augen gneiss containing lenticular units of quartz and pegmatite oriented parallel with the major stratification (*see* Plate IV A). These gneisses are mylonites in the broad sense of the word. A few such zones, up to 200 feet thick, consist of fine-grained, tough, flinty, mylonite. These mylonites exhibit in places, light and dark grey layers resembling those of sedimentary rocks, although other features, such as tiny 'eyes' of broken feldspars, strong lineation, and microscopic texture, indicate the layers to be deformational. In addition to colour layering, the rock has a splitting quality which is parallel with the layering and apparently due to micro-faults. In both coarse- and fine-grained mylonite the bedding is destroyed, and what appears to be bedding is actually foliation.

Veins and dykes older than the Older deformation can rarely be recognized. Probably there were many but they were so disrupted by later movements that they cannot be recognized in the fragmented state. For example, limestone pseudo-conglomerates exposed in road-cuts 8 miles east of Lumby contain angular pieces of granite that are parts broken from small dykes or sills. Similarly, quartz lenses seen in road-cuts at Summit (Clanwilliam) Lake 8 miles west of Revelstoke seem to be parts of dismembered veins. On the other hand, a few dykes that are not deformed beyond the point of recognition have been found, and these indicate qualitatively the nature of the deforming movements.

One such dyke, at elevation 6,000 feet on the west flank of Silver Star Mountain 12 miles northeast of Vernon, is about a foot thick and consists of a fine- and even-grained granite. It contains no dark minerals, is homogeneous throughout, and has relatively sharp margins without signs of chilling. The wall-rock is a light grey, thin-bedded, largely calcareous quartzite carrying muscovite, especially in thin, fissile, limy bands. The beds dip 45 degrees east and are crossed by the dyke which dips 60 degrees south. The quartzite easily cleaves into tablets parallel with bedding and of almost any thickness, and all foliation surfaces clearly show the regional lineation. This lineation of parallel, discontinuous ridges and grooves probably resulted from movements along the layers as no intersecting cleavage can be seen. Although no folds were seen in this outcrop, recumbent drags nearby have axes parallel with the lineation. Structures similar to those in the quartzite are also found within the dyke, although, foliation in the dyke is not as distinct as that in the wall-rock. Foliation in the dyke is indicated by widely spaced, discontinuous layers or slivers of quartz which are 2 or 3 inches in length and ¼ inch thick and by the parallel alignment of muscovite flakes and tiny, lath-like rods of quartz. The rods are irregular but the thickness is roughly one-fifth of the width, and the width one-fifth of the length (*see* Figure 4).

Lineation of the rods is parallel with that of the wall-rock. The dyke is not curved and has no other marks of folding, but the foliation suggests shearing. In thin section, the feldspar is seen to be crushed and the quartz strained and similarly oriented optically. The quartz grains of the matrix are curved and have the appearance of flowing around the feldspar fragments. Individual quartz grains are many times longer than wide and are distributed in swarms that curve around hard feldspar fragments that form augen. The curved grains show strong undulatory extinction and have a 'liquid' appearance when the stage of the microscope is rotated. The foliation of the granite dyke is not inherited from the wall-rock by replacement because feldspar, which is the crushed mineral in the dyke, is not present in the wall-rock quartzite, and must

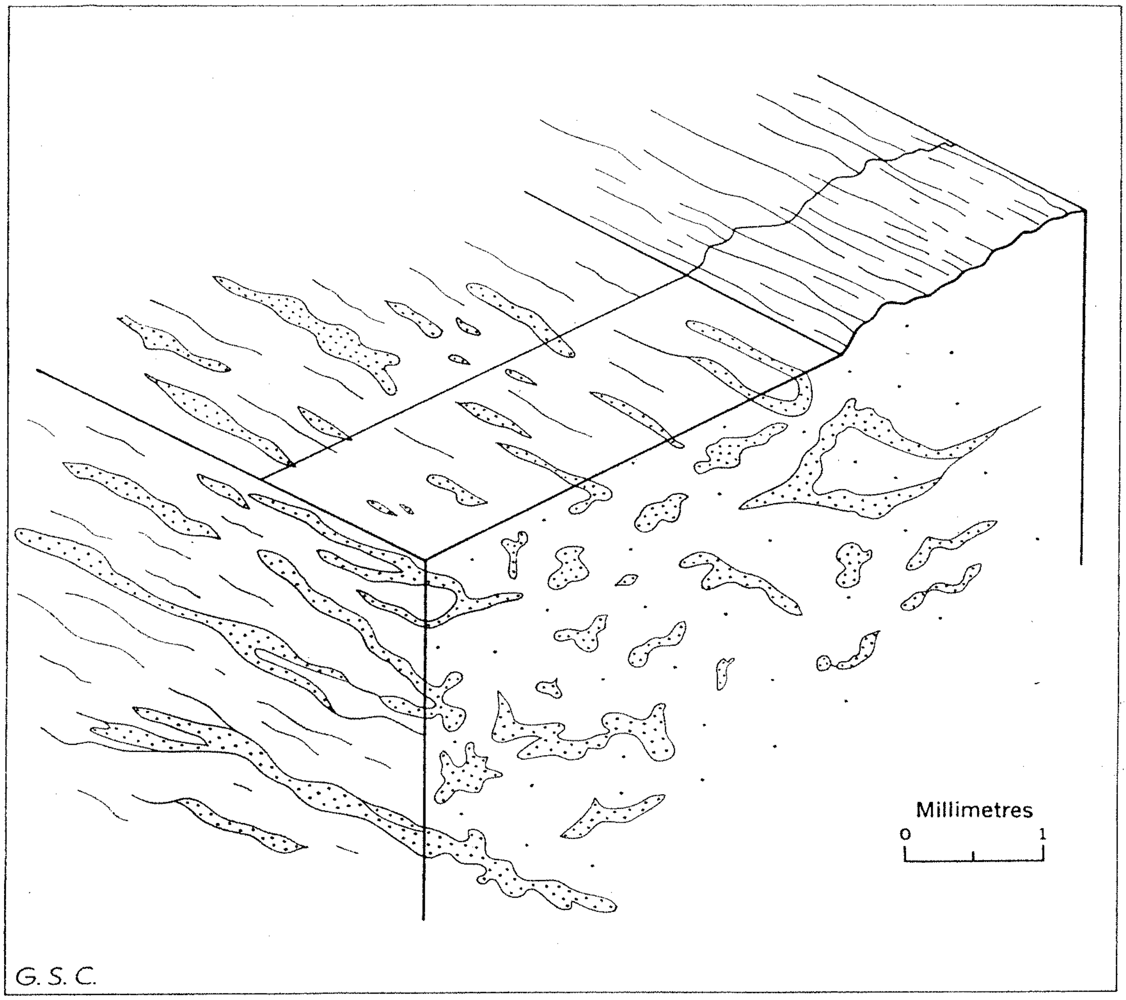


Figure 4. ***Block diagram showing general shape of quartz grains in foliated granite of the Silver Star intrusions. The stippled parts are quartz and the white part is mostly feldspar. Lineation on the broken foliation surface is as shown.***

have been crushed by forces that acted after the dyke was formed. The only hypothesis tenable in light of the assembled facts is that the quartzite beds moved over one another like cards during or after the intrusion of the dyke. Under these conditions the minerals of the granite grouped or regrouped themselves into planar and linear structures parallel with those simultaneously created in the wall-rock[1].

Similar tectonic movement occurred in other nearby dykes and in a quartz vein. The vein, approximately 2 inches thick, has a sinuous shape, and cuts

[1]It is interesting to note that Daly (1915) describes a similarly foliated dyke near Clanwilliam but attributes its structure to static metamorphism. Daly's dyke could not be found during the present survey.

unfolded quartzite gneiss that bears strong lineation on its bedding planes. The vein is layered with milky white quartz and clear glassy quartz and this layering lies parallel with that in the wall-rock gneiss. The individual grains of quartz are oriented dimensionally and optically in a way that would result only from intense deformation similar to that which foliated the dyke described above except that the curves in the vein show that some layers moved farther than others.

Near the quartz vein but at lower elevation and farther west are a few granite sills 20 to 100 feet thick. Each of these bears strong foliation parallel with its borders as indicated by alignment of feldspar, cleavage, and thin layers of quartz. Each also has a lineation in the form of grooves and ridges. Both foliation and lineation are parallel with those in the neighbouring rocks and originated in the same way as those in the vein and dyke described above.

In the Sawtooth Range north of Tsuius Mountain a granite sill about 100 feet thick is enclosed in, but locally discordant to, interlayed limestone, hornblende gneiss, and biotite gneiss. These layers are nearly horizontal but are contorted by recumbent, isoclinal folds, the upper beds of which moved southwards relative to the lower. Clearly marked foliation parallels the bedding, and lineation parallels the fold axes in both limestone and gneiss. The granite, one of the Silver Star intrusions, weathers light pinkish grey and contains some hornblende and biotite. Its dark minerals are disposed in thread-like, discontinuous strings marking a good lineation and the strings are slightly clustered in planes marking a poor foliation. Purplish smoky quartz is in discontinuous layers 1 or 2 millimetres thick that are parallel with the vague foliation in the granite and with the foliation in the country rock. Ridges and grooves on the surface of the quartz layers give a strong lineation in the country rocks. The simplest and most reasonable explanation for the identical orientation of planar and linear structures within intrusion and host is that they were formed simultaneously by shearing along planes parallel with the major bedding.

Numerous sills of mafic igneous rock were intruded into the Monashee group prior to or during the Older deformation and were subsequently altered to garnetiferous hornblendite and dismembered into boudinage. Although the sills originally were mineralogically and structurally homogeneous, many of them now exhibit pronounced marginal foliation. This foliation is marked by pegmatite streaks or by micaceous fissility clearly produced by shearing resulting from the sliding of the host beds past the margins of the sills.

Dykes feeding the mafic sills were found in three widely separated places but are of uniform structure. Each dyke is sinuously curved like the quartz vein described above, and shows a parallel orientation of hornblende grains concordant with the layering of the enclosing gneiss and discordant to the walls of the dyke. Each dyke passes into a boudinaged sill.

Foliated pegmatite is common in the rocks of the Monashee group and forms small concordant lenticular bodies or discontinuous sill-like layers. The walls of the pegmatite bodies are parallel with this foliation and most are also parallel with the layers in the wall-rock. Some foliated pegmatites may have originated through replacement of the gneiss but the foliation in most has probably originated by the deformation of intrusive pegmatite. The most strongly and clearly foliated pegmatites intrude the more highly deformed gneisses. The foliation is marked by micaceous streaks, by layers of relatively pure quartz alternating with layers of relatively pure feldspar, and by parallel chains of feldspar rhombs arranged in augen shapes. The pegmatite, where split along folia, exhibits good lineation parallel with that in the country gneiss. Some discordant pegmatite was clearly emplaced during deformation rather than before (*see* Plate II B).

Concordant bodies of foliated pegmatite occur in the gneisses between Peters Lake and Fosthall on the west shore of Upper Arrow Lake. These sheet-like bodies are all sizes up to many tens of feet thick and are fairly uniform in composition and texture throughout except for a few parallel slivers of gneiss (*see* Plate IV B). The pegmatite itself exhibits a remarkable internal foliation that imparts a slab-like or cleaved appearance. The cleaveage planes are indistinct and discontinuous and may be interlinked. Lineation on the cleavage surface appears as rather coarse grooves resembling mullion or slickenside structures on fault planes but is, nevertheless, parallel with lineation and fold axes in the adjacent gneiss. Large feldspar crystals form augen in a matrix of smaller grains of feldspar and quartz. The quartz is in thin sheets and linear streaks around the augen. The orientation of the lineation and the texture of the pegmatite demonstrate that the sheeting is the result of shearing. The most reasonable explanation is that the pegmatite followed along bedding planes during folding, that is, 'syntectonically'.

Layering in gneiss does not always represent bedding. Some augen gneiss contains discontinuous layers of different composition, such as streaks of pegmatite and thin lenticular slivers of normal gneiss (*see* Plate IV A). These layers are not noticeably folded, but on close examination, the tiniest layers are seen to be in recumbent folds with crests so sharp that the limbs converge acutely. Those small units of layering record intense deformation, which may or may not have affected the larger layers. Large folds may go unrecognized because they have been compressed and attenuated to such a degree that the two limbs are parallel and the nose has been destroyed by axial-plane shearing.

Younger Planar Structures

Planar structures resulting from the Younger deformation are relatively few and important only locally. Nevertheless, some of the earlier phases of this deformation produced shear planes that cross the flat-lying Older planar structures at relatively high angles and opened fractures that were later sealed with pegmatite (*see* Plate V A). The later phases of the Younger deformation produced shear zones and closely spaced joints, mostly associated with faults, that are open except in a few places where they are filled by quartz veins or by basalt dykes.

The dating of joints that have produced planes perpendicular to the axis of the large overturned Fosthall Mountain fold is of interest. The fold is believed to have been produced by the Older deformation. The joints are spaced at intervals of 6 inches to 2 feet and are confined to the core of the fold where the strata have been most intensely deformed and where rodded or pencilled structures have developed. They are perpendicular to the core of the fold and, therefore, are typical of so-called *ac*-joints which are usually presumed to form essentially simultaneously with the folding. The Fosthall Mountain fold is, however, cut by unfolded granitic dykes that cross all structures obliquely but are themselves segmented by these joints. The jointing could not, then, be directly related to the tectonic processes that caused the folding and must belong to the Younger deformation. It is probable that the concentration and orientation of joints in the core of the fold were controlled by a directed weakness developed there during folding but that the joints were actually formed during the Younger deformation which took advantage of this incipient weakness.

Summary and Conclusions

Some of the most important characteristics of layering in the Monashee group are as follows:

(1) Layers of contrasting composition and colour are the most conspicuous of the planar structures and are, in most cases, inherited through metamorphism from original sedimentary bedding.

(2) Foliation is exhibited in several ways, the most important being the planar parallel alignment of inequidimensional mineral grains.

(3) Foliation is accompanied by both recumbent drag-folds and strong lineation and, like those structures, results from shearing parallel with the principal stratification.

(4) Foliation lies parallel with bedding on a regional scale and also at many places on a small scale.

(5) Foliation diverges from bedding only where strong axial plane cleavage has developed. Where deformation is extreme the crestal parts of folds are destroyed and the rocks superficially resemble undeformed bedded gneiss.

(6) Recrystallization kept pace with the shearing and fracturing of the minerals and open fissures are rare.

(7) Foliation is also present in some intrusive rocks and veins.

(8) The shearing movements that produced the foliation were mainly directed along and parallel with the bedding. In addition to foliation, both lineation and drag-folds resulted. The rock movement that formed these structures resembles plastic laminar flow between exceedingly close-spaced parallel layers but the net amount of slip is not always the same in amount or direction on adjacent layers. The movement can be considered as a plastic equivalent to 'Gleitbretter' (*see* Figures 5 and 6).

(9) Planar structures resulting from the Younger deformation are mostly local in effect and associated with faults.

(10) Joints of the *ac*-type have developed during the Younger deformation on folds developed during the Older deformation.

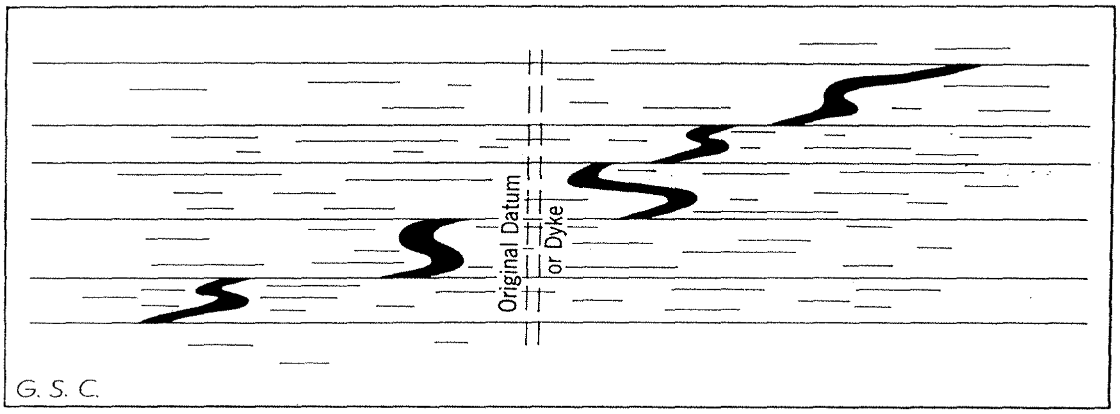


Figure 5. ***Gleitbretter structure — certain slip-planes bear most of the movement and are planes of discontinuity. This is 'slip cleavage'.***

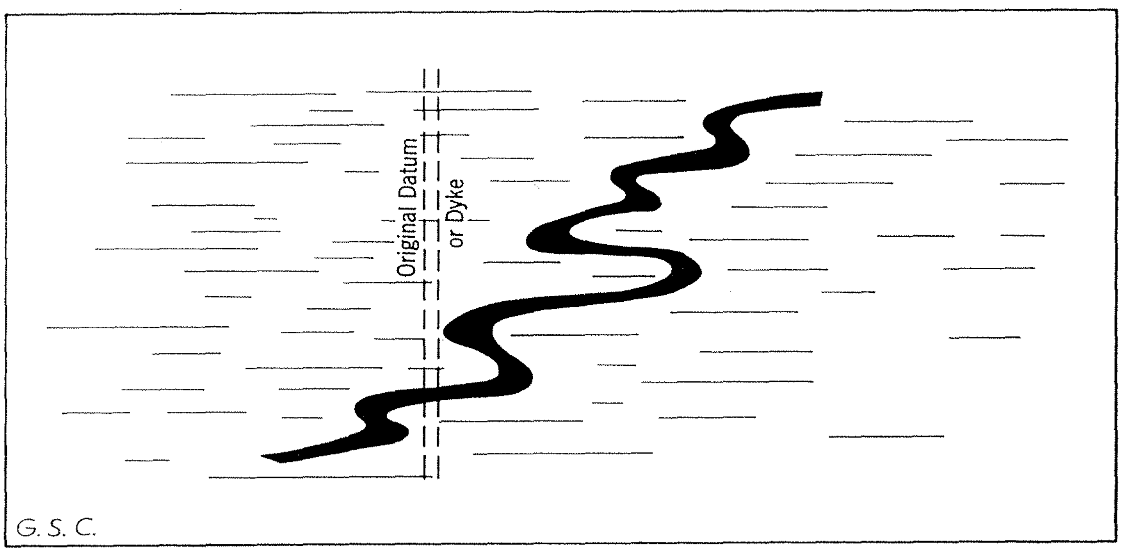


Figure 6. ***Plastic Gleitbretter structure — no planes of discontinuity although some layers bear more movement than others.***

PLANAR STRUCTURES IN THE MOUNT IDA GROUP

The planar structures of most significance in the Mount Ida group belong to primary sedimentation and the Older deformation. Planar features attributable to Younger deformation are restricted to local jointing and some fracture cleavage crossing the Older structures.

Older Planar Structures

Foliation in the Mount Ida group differs from that in the Monashee group in appearance but is similar to it in mode of origin and is even more clearly attributable to shear. The differences in character may well be due to the difference in the degree of metamorphism of the two groups. High-grade metamorphism is present locally in the rocks of the Mount Ida group but was produced after the structures of the Older deformation were developed. The four basic types of foliation found in rocks of the Monashee group (*see* Figure 3) appear also in the Mount Ida group but their order of importance is different. In the Mount Ida group mechanically induced planes of weakness (for example slip cleavage) are quantitatively more important than grain orientation. Layering on a small scale, marked by mineralogical, textural, or colour contrast, is of still less importance and the orientation of lenticular units is rarely observed. As a result rocks of the Mount Ida group typically weather with a slaty or platy structure (*see* Plate V B).

Most rocks in the Mount Ida group are sedimentary, consisting of phyllite, slate, limestone, quartzite, and minor conglomerate. Some 30 per cent, however, is probably of volcanic origin and consists of chloritic greenstone schist. Due to the severity of shearing during metamorphism the origin of many rocks remains in doubt. The type of foliation present in any specific example is somewhat dependent on the mineralogy of the rock in which it occurs, indeed different types of similarly oriented foliation may be found in a single outcrop, each type being restricted to a lithologically different rock. Thus, slip cleavage in argillite passes into flow cleavage in greenstone. The different cleavages are mutually parallel, have a common low to moderate dip, and are, in general, parallel with the principal bedding as well as with the axial planes of folds. Furthermore, lineation on the cleavage faces is generally aligned with axes of folds.

Recumbent, isoclinal folds are as numerous in the Mount Ida group as they are in the Monashee group, and originated at the same time as the secondary foliation. This is clearly demonstrated by the parallelism of fold axes with lineation on the surface of the folia and the parallelism of axial planes with the folia. Bedding in the low-grade metamorphic rocks of the Mount Ida group is more thoroughly obliterated than in the rocks of the Monashee group, even in less folded strata.

Presumably the rocks of the Mount Ida group were not, under the conditions of metamorphism, as plastic as those of the Monashee group and, consequently, the strain of drag-folding found them more susceptible to shearing parallel with the axial planes. In the Monashee group, axial plane cleavage across the bedding has developed only in the tightest folds, whereas, in the Mount Ida group, axial plane cleavage is universal and commonly dominates bedding even in relatively open folds. Where bedding is still recognizable in detail it appears in S-shaped folds and hook-like forms and is, therefore, not everywhere parallel with the general trend of the strata.

The planes of shearing and direction of rock movement are closely parallel with the general trend of strata and can be regarded as close-spaced bedding faults. The recumbent drag-folds can, by the same tokens, be considered as drags along the system of bedding faults. Instead of the slip-movement being confined to relatively thin zones, as in the Monashee rocks, it is rather uniformly distributed throughout the strata, parallel with them as a whole but not in detail. In any stratigraphic zone where bedding was recumbently folded the cleavage is parallel with the axial planes and at an angle to bedding; where bedding was not folded, however, the cleavage is parallel with the bedding. In the absence of recognizable bedding the situation is obscure. The main lithological boundaries are, however, essentially parallel with the foliation, and, for purposes of general mapping, foliation may be considered to represent bedding.

Certain beds of limestone interstratified with slate and chlorite schist in the Eagle Bay formation bear internal folding and yet are not appreciably folded as a whole. The internal folds appear as recumbent, V-shaped zigzags that are especially abundant near the centre of the bed and have axial planes nearly parallel with the bed as a whole (*see* Figure 7). Cleavage in the rocks enclosing the limestone is also parallel with the bed. Lineation on

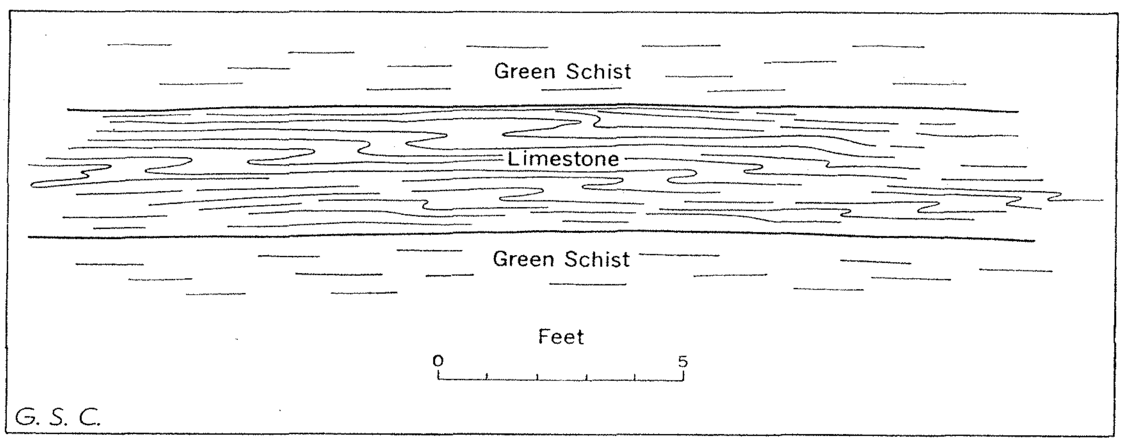


Figure 7. ***Sketch of a thick limestone bed that contains internal folds but, as a unit, is not folded.***

the surface of this cleavage is parallel with axes of the folds in the limestone. Evidently both folds and cleavage resulted from a force that caused the beds to slide over one another, the difference in expression being due to the physical differences in the rocks affected.

By using attitudes of the Older foliation, beds can be traced to outline Younger folds and faults as if the attitudes were of bedding. The conclusion of Dawson, Daly, and Brock, that 'schistosity' is parallel with bedding is therefore true, at least on the scale of the map, although it commonly is not true on the scale of the hand specimen or outcrop. In many exposures bedding may seem to lie parallel with shearing and be unfolded yet, actually, the shearing has been so intense that it has destroyed most evidence of fold crests and only the parallel limbs of folds remain.

The argillaceous and quartzitic rocks of the Eagle Bay formation show detailed structures particularly well and good exposures can be seen along the shores of Shuswap Lake. The outcrops on the beaches and in road-cuts show excellent intersections of cleavage and bedding. Although associated with folds in orientation and genesis, the cleavage is not necessarily confined to folds or to any particular part of them, but may occur where folds are absent.

The foliation in the argillaceous and quartzitic rocks corresponds with the 'slip cleavage' of geologists in other fields. Most volcanic members and sericite- and chlorite-rich sedimentary rocks exhibit parallelism of the platy minerals solidly throughout the rock instead of along discrete shear planes. This type of foliation is identical to 'flow cleavage' but as the two types are parallel in adjacent beds the essential difference between them must lie in the lithology of the rocks affected and not in mode of origin. Apparently the soft chloritic beds sheared throughout, whereas movement in the argillites and quartzites was restricted to definitely spaced planes.

Limestones in the Sicamous formation have been described as characteristically thin bedded or 'flaggy'. The intense shearing to which the Sicamous limestone has been subjected contributed to the thin-bedded appearance, but is believed by the writer to be superimposed on originally thin-bedded strata. Most of the rock is made up of somewhat discontinuous and lenticular layers of platy limestone, weathering bluish grey, separated by laminæ of buff weathering, calcareous, highly sericitic and commonly graphitic schist. This schist also appears in relatively pure units interstratified with zones of the platy limestone and characteristically bears numerous small lenses of limestone or quartzitic limestone. The zones of platy limestone are characteristically shot through with coarsely crystalline white calcite in thin laminæ and layers or chains of lenses. Some of this white calcite is later than the shearing because it fills cleavage planes that cut across bedding and also fills tiny cracks in the limestone itself, but some of it is undoubtedly original bedding.

The intricate detailed folding of the beds can be seen best in finely crystalline, soft schist exposed in overhanging cliffs that are not wave-washed. A good exposure of cleavage crossing bedding in detail and simultaneously lying parallel with the long limbs of folds and the main bedding is seen in the small cliffs ⅖ mile south of the contact between the Sicamous and Eagle Bay formations on Blind Bay and about 100 feet east of the shoreline road. The cliffs of Bastion Mountain (north of Salmon Arm) are unsurpassed for good exposures of the larger recumbent folds with flat-lying axial plane cleavage and beds sheared into discontinuous lenses. A typical recumbent isoclinal fold within a bedding plate of the limestone is shown in Plate VI A.

Limestone more massive than that in the Sicamous with no marked cleavage planes occurs, especially among the upper members of the Eagle Bay formation. Deformation has expressed itself in intricate internal folding but the nature of the limestone permitted folding without noticeable shearing. The folding may be clearly seen where bedding in the limestone is marked by colour differences. Where fine bedding cannot be seen, as in the white marble of the Tshinakin limestone, the rock may appear undeformed but is actually so highly deformed that the carbonate crystals are seen in thin section to be extremely elongate and finely twinned.

Conglomerates are very minor constituents in the Mount Ida group, but are also sheared. Chert and quartzite pebbles are slightly elongated parallel with the local lineation and are also considerably flattened in the plane of shearing. Inasmuch as the bedding coincides with the shearing planes where this was observed there is some doubt as to whether the pebbles were mechanically flattened or were originally that shape.

Lineation in rocks of the Mount Ida group is rarely as pronounced and consistent as that in the Monashee group, but it, too, is parallel with the axes of associated drag-folds and evidently has the same structural significance. Most lineation in the Mount Ida group is formed by the intersection of cleavage and bedding. The amount of shear movement along any single foliation plane is probably small but the aggregate movement within a few stratigraphic feet is probably impressive although difficult to estimate.

The deformation producing 'slip cleavage' in the Mount Ida group can be described as 'Gleitbretter', because most of the movement is taken up along definite, wide-spaced planes and the rock between is comparatively less deformed. Where the planes of slip are closely spaced and the deformation is of the type known as flow cleavage, the movement cannot be called 'Gleitbretter' but is rather 'flowage'. Many lenticular bodies in the schists of the Sicamous formation are dismembered parts of beds and so also, probably, are the lenticular bodies commonly seen in the greenstone schists, but examples of boudinage with neckfolds, mineralized scars, and allied structures, so common in the Monashee group, are rare.

Younger Planar Structures

The Younger deformation did not profoundly or widely affect the rocks of the Mount Ida group and confined its effects mainly to cleavage or crenulation. Disruption of the Older foliation by Younger cleavage is relatively common especially near Younger faults.

Some movements belonging to the Younger deformation followed folia of the Older as these were already planes of weakness, but most were disposed along planes at a considerable angle to the Older folia, thereby causing shear-fold crenulations. Both types of shear movement caused lineation on the foliation surfaces already present and, ordinarily, this lineation differs in direction from that resulting from the Older deformation alone.

An example of all phases of the deformation can be seen in outcrops on the beach west of Canoe Point on the north shore of Salmon Arm. There beds of argillaceous quartzite were recumbently folded during the Older deformation and developed strong cleavage and micaceous fissility in planes parallel with the axial planes of the folds and across most of the bedding. The cleavage is however not smoothly planar as it would be if resulting from a single stress, but has been strongly crenulated and, in places, slightly faulted by shear movements originating with Younger deformation.

Summary and Comparison of Shuswap Planar Structures

Mount Ida Group	Monashee Group
OLDER DEFORMATION	
(1) Types belong mostly to group B, Figure 3.	Types belong mostly to group A, Figure 3.
(2) Foliation in general parallel with bedding.	Foliation in general parallel with bedding.
(3) Foliation parallel with bedding in detail except where bedding folded, there discordant to bedding.	Foliation parallel with bedding in detail except where bedding very tightly folded.
(4) Foliation involves slip movement on cleavage surfaces; movement disrupts or folds pre-existing structures and quartz veins.	Foliation involves slip movement on cleavage surfaces; movement disrupts, folds, and foliates pre-existing structures, veins, dykes, sills, etc.

(5)	Foliation genetically associated with recumbent drag-folds and *b*-lineation.	Foliation genetically associated with recumbent drag-folds and *b*-lineation.
(6)	Origin and occurrence of foliation not necessarily attended by folds.	Origin and occurrence of foliation not necessarily attended by folds.
(7)	Foliation assumes axial planar parallelism with respect to recumbent folds.	Foliation assumes axial planar parallelism with respect to recumbent folds.
(8)	Development of foliation accompanied by low-grade metamorphism. Higher grades of metamorphism were later.	Development of foliation generally accompanied by high-grade metamorphism, but also with low-grade metamorphism in certain southern parts of area.
(9)	Non-affine deformation, "Gleitbretter".	Non-affine deformation "Gleitbretter"; locally affine.
YOUNGER DEFORMATION		
(10)	Local importance only.	Local importance only.
(11)	Limited to cross-shearing of Older structures in connection with Younger faulting and folding.	Limited to cross-shearing of Older structures in connection with Younger faulting and folding.
(12)	In part associated with Younger granitic intrusion.	In part associated with Younger granitic intrusion.

THEORETICAL ASPECTS OF SHUSWAP FOLIATION

The foliation of the Shuswap rocks has been described in detail and in the following paragraphs theories as to the origin of this foliation and its interpretation will be discussed.

Foliation in the Shuswap rocks undoubtedly resulted from shearing stresses in the rocks and these stresses also produced lineation, drag-folds, boudinage, and mylonite gneiss. Static or load metamorphism, therefore, cannot possibly account for the Shuswap foliation, despite the general parallelism of bedding with foliation.

The differences in the character of foliation in the Monashee group from that in the Mount Ida are probably due to differences in the physical properties of the component rocks rather than to any basic differences in the type of deformation. Presumably the low-grade metamorphic rocks of the Mount

Ida group were not as deeply buried nor as hot as the high-grade metamorphic rocks of the Monashee group when the stresses were imposed. As a consequence they responded to the stresses in somewhat different fashion.

Low Dip of Foliation

Foliation in both the Mount Ida and Monashee groups varies in direction and amount of dip (*see* Map 1059A), but this is probably the result of tilting from universal, nearly horizontal position. The following facts support this contention:

(1) Many large areas of rocks with horizontal or low-dipping cleavage are known on Mount Griffin and in the Mabel and Sawtooth Ranges, and north of Salmon Arm. Nevertheless, in each of these places the rocks are sheared in the same manner and to the same degree as in those places where foliation has a moderate or steep dip.

(2) Foliation with steep dips is largely localized in the vicinity of folds and faults of the Younger deformation.

(3) Within certain individual fault blocks the attitudes of folia are uniform, suggesting that the foliated strata have been tilted as a unit from a nearly horizontal position.

(4) Axial planes, foliation, and the principal beds are parallel over the whole terrane. This can only be explained by assuming that the structures developed from the deformation of a succession of parallel, unfolded beds. These must have been more or less flat lying, for so extensive a series as the Shuswap terrane could not have any significant dip, and at the same time, not be folded.

(5) Lineations with anomalous strike and plunge are most characteristically on layers with anomalous strike and dip. On the other hand, lineations with normal strike and plunge are largely restricted to layers that are horizontal or nearly so. Figure 8 is a weighted plot of the poles to foliation in the Monashee group south of Eagle Pass and shows that most foliation is nearly horizontal, dips over 45 degrees being rare. Figure 9 is a plot of all lineation measured over the same area and shows high concentrations at north 75 degrees east and nearly horizontal. Lineations whose attitudes lie in concentrations of ½ per cent or less on this diagram are considered anomalous and the poles to their corresponding foliations are plotted in Figure 10. Evidently the attitude of most foliation bearing anomalous lineation, is, itself, anomalous, for Figure 10 does not agree with Figure 8 but does, in fact, show a low concentration where Figure 8 shows its highest. The most logical explanation of this discrepancy is that the abnormal folia were brought to their present position through later deformation and the abnormal lineation thereon is a product of this later deformation or is the earlier lineation turned out of line.

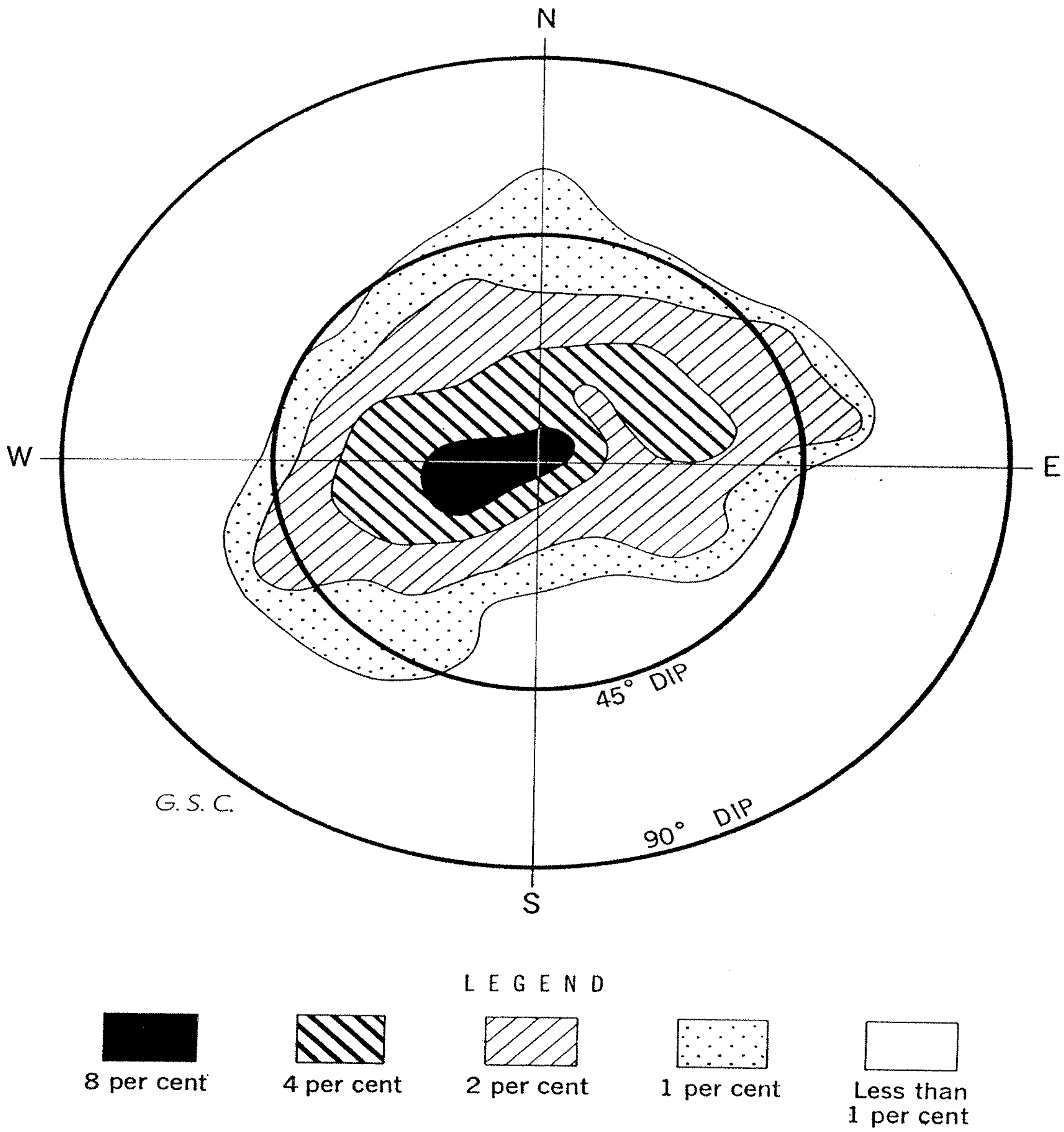


Figure 8. Equal-area lower hemisphere projection of the poles to foliation in the Monashee group. All data are taken in the area south of the railway through Eagle Pass. Five hundred poles are plotted, each representing four square miles; the contour areas represent 8%, 4%, 2%, 1%, less than 1%.

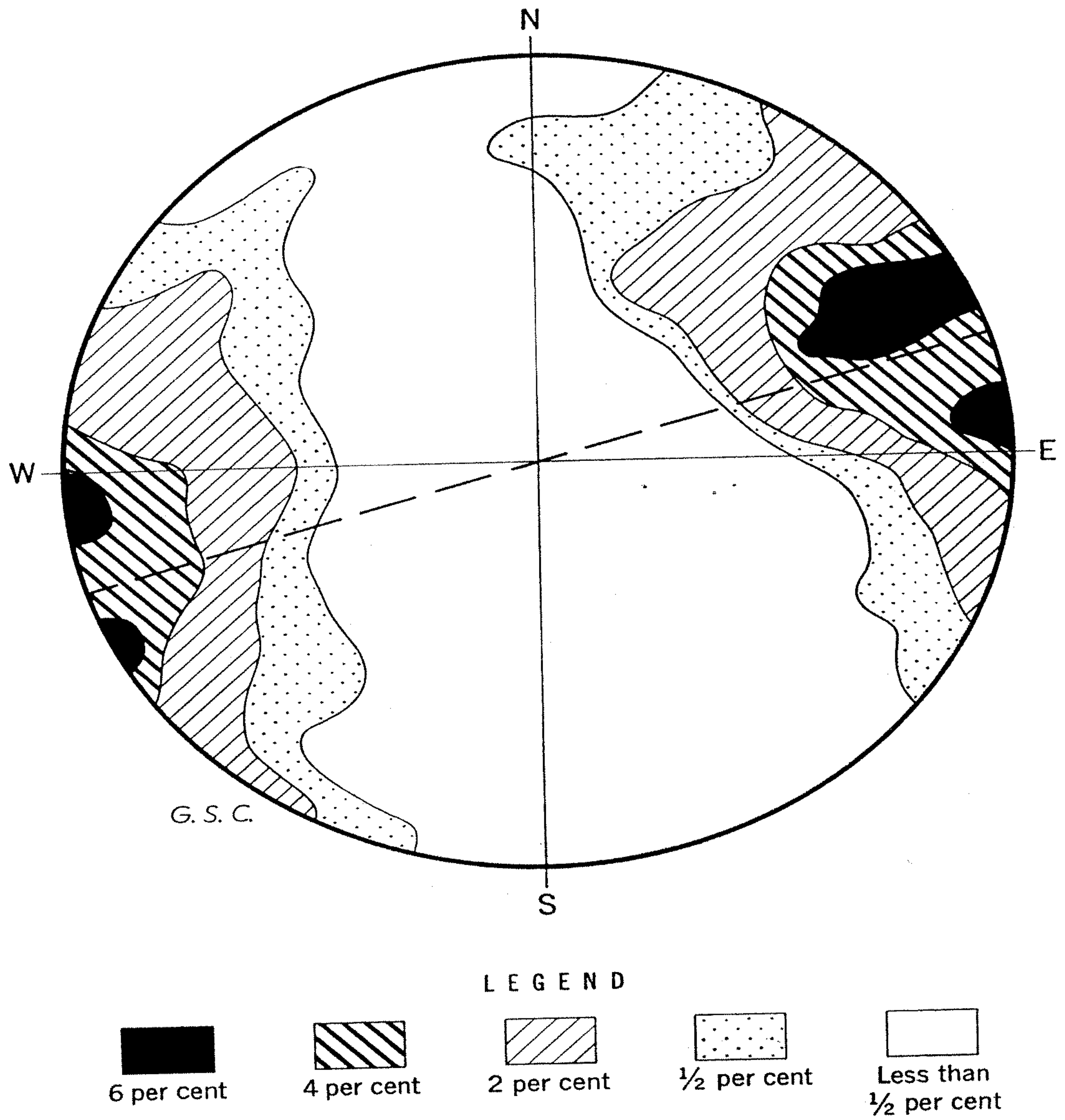


Figure 9. Equal-area lower hemisphere projection of all measured lineation in the Monashee group for the area south of the railway through Eagle Pass. Eight hundred and twenty-five poles are plotted; the contour areas represent 6%, 4%, 2%, ½%, less than ½%.

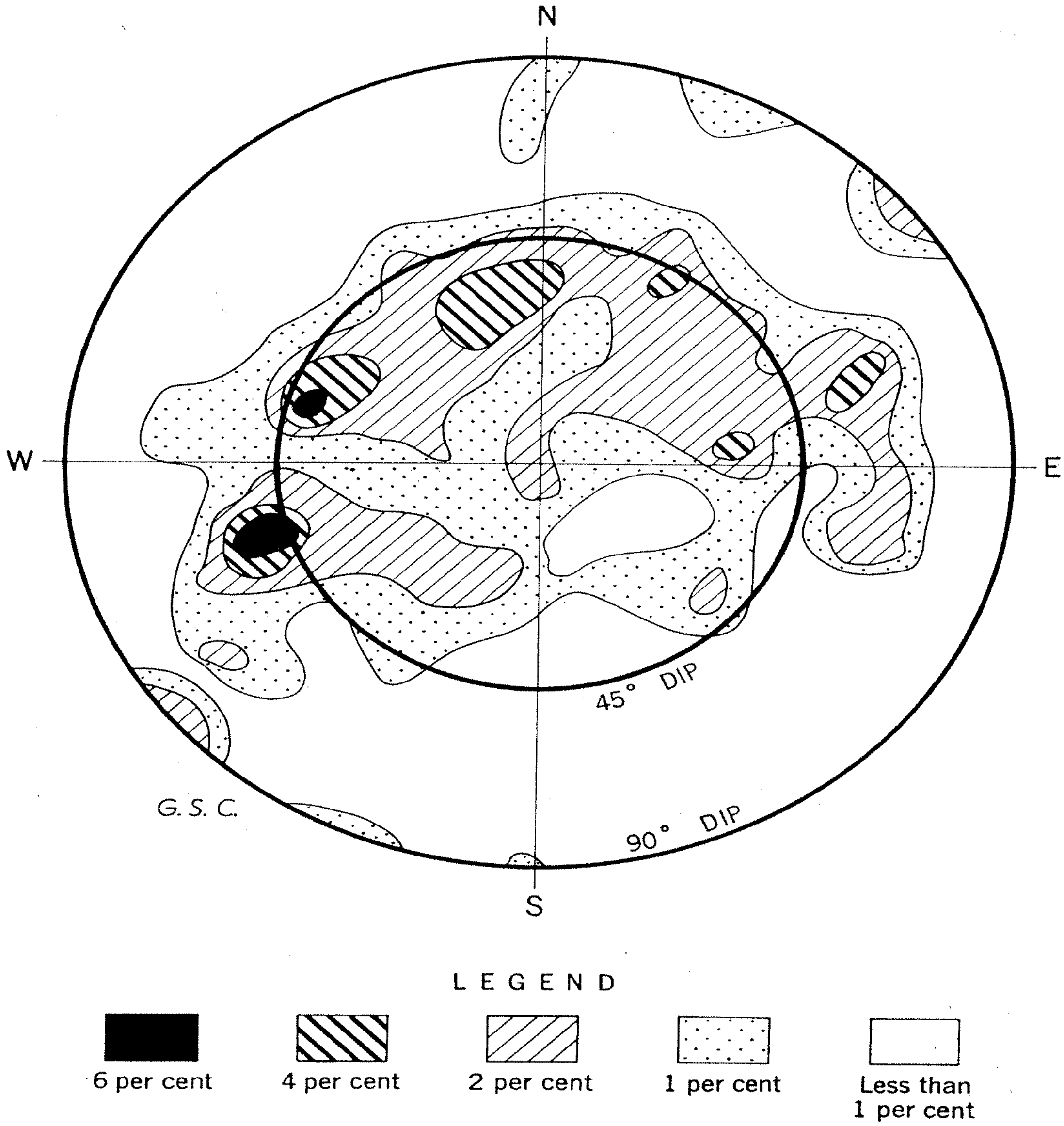


Figure 10. *Equal-area lower hemisphere projection of the poles to foliation that bears anomalous lineation. Anomalous lineations are those falling in the ½%-or-less areas of Figure 9. One hundred and eighty-five poles are plotted; contour areas represent 6%, 4%, 2%, 1%, less than 1%.*

Daly (1915) emphasized the fact that both bedding and foliation of rocks of the Shuswap terrane were nearly horizontal. Investigations beyond the belt mapped by Daly, however, show that dips up to 45 degrees are abundant and still steeper dips are by no means rare despite the fact that the average attitude is nearly horizontal as shown in Figure 8.

Relation of Foliation to Bedding

The hypothesis of load metamorphism has already been discarded as unsatisfactory in explaining the parallelism of foliation with bedding in the Shuswap terrane. In its place a theory of dynamic deformation is proposed. The parallel relation of foliation and bedding depends upon the direction of shear lying close to the direction of bedding and upon the bedding providing incipient planes of weakness. The slip of layer over layer is sufficient in itself to account for the parallel arrangement of inequidimensional minerals but other factors may contribute. Orientation of platy and prismatic minerals parallel with bedding can take place during sedimentation or by metamorphism without accompanying deformation.

Most clastic sediments derived from igneous and metamorphic rocks contain flakes of mica and where these flakes are deposited with their flat sides parallel with stratification, as is generally the case, they can become 'seeds' for recrystallization and thereby dominate the fabric of the new rock to produce schistosity or gneissosity without rock movements. Even without the presence of flat 'seed' crystals certain inequidimensional metamorphic minerals may develop parallel with bedding. This may result from the favoured growth of crystals parallel with bedding planes that either contain materials necessary for their growth, or are channels for solutions necessary for their growth, or that offer least physical resistance to their growth. Certain of these conditions may, indeed, contribute to the development of the foliation that follows bedding around the crests of many folds in the Monashee group. Nevertheless, the factors outlined above are undoubtedly of minor importance for they do not account for the widespread lineation, the foliation in intrusive rocks, or for other deformational structures present.

Foliation of tectonic origin is easily identified in intrusive rocks but is more difficult to establish in most rocks of sedimentary origin. The problem, then, is to determine how much of the foliation in the metamorphosed sedimentary rocks is due to deformational processes and how much to factors related to primary deposition. Foliation in the well-bedded sedimentary rocks of the Mount Ida group can clearly be seen to cut across minor features of sedimentation but in other rocks of the Mount Ida group and in many coarse-grained gneisses of the Monashee group there is doubt as to whether bedding is preserved and emphasized by foliation or is masked and destroyed.

Solutions carrying materials for the growth of quartz and feldspar were available to most of the gneisses of the Monashee group, for these minerals formed pegmatite in boudinage scars (*see* section on Boudinage, p. 104) and along certain planes of foliation. It is reasonable to conclude, therefore, that some severely sheared stratigraphic zones were flooded with pegmatite solutions during deformation and the details of bedding lost through coarsening of the grain, replacement by granitic material, and the production of composition layers or 'pseudo-beds' by the introduction of materials along foliation planes. Granitic gneiss is a typical member of the Monashee group and much of it contains boudinage lenses, coarse lineation, and augen feldspar, all indicative of movement parallel with the foliation. The foliation in this gneiss may be unfolded but lacks the sharp composition layering of foliation inherited from bedding. Such gneissic banding may not follow bedding in detail but in general is parallel with the major stratification.

Some shear planes in the rocks of the Mount Ida group are filled with quartz or carbonates to produce a composition layering. This layering may erroneously give the impression that the foliation is undeformed bedding.

If the rocks of the Mount Ida group had been as severely metamorphosed as those of the Monashee group during the last stages of deformation most of the details of bedding that can now be seen would undoubtedly have been destroyed. Even as it is, the foliation in the Mount Ida group dominates and obscures details of bedding in most places. If metamorphism had been carried farther, accompanied by the introduction of pegmatite and more extensive orientation of minerals, a schist, marble, and gneiss series would have resulted in which the foliation was parallel with larger stratigraphic units although discordant to much of the bedding in detail. The foliation in many of the Monashee group gneisses may have originated in just such a way and, therefore, many structures that appear to be bedding may be only emphasized foliation.

Origin of Flow Cleavage

The genesis of flow cleavage has been a controversial issue for several decades and the consideration of data gained from a study of the Shuswap terrane seems worth while.

The two principal hypotheses for the origin of the flow cleavage are (1) the recrystallization hypothesis ('Wisconsin School'), and (2) the movement hypothesis ('Sander School'), (Swanson, 1941). The recrystallization hypothesis supported by Leith, Harker, Swanson, and many others, holds that flow cleavage results from the static recrystallization of minerals in folded rocks under stress to give a parallel arrangement of platy and prismatic minerals in planes perpendicular to the direction of maximum stress. The movement hypothesis, supported by Sander, Schmidt, Becker, Fairbairn, Knopf, Ingerson, Turner and others, holds that flow cleavage arises through movement within the rocks and is the result of strain and therefore follows the plane of maximum shear.

All agree in general that slip cleavage is the result of shear because of clear evidence of movement along cleavage planes and absence of extensive recrystallization. Flow cleavage, on the other hand, is accompanied by so much recrystallization that bedding is commonly destroyed and the amount, or even the presence, of shear movement cannot be determined.

Most advocates of a movement hypothesis do not distinguish between flow cleavage and slip cleavage except in degree. Both cleavages, to them, represent shearing due to strain with resulting orientation of minerals by rotation, rotation and gliding, and twinning of crystals. Recrystallization in parallel alignment may accentuate the foliation but is merely a reflection of pre-existing strain.

An axiom of the recrystallization hypothesis is that cleavage and bedding are never exactly parallel for any significant distance although cleavage may locally be parallel with bedding on the limbs of isoclinal folds.

All foliation in rocks of the Mount Ida group lies parallel with bedding over wide areas and clearly originates through movement and shearing. Both flow cleavage and slip cleavage by Swanson's definitions are present and are unquestionably the result of a single process, for in adjacent rocks of different lithology has been found mutually parallel cleavage that in one rock is flow cleavage and in the other slip cleavage. The distinction between flow and slip cleavage in the Mount Ida group is strictly arbitrary as the two cleavages coalesce and grade in spacing, appearance, and origin. Also, either type of cleavage may be mapped regionally as bedding without causing serious error, because in most places both types are parallel with bedding. Cleavage is parallel with bedding in unfolded strata and, therefore, is not a structure limited only to the limbs of isoclinal folds. On the basis of these and other evidences one must conclude that flow cleavage in the Shuswap terrane, at least, can only be explained by the movement hypothesis and is of similar origin to slip cleavage.

PLANAR STRUCTURES IN ROCKS WEST OF THE SHUSWAP TERRANE

Cache Creek Group

In the sedimentary rocks of the Cache Creek group bedding is present but not everywhere easily recognized. As for the volcanic rocks, the lavas exhibit flow structure and flow breccia by which the attitude of flows may in places be recognized and the tuffs, although mostly non-bedded, are in some places water-lain and contain well developed, fine-scale bedding and graded bedding.

Only one major stage of deformation has been recognized in the Cache Creek group and it resulted in faults rather than folds. These faults are numerous and strike northwest along the main belt of Cache Creek rocks, slicing it into long, thin strips. The strata in these slices dip steeply and some folds are present whose axes trend along the slice and are more or less horizontal. Secondary planar structures include cleavages and joints but are largely restricted to the vicinity of faults and have haphazard alignment. The Cache Creek rocks are relatively unmetamorphosed except near granite intrusions where contact metamorphism later than most of the deformation is generally present. No structures were found in the Cache Creek group to correspond with the foliation of the Older deformation in the Monashee and Mount Ida groups, and all structures present are parallel with those of the Younger deformation in the Shuswap terrane.

Granitic and Tertiary Rocks

Most of the granitic rocks were intruded after the main faults developed but were, in some places, crushed by late movement along them. The resulting planar structures are relatively inconsequential, haphazard, shatter cracks. The Tertiary rocks are practically undisturbed and, with few exceptions, planar structures are restricted to depositional features in the sedimentary rocks and to flow and cooling features in the lavas.

PLANAR STRUCTURES IN ROCKS EAST OF THE SHUSWAP TERRANE

Formations of Windermere Age

Relatively little of the map-area is underlain by the rocks of Windermere age. In those studied, broad scale bedding is reasonably distinct, but secondary planar structures are largely restricted to shear zones in or near faults. No structures corresponding with those of the Older deformation of the Shuswap terrane were seen in Windermere rocks.

Slocan Group

Argillaceous and quartzitic sedimentary rocks on the west shore of Upper Arrow Lake opposite Nakusp, considered to belong to the Slocan group, are intensely sheared and jointed by planar structures that dip steeply and transect bedding at large angles. These are, however, in nature and orientation unlike structures of the Older deformation in the Shuswap terrane.

• FOLDS

FOLDS IN THE SHUSWAP TERRANE

The absence of folds in the strata of the Shuswap terrane was one of the main bases for the theory of load metamorphism as applied by Daly, and except for a few post-foliation warps, few upright folds are known. Although superficially appearing unfolded, the rocks of the Shuswap terrane are, nevertheless, folded on a small scale to a degree that is most extraordinary. These folds average a few feet in amplitude and are recumbent and isoclinal with horizontal or shallowly plunging axes. A remarkable feature of these folds is their prevalence throughout the Shuswap terrane and the evidence they provide of widespread, horizontal thrusting movements throughout the thick assemblage of nearly horizontal beds.

Other folds in some places are clearly superimposed on the recumbent type and therefore belong to the Younger period of deformation. More than one stage of this folding can in places be identified but, for convenience, all are grouped together as the Younger folds to distinguish them from the earlier recumbent ones which are here designated as Older folds.

Older Folds

The Older folds are of the same type in both Monashee and Mount Ida groups. They are typically recumbent drag-folds with long flat-lying upper limbs short, steeper, overturned middle limbs and long, flat-lying lower limbs. The long limbs follow the general layering, whereas the middle limb may be at a slight angle to it. This form may be modified where deformation is severe enough to give an isoclinal type of fold and to obliterate limbs and noses by thinning and shearing.

The axial planes of the recumbent folds make small angles with the principal beds. This divergence decreases with increase of differential slip between the bounding strata and becomes so small that axial planes are, for all practical purposes, parallel with stratification (*see* Plates VI A, B and VII A, B). The folding is commonly confined to a relatively thin layer which is apparently bounded by bedding faults (*see* Plate VI B). The drag-folds die out towards the boundaries of the layer and the layer itself is not sensibly folded as a whole although its thickness may be changed.

The drag-folds range from a few millimetres up to several tens of feet along the middle limb but average about 2 feet for the largest folds measured in outcrop. The Fosthall Mountain fold is the largest recognized and measures about 5 miles on its middle limb. Large drag-folds may be more abundant than suspected, for the scarcity of stratigraphic markers and severity of the shearing make the detection of such folds difficult.

The gneisses of the Monashee group are monotonously uniform in composition, and folds in these rocks are only recognized after close scrutiny. Folds in the Mount Ida group also are generally obscure for in these rocks shear cleavage conceals the bedding. Close study of cliffs that cross the regional trend of fold axes and lineation, however, rarely fails to disclose some folding. All the Shuswap rocks were affected by the Older deformation but certain beds contain more folds than others either because the deformation was not equally distributed or because the movement was taken up in some strata by other structures such as shear planes. The variation in the distribution, character, and strength of lineation, foliation, boudinage, and other effects of deformation bears out this conclusion.

Lineation in all rocks of the Shuswap terrane is parallel with the axes of the Older folds but differs in each of the two groups in quality and degree. In the Monashee group lineation can be found everywhere regardless of the presence of folds or parallelism of bedding and foliation. Folds and lineation are, however, genetically allied for they are similarly oriented (*see* Figures 11 and 9, and 13 and 14).

Axes of Older folds in the Monashee group are, on the whole, nearly parallel both locally and areally, and trend predominantly northeast. In carbonate rocks, however, some fold axes diverge as much as 90 degrees, probably because of the extreme incompetence of the rock.

The shape of Older Shuswap folds is that of typical S-shaped drag-folds. Many folds are, however, modified because of (1) the plastic quality of the rocks; (2) the amount of rock movement; (3) the distribution of the movement evenly or unevenly in different beds; and, possibly, (4) the position occupied by the folds in relation to a major unseen structure such as a thrust plane or a large recumbent fold. Despite all variations the fold axes are mutually parallel over extensive areas indicating that the small folds are due to a single regional structural process. A few examples of Shuswap folds are given below not only to illustrate the varieties and types of folds but to present the problems introduced by the configuration, special relations, and orientation of the folds.

Examples of Older Folds

The Fosthall Mountain fold, northeast of Sugar Lake, is the largest demonstrable fold belonging to the Older deformation. It is a combination of an overturned anticline and syncline in the form of a giant drag-fold. The axes plunge gently to the southwest or are horizontal and the axial planes and middle limb are overturned to the north or northwest. The traces of the axial planes of the Fosthall Mountain fold, which are 2 to 4 miles apart are shown on the map; Figure 15 shows a cross-section of the fold.

The fold was first detected when the sense of drag-folds in the long limbs was found to differ from that of drag-folds in the middle or overturned limb, and was later confirmed by stratigraphic evidence. The core region of the anticline contains unusually steep dips as well as coarse rodding caused by giant crenulations and rolling of beds (*see* Plate VIII A).

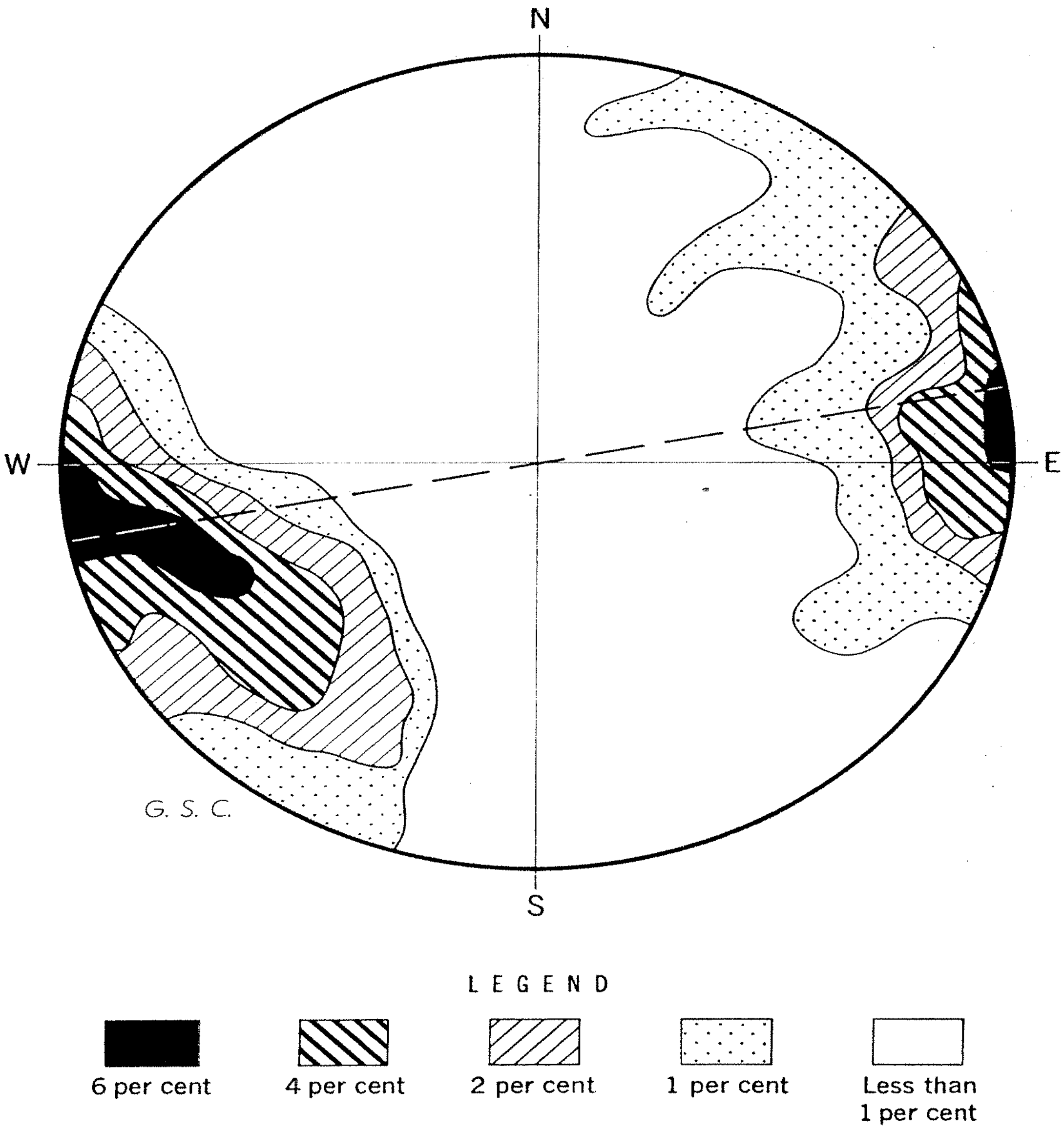
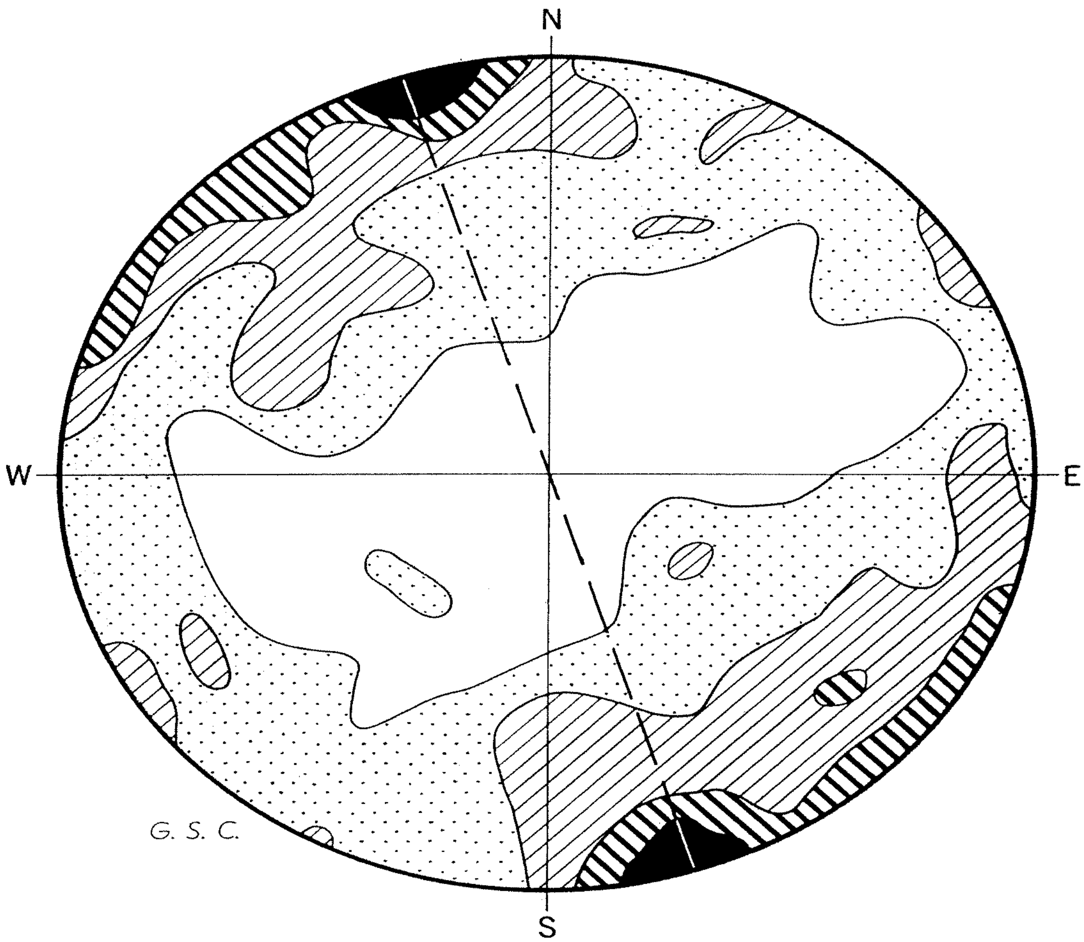


***Figure 11**. Equal-area lower hemisphere projection of axes of folds in the Monashee group associated with a rock lineation that is generally parallel with them. Both are presumed to belong mainly to the Older deformation. All data are taken from the area south of the railway through Eagle Pass. Three hundred poles are plotted; the contour areas represent 6%, 4%, 2%, 1%, less than 1%.*



LEGEND

6 per cent | 4 per cent | 2 per cent | 1 per cent | Less than 1 per cent

Figure 12. Equal-area lower hemisphere projection of axes of folds in the Monashee group not associated with a rock lineation and presumed to belong mainly to the Younger deformation. All data are taken from the area south of the railway through Eagle Pass. One hundred and sixty-four poles are plotted; the contour areas represent 6%, 4%, 2%, 1%, less than 1%.

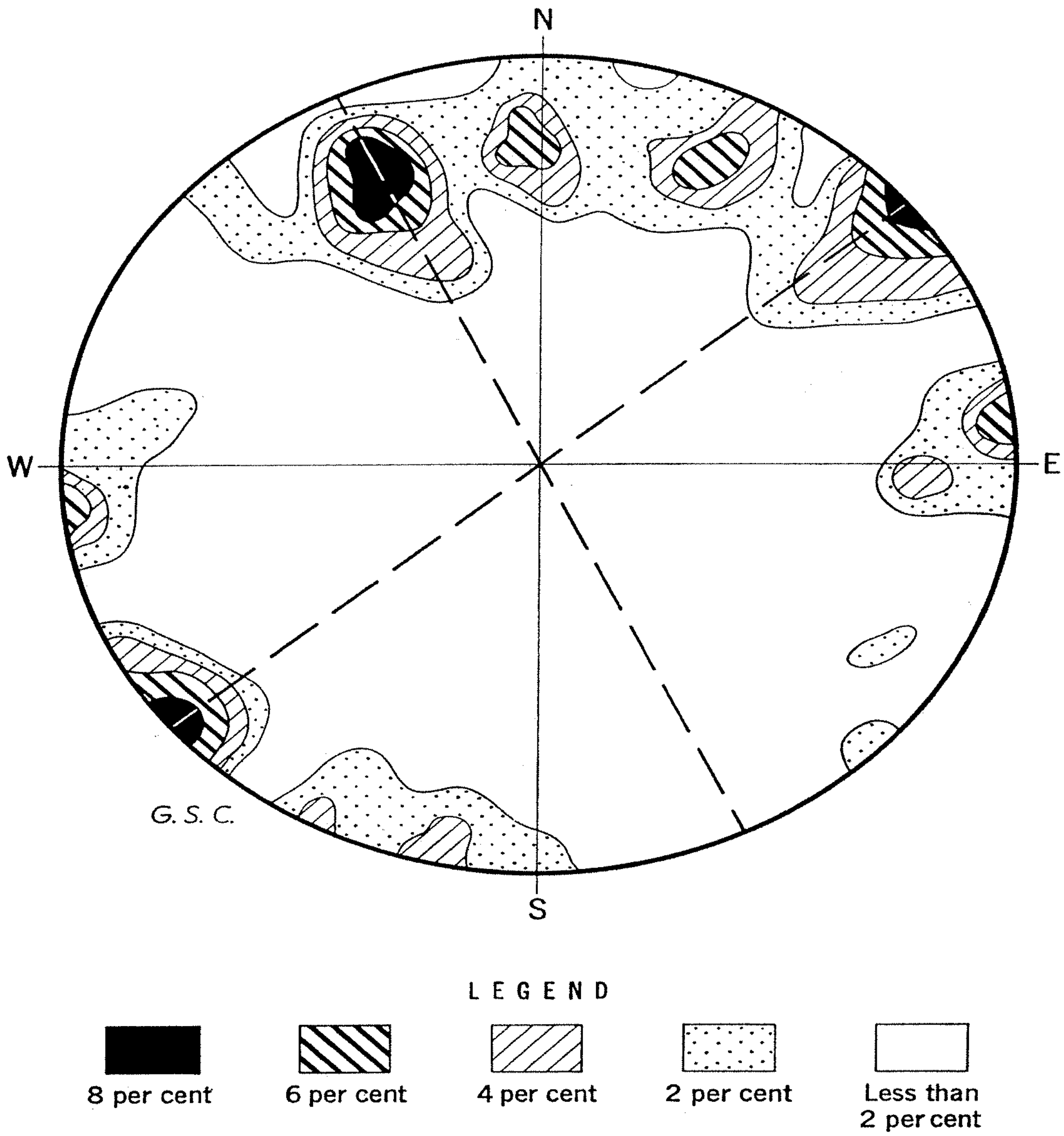


Figure 13. Equal-area lower hemisphere projection of drag-fold axes in the Mount Ida group. One hundred and five poles are plotted; contour areas represent 8%, 6%, 4%, 2%, less than 2%.

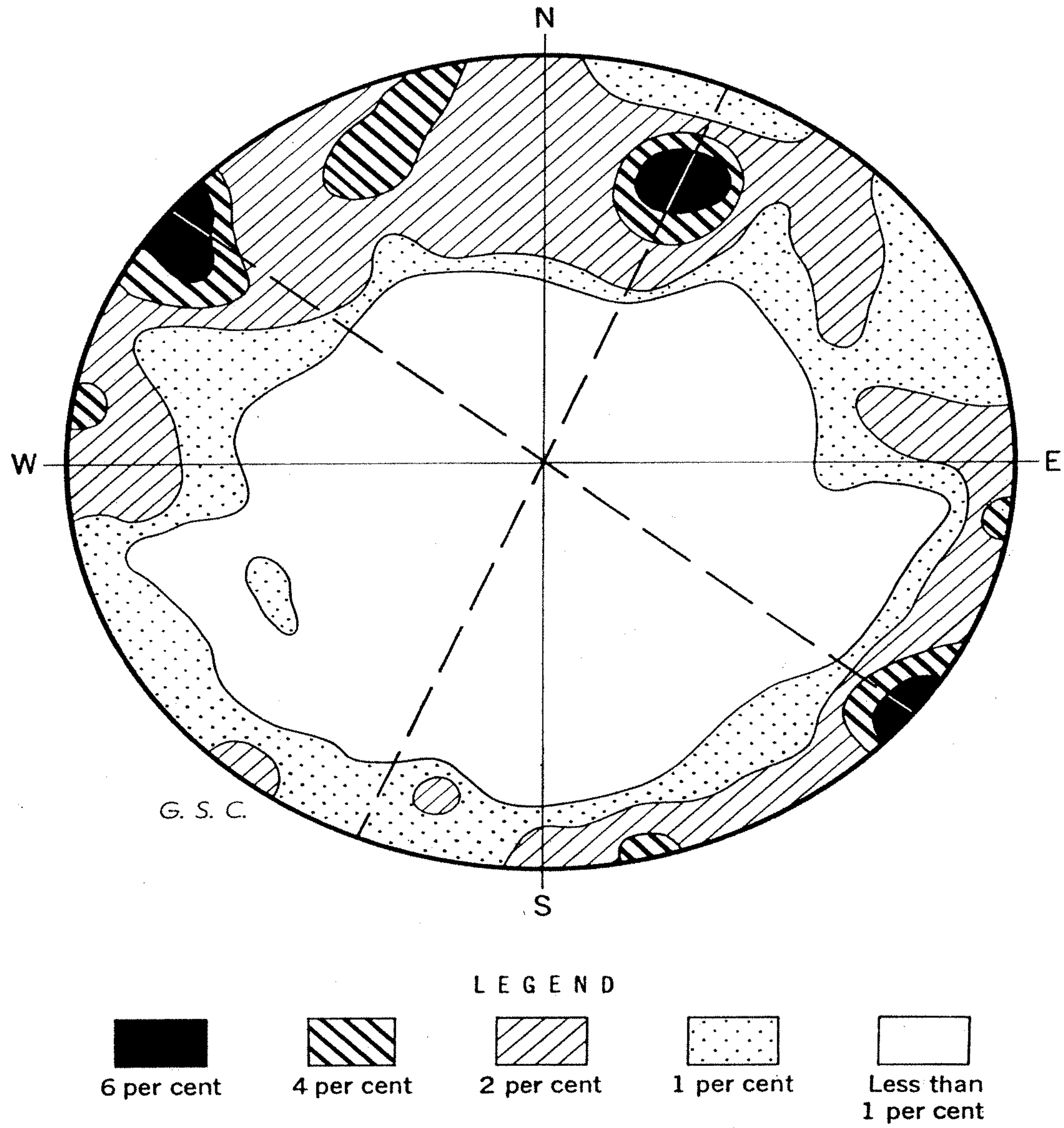


Figure 14. Equal-area lower hemisphere projection of lineation in the Mount Ida group. Two hundred and fifty poles are plotted; contour areas represent 6%, 4%, 2%, 1%, less than 1%.

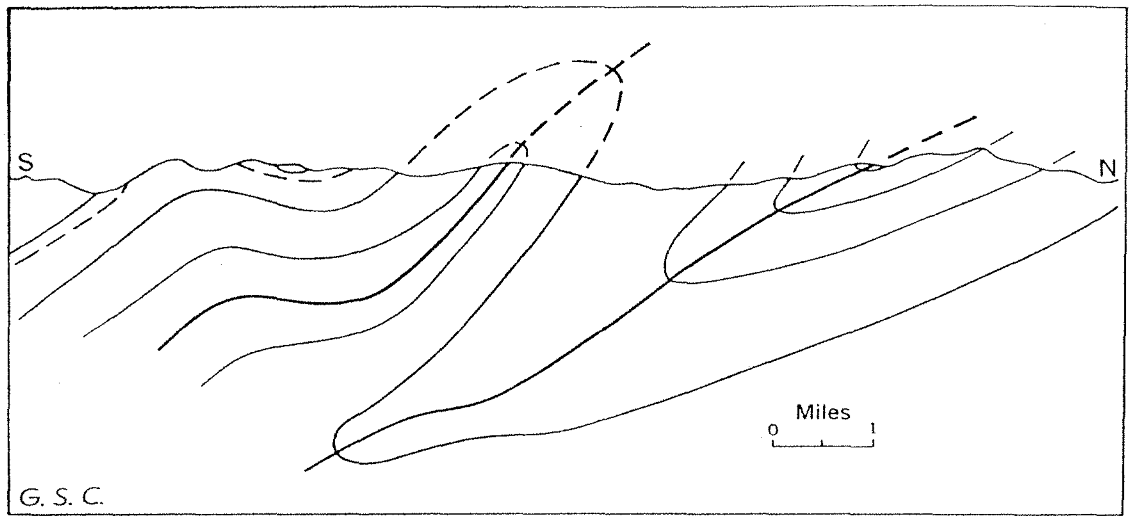


Figure 15. ***Cross-section of Fosthall Mountain fold. The Younger deformation has refolded the south limb of the anticline.***

Isoclinal folds are also common in the core of the anticline (*see* Plate VIII B). Plate II B shows drag-folds in the middle or overturned limb of the Fosthall Mountain fold.

The core region of the syncline is more difficult to recognize because axial plane shearing has more or less obliterated all planar and folded structures. This shearing is nearly parallel with the strata in the lower long limb and is so strong in the overturned middle limb that from a distance the shear planes may be mistaken for bedding and the assemblage regarded as a normal unfolded stratigraphic succession. Rodding and strong *ac*-jointing are rare in the synclinal core and axial planar shears and faults predominate. This type of shearing, where extensive, is closely allied to thrust faulting, and, indeed, small thrust faults may be present in some parts of the Fosthall Mountain fold.

From the foregoing it will be noted that folds in Shuswap rocks are not readily recognized, for strong axial planar shearing and thrust faulting commonly obscure the crests of folds and produce a false regularity of layering that is misleading. Other large folds that were undetected may consequently be present. Rodding and associated structures, such as appear in the anticlinal part of the Fosthall Mountain fold, are the only readily apparent features and, where observed, suggest the presence of a fold crest.

The absence of major folds over much of the Shuswap terrane is well illustrated on the Sawtooth Range where it was possible to trace a zone several hundred feet thick containing thick limestone beds from Peak 7730 to Mount Tsuius, a distance of nearly 4 miles. Throughout this distance the zone was nearly flat lying with no more than gentle undulations, and yet both beds of limestone and interbedded mica and amphibole gneiss are strongly deformed internally by drag-folds, all more or less in same direction. The axial planes of these drag-folds are roughly parallel with the zone as a whole and shearing along many of them, particularly in the gneiss, has largely obliterated the crests. The foliation thus resembles bedding and it is, indeed, parallel with the zone as a whole and its principal component beds.

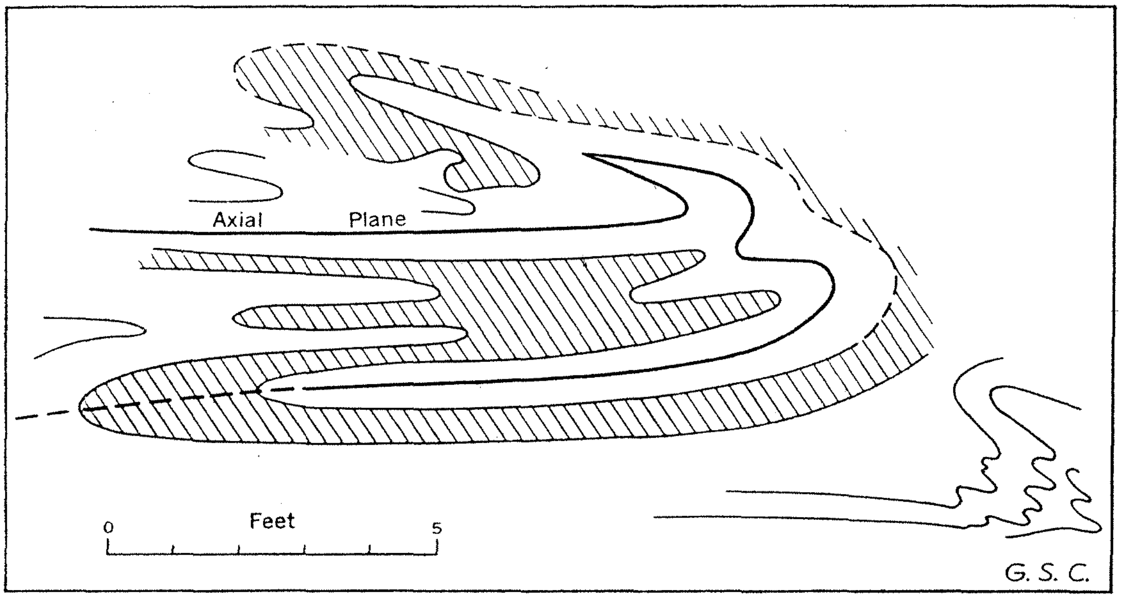


Figure 16. ***Complex fold in gneiss and schist of the Monashee group, Hunters Range; sketched from photograph.***

The fold shown in Figure 16 is a quarter mile east of the Mount Mara forestry lookout in Hunters Range. The particular feature of interest is the opposite sense of drag above and below the central rib as if the rib area had 'punched' its way to the right dragging the nearby beds with it. Whatever the origin of this action may be, it is possible that the same process may occur elsewhere on a much bigger scale and account for reversals in shear sense that might be incorrectly interpreted as marking complementary limbs of large folds.

The strata outcropping along the shore of Black Point in Mara Lake, for instance, dip uniformly and gently to the south and consist of an upper and a lower series of limestone and calcareous sedimentary rocks separated by a middle series of thinly layered hornblende gneiss. All the strata are deformed as proved by the prevalence of pseudo-conglomerate, boudinage, and isoclinal drag-folds, but the strata appear conformable and unrepeated. The shear sense of the drag-folds in the hornblende gneiss middle member is, however, opposite to that in the limestones above and below, but as there is no evidence to suggest the presence of a large recumbent fold, this condition is best explained by some 'punching' mechanism such as that described in the preceding paragraph.

Figure 17 is a profile sketch of a fold on the south flank of Mount Macpherson at elevation 7,000 feet. The sharpness of the fold notably increases towards the right until the limbs become isoclinal and the core of the fold is obscured. From there it passes into a bedding fault. To the north the fold opens and within a short distance disappears entirely. Presumably the situation was repeated at the other end of the fault and the structure as a whole was a simple thrust producing a relatively local bedding fault terminating in folds at each end (*see* Figure 18).

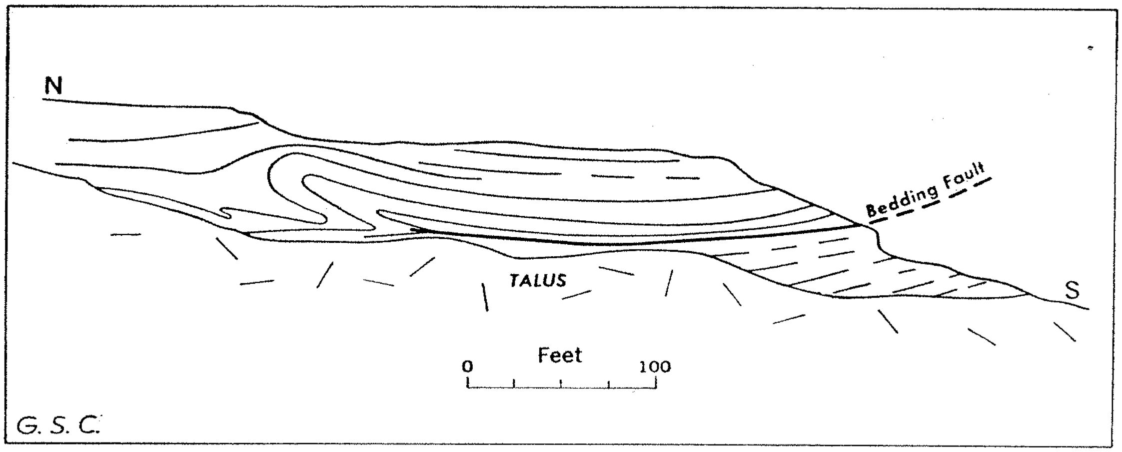


Figure 17. ***Fold on Mount Macpherson showing rapid transition from bedding fault into fold; sketched from photograph.***

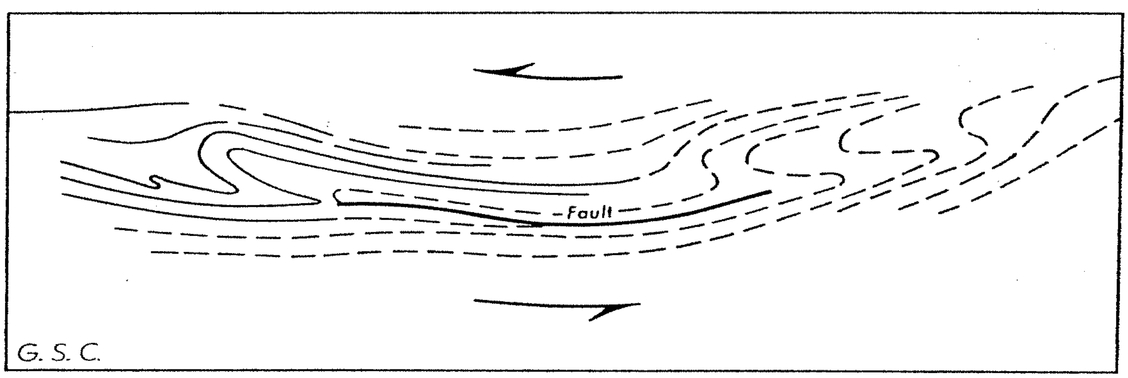


Figure 18. ***An interpretation of the complete structure shown in Figure 17.***

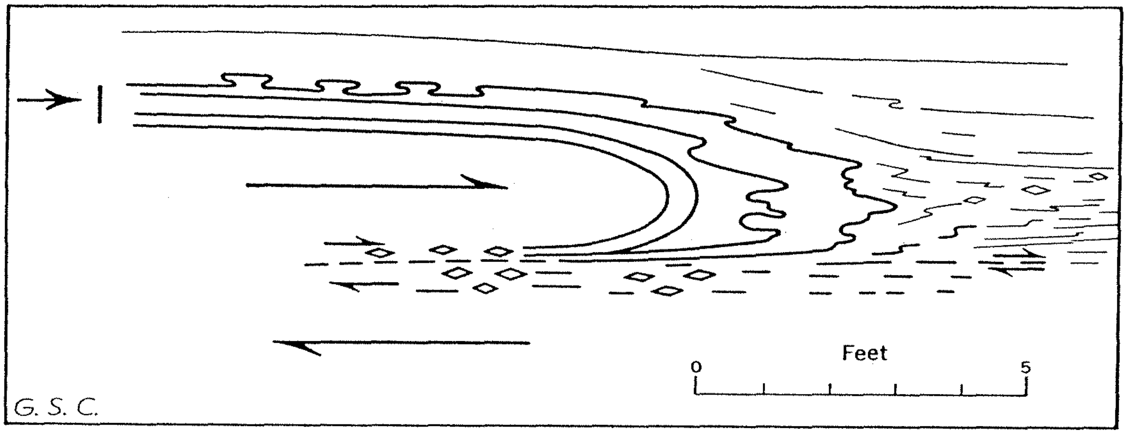


Figure 19. ***Fold in gneiss and schist of the Monashee group, Hunters Range. Apparently a driving force acted along the upper limb and dragged the lower limb into augen gneiss; sketched from photograph.***

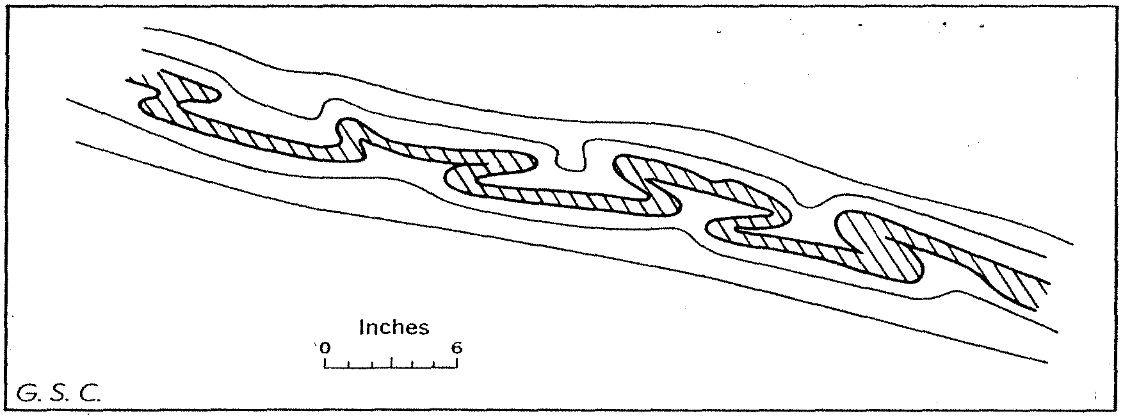


Figure 20. ***Detail of upper limb of fold shown in Figure 19. Ptygmatically folded layer is granitic gneiss; sketched from photograph.***

The fold shown in Figure 19 occurs half a mile west of Mount Mara forestry lookout in the Hunters Range and is typical of many folds in gneisses of the Monashee group. The development of augen gneiss in the under limb was discussed in the section on foliation. It is due to shearing and extension of the beds. Folding in the upper limb, however, (*see* Figure 20) suggests that the layers there were shortened by compression. Apparently the fold formed by a force that acted along the upper limb, compressed it, and sheared and dragged out the lower limb. It is more probable that a structure such as this would be produced as the drag of a horizontal stratum overriding a bedding fault than as a drag-fold on the limb of a larger fold.

Illustrations of other typical small folds in the Monashee group are given in Plates VI B, VII A, B, VIII A, B, and IX A, B.

Summary

The basic mechanical principle in every fold observed can be best described as 'smearing' due to simple slipping of upper layers over lower ones, without much buckling or folding of the layers as a whole. The individual small layers may deform by simple laminar flow ('Gleitbretter'), which would produce a bedding cleavage, or by rotation which would cause recumbent folds. The shape and orientation of these folds disclose the major shear sense. Complexities arise, of course, where cleavage, folding, and refolding combine during continued deformation.

A distant or cursory inspection of strata of both Mount Ida and Monashee groups gives the impression that the rocks consist of horizontal or rather gently dipping, well-layered strata that are in other respects undisturbed and undeformed. Close inspection, nevertheless, invariably discloses the fact that the rocks have been subjected in detail to profound tectonic movements that have produced lineation, foliation, and recumbent drag-folds. The larger scale layering, which is apparently undeformed, is the normal slightly modified sedimentary stratification.

Although drag-folds commonly reveal the sense of shear in folded rocks interpretation of them in Vernon map-area was difficult because of any one of four circumstances (1) many drag-folds are so attenuated and compressed, and the limbs so thinned and nearly parallel that middle limbs cannot be distinguished from long limbs; (2) strong axial plane shearing across crests may mask the folded bedding; (3) the observed drag-fold may be on the middle limb of an unseen, larger fold and therefore may not be representative of the regional movement; (4) the number of drag-folds yielding one shear-sense is sometimes nearly equalled by interspersed folds yielding the opposite sense. Determinations of shear-sense were made in many places over the area and the results obtained were moderately consistent (*see* Figure 2). Each of the arrows represents several or many observations and shows the estimated direction of the net shear-sense. In nearly every group of observations some drag-folds with opposite shear-sense were seen, but the direction indicated is that of the larger folds or the greater number. Where the two directions were in nearly equal numbers no symbol is recorded on the map.

The validity of such determinations may be questioned, or observations restricted to widely spaced lines of traverse may be considered insufficient, but it will be noted that the results are consistent within blocks separated by younger unrelated faults. This consistency is itself evidence for the usefulness of the method.

The interpretation of drag-folds was to some extent useful in recognizing larger folds and the Fosthall Mountain fold was primarily discovered and outlined by this means. The Fosthall Mountain fold is just large enough that the shear-sense on its limbs can be shown on the map. Other large folds were recognized but were generally too small to be shown in their entirety on the map.

The way in which folding is restricted to drag-folding within otherwise relatively undeformed layers is so universal throughout the Shuswap rocks that it must be considered to represent the basic nature of the deformation. Is there, however, folding on a vastly greater scale, of which the folding observed is only a minor result? The largest fold discovered in the terrane, the Fosthall Mountain fold, has a middle limb about 5 miles long. Other folds have been recognized with middle limbs estimated to be a few hundred yards to half a mile in length, but all, including the Fosthall Mountain fold, are essentially giant drag-folds. But when the great areal extent of the Shuswap terrane is considered as well as the degree to which it is everywhere deformed even these giant drag-folds are comparatively minor. The crestal part of the Fosthall Mountain anticline is a striking and unmistakable feature, and if still larger folds are at all common at least their crests should be recognizable unless they are obliterated by thrust-faulting or shearing along their axial planes. Evidence for larger folds has not been found.

In the Mount Ida group the stratigraphic sequence consists of formations that are lithologically distinctive one from the other. The group is folded in the typical Shuswap manner and intensity, but the major strata are not repeated. If a major fold is present the whole stratigraphic sequence of 60,000 feet must lie on one limb, a situation that is most improbable. Similarly, the great block of gneisses in the Gold Range everywhere exhibits typical Shuswap structures and can be traced for miles along the strike at right angles to the tectonic trend of Older formation. The only large fold observed there was the Fosthall Mountain fold.

The conclusion therefore seems inescapable that the folds seen everywhere and described above are the largest and 'highest order' effects of the Older deformation.

Figure 2 shows the principal recorded directions of drag-folds by a small arrow. The large, solid arrows have the same structural meaning as the small ones but represent the general direction over the large area in which they are centred. These areas or 'fields' are outlined on the map and in them the shear-sense of the drag-folds is essentially in the same direction. The main body of Monashee group rocks contains three such fields within which the drag direction is either to the north and northwest or to the south and southeast. In the Queest Mountain block, immediately east of Shuswap Lake, and in the area of the Mount Ida group the direction is mainly to the east or northeast.

Further discussion will be postponed to the section in which the implication of all types of structures in the Shuswap terrane is considered.

Younger Folds

Folds of the Younger deformation are distinguished not so much by the fact that they are superimposed on the Older folds as by their characteristic shapes and orientation. The Younger folds are described as 'buckle-folds' because of their warped or buckled shapes and their irregularity. They range in size from small crenulations to warps up to at least a mile between limbs, although the larger folds were difficult to trace due to the lack of stratigraphic markers and poor exposures. Regular anticline-syncline repetition is rare in a succession of Younger folds except in folds a foot or so across. The lack of rhythmic repetition in the large folds suggests that they result from localized disturbances such as occur near faults or intrusions. They apparently formed during the period of local intrusion and metamorphism, and reveal that the rocks were in a plastic condition when folded.

The axial trends of Younger folds (*see* Figure 2) are to the northwest, but are not as orderly and consistent as those of the drag-folds of the Older deformation. Figure 12 is a statistical analysis of Younger fold axes.

Examples of Younger Folds

In the vicinity of Blanket, Cranberry, and Odin mountains the strata are, in some places, folded on a small scale and in a rather patternless manner suggestive of plastic condition in the rock. Zones containing this phenomenon grade into other zones in which the rocks have clearly yielded by shearing (*see* Plate V A). On the shores of Mabel Lake, particularly on the northwest side north of Dolly Varden Beach, are excellent exposures of Shuswap gneiss distorted by the Younger folds.

Towards the northeast flanks of Mount Macpherson the nearly horizontal strata turn down to the northeast in a sharply crested fold. A fault parallel with the Columbia River fault appears to occur at the crest but the displacement is considered to be negligible. Horizontal lineation parallel with the fold axis occurs near the core as coarse mullion structure and is one of the few examples of lineation associated with Younger folds. The shape of the fold and its parallelism with the nearby Columbia River fault suggest that the fold is actually a drag with the upthrown side on the west.

Between Columbia River and Victor Lake, in Eagle Pass, the strata are arched in a broad, gentle flexure whose axis plunges gently to the south. Both limbs of this fold terminate against faults.

In the saddle immediately north of Blanket Mountain the strata are folded into a broad, westerly plunging syncline. This structure is apparently bounded on all four sides by faults and may have been formed by some wedging action at the time of the faulting. On the south limb of this syncline small-scale shear-folding is intense (*see* Plate X A). This is a rare example of Younger folds that resemble Older drag-folds in shape and intensity. The axial trend of these folds differs markedly from that of typical Older recumbent drag-folds nearby and, moreover, despite the high degree of folding and crenulation, the Older lineation is preserved and crosses the axes of crenulations at about 55 degrees. Although both syncline and shear-folds are believed to be parts of the Younger deformation, it is unlikely that they had a common cause in so far as the directions of the axial planes and the relative intensities of folding are so different. It is interesting to note that in this region, immediately north of Blanket Mountain, at least three and perhaps four periods of deformation have left their mark. In chronological order the structures marking these are (1) recumbent drag-folds on axes trending north 60 degrees east (Older folds); (2) shear-folds on axes trending north 30 degrees west; (3) the broad syncline plunging due west; accompanied or succeeded by, (4) block faults.

The haphazard attitudes in Hunters Range and southeast towards Mabel Lake are testimony to Younger plunging folds. Only small folds are actually seen in this region but in all probability these are minor manifestations of larger folds. The folds may actually be broad and open for in such flat-lying strata even a gentle fold would produce marked changes in the strike.

One of the clearest examples of a Younger fold superimposed on Older folds is found among some nameless mountain summits and ridges about 4 miles south of Fosthall Mountain, northeast of Sugar Lake. The strata are warped into an anticline and syncline with axes plunging to the southwest. The axial direction of small recumbent folds is closely parallel with that of the main folds. The drag-sense is, however, in the same direction on all limbs, not in the opposite direction on opposite limbs as would be the case if the folds were related. Evidently the recumbent folds were formed during Older deformation and the upright folds were superimposed on them during Younger deformation, both sets of structures fortuitously occurring on nearly parallel axes.

All the above examples are from the Monashee group for, with the exception of small drag-folds obviously caused by movement along faults, recognizable folds of the Younger deformation are rare in the Mount Ida group. Gentle folding is clearly marked by the limestone band in the vicinity of Eagle Bay on the south shore and by the Tshinakin limestone on Aline Hill. In the Larch Hills south of Salmon Arm flat-lying Sicamous limestone and the underlying Mara formation are clearly warped into open folds. Other similar examples are known but are not common.

Small-scale Younger folding in the Mount Ida group is important only near intrusive bodies of granite, aplite, and pegmatite. It may have resulted from a concentration of stress around the unyielding intrusions, or may be due to a relative plasticity of the intruded rock in the aureoles.

Except for local forces associated with intrusion of the granites, the origin of most Younger folds in the Shuswap terrane can best be related to the period of faulting and folding that affected the entire Cordillera during the late Mesozoic. The trend of both folds and faults agrees closely with that of similar features in the younger rocks on either side of the Shuswap terrane (*see* Figure 2).

Comparison of Older and Younger Folds in the Monashee Group

The information given below is from the Monashee group south of the Canadian Pacific Railway through Eagle Pass. Data on Younger folds were not available or were insufficient in other areas to allow reasonable comparison.

Older Folds	Younger Folds
(1) Highest statistical concentration of axial orientation nearly horizontal at north 75 degrees east (*see* Figure 11).	Highest statistical concentration of axial orientation nearly horizontal at north 20 degrees west (*see* Figure 12).
(2) Relative high degree of alignment of axes—Figure 11 has a single strong maximum.	Relatively low degree of alignment of axes—Figure 12 has a girdle-like concentration.
(3) Strong parallel lineation rarely absent.	Associated lineation rare; in places weak mineral alignment or crenulation lineation.
(4) Folds recumbent, commonly isoclinal; axial planes mutually parallel and essentially parallel with major strata; high degree of repetition in fold pattern.	Open, upright folds, rarely recumbent; axial planes rarely parallel and commonly at high angles to foliation and bedding; low degree of repetition in fold pattern.
(5) Degree of deformation variable but commonly severe, tending to obliterate fold structures by the production of mylonite gneiss.	Degree of deformation variable but generally relatively gentle warps; Older lineation commonly preserved.
(6) Present in horizontal or gently dipping, otherwise undisturbed strata.	Involving buckling of strata, anomalous strikes, and steep to vertical dips; most strata conspicuously deformed.

FOLDS EAST OF THE SHUSWAP TERRANE

In comparison with the rocks of the Shuswap terrane those to the east are little deformed and small folds are rarely seen. Some large folds of mappable size are however present, the most important being the Lardeau synclinorium most of which lies to the east of the area. Some folds were observed that constitute part of this synclinorium and that have axes trending northwest parallel with that of the main structure. A few have axes crossing this direction at large angles. Most of the folds in this region are upright and open unlike the recumbent, isoclinal drag-folds of the Older deformation in the Shuswap rocks. Some small drag-folds of the Shuswap type were seen in the vicinity of Mount Cartier among members of the Badshot limestone, but, unlike the Shuswap drag-folds, their axes follow the regional northwest trend. Near intrusive bodies the strata are commonly deformed in irregular buckles and warps. All folds observed are apparently equivalent to the Younger folds of the Shuswap terrane.

FOLDS WEST OF THE SHUSWAP TERRANE

Folds in rocks west of the Shuswap terrane are, within the map-area, even more inconspicuous and scarce than those to the east of it. Deformation of the Cache Creek rocks has resulted in parallel and subparallel faults between which the strata are tilted into monoclinal units. Some buckling and warping accompanied the tilting but is mostly due to drag on the faults. The axes of most of these folds strike northwest, parallel with the belt of Cache Creek rocks, and are more or less horizontal. The tilting of strata in the Cache Creek group is due primarily to the movement on faults but the strike of the strata resulting from this tilting also corresponds with the directions of tectonic and fold axes.

The Cache Creek is the only group that yields useful information on folds in this part of the map-area, for exposures of the Nicola group are scanty and the Kamloops group is essentially undeformed. For the purposes of this report the matter of special interest in the Cache Creek group is the total absence of folds resembling those of the Older deformation in the Shuswap terrane, in shape, orientation, abundance, or intensity.

• LINEATION

"Lineation is a descriptive and non-genetic term for any kind of linear structure within or on a rock" (Cloos, 1946), regardless of whether it originated with the rock (primary) or was impressed upon it later (secondary). Cloos lists fifteen kinds of lineation and distinguishes between them principally on the basis of their origin. In so far as the origin of much of the lineation in the Shuswap terrane is not known, the classification used in this report is purely descriptive. Only small, oft-repeated structures are referred to as lineation; larger, special linear features (for example fold axes, boudinage necklines, and fault lines) are referred to by name, although they, also, are lineation as defined by Cloos.

The Shuswap lineation can readily be divided into two principal categories (1) formed by oriented minerals or small groups of minerals, (2) formed by the intersection of planes. Each of these may be further subdivided into fundamental categories as shown in Figure 21, although Shuswap lineation is generally due to a combination of two or more.

Within a group of rocks similarly metamorphosed the type of lineation present depends largely upon the lithology of the rock, whereas in rocks differently metamorphosed the type of lineation depends more on the grade of metamorphism; for instance, lineations in the gneisses of the Monashee group are almost entirely due to mineral alignment (class A, Figure 21), whereas those in the schists and slates of the Mount Ida group are largely due to intersection of planes (class B, Figure 21). Lineation of class B type is also prevalent in schists and slates of the Monashee group, indicating that the type of lineation present depends on the metamorphic condition of the rock rather than on its geographical or geological location.

In Vernon map-area lineation is one means of distinguishing between rocks of the Shuswap terrane and those of the nearby groups to the west and east. Lineation in the Shuswap is persistent and easy to find in nearly every outcrop, whether the rock is of sedimentary, igneous, or hydrothermal origin. Lineation in the Mount Ida group as a whole is neither as abundant nor as strong as in the Monashee group, and is generally more pronounced in argillaceous rocks than in immediately adjacent greenstone schists. In rocks of the Cache Creek group lineation is typically inconspicuous and consists mainly of ill-defined intersections of haphazard joints and cleavages. In fact, lineation in all the rocks neighbouring the Shuswap terrane is so inconspicuous and disordered that it seemed valueless to attempt to record it.

LINEATION IN THE MONASHEE GROUP

Lineation in the Monashee group is perhaps the most distinctive minor structure in those rocks and is developed better in them than in any others of the Shuswap terrane. It is not exhibited to the same degree everywhere in the group but is, nevertheless, present in nearly all outcrops except those rocks that were introduced into the Monashee group subsequent to the Older deformation which created the lineation.

Types of Lineation

Lineations in the Monashee group are almost entirely due to mineral alignment (class A, Figure 21), except in low-grade metamorphic rocks. With a single exception noted all are *b*-lineations according to Sander's terminology, that is, they lie parallel with fold axes. In the single instance where *a*-lineation was recognized, it appeared on the crestal part of a small recumbent fold as vague, wide-spaced, mullion-like ripples on the bedding at right angles to the fold axis.

The common types of lineation, such as parallel orientation of the prismatic

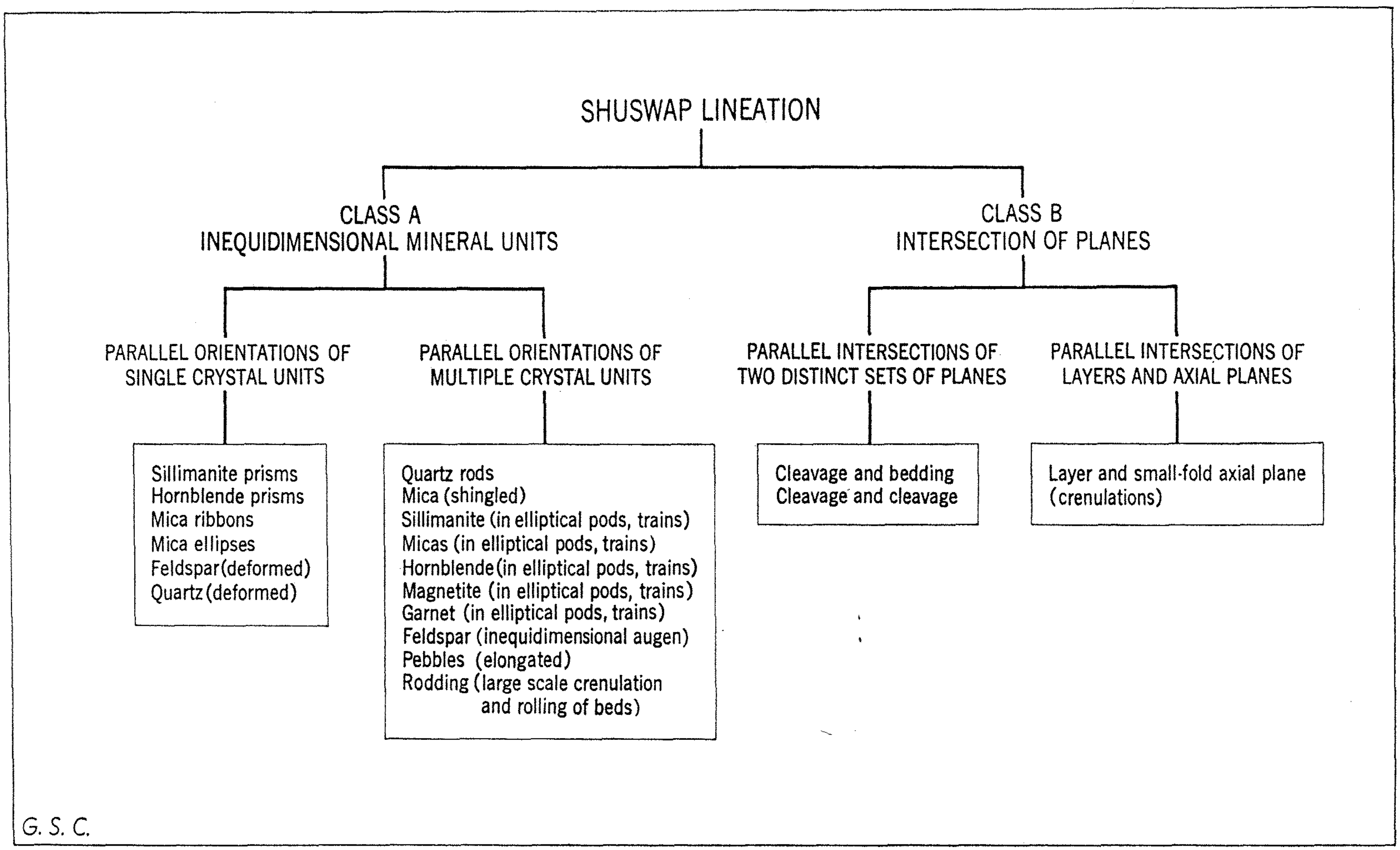


Figure 21. ***A classification of Shuswap lineation.***

minerals, elongation of pebbles, intersection of cleavage and bedding, and intersection of cleavage and cleavage, need no further comment here. Certain types of lineation that are rarely described in the literature or are perhaps rarely encountered in other metamorphic terranes are, however, described below. Most of these are common in the Monashee group and are characteristic of the rock type mentioned with each example.

(1) *Mica ribbons and ellipses.* In quartzite and quartzose gneiss both biotite and muscovite tend to be in inequidimensional plates with long axes parallel with the *b*-lineation direction and their flat faces parallel with the foliation. The individual crystal plates may be simply elliptical but commonly they are elongate in the forms of tiny ribbons that are up to ten times longer than wide. Mica of this sort is generally seen in trough-like depressions on the surface of quartzite layers and may be partly enclosed by quartz moulded around it. Such mica may be eroded away on weathered surfaces leaving only the peculiar troughs and grooves of quartz, some of which have 'undercuts' along their sides that were formerely occupied by ribbons of mica (*see* Figure 22).

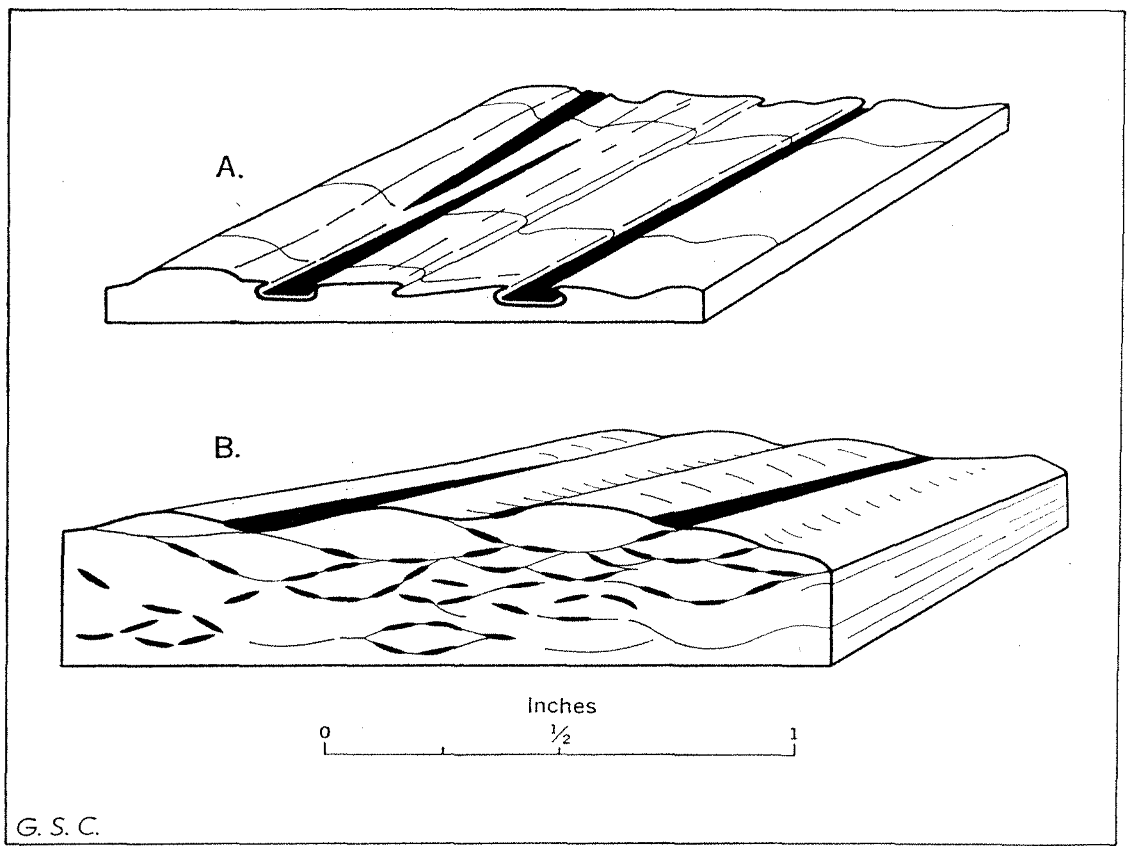


Figure 22. A. Lineation of mica ribbons in grooves and troughs on surface of quartzite.
B. Mica ribbons around close-packed quartz rods in lineated quartzite.

(2) *Quartz rods.* Rods of quartz are common, small scale structures in granitic rocks and pegmatite and, on a larger scale, in quartzite. Rods in the quartz-feldspar rocks are discontinuous, crooked, ragged-edged units composed of numerous quartz crystals that are themselves dimensionally oriented and show optical evidence of strain. The general distribution of quartz and feldspar is superficially like that in graphic granite (*see* Figure 4). The surfaces of some folia show this lineation as a light streaking due to the difference in colour between quartz and feldspar, or as grooves where the rock has broken around the units or where the feldspar has been preferentially weathered out.

Large quartz rods are particularly characteristic of relatively pure quartzite layers separated by partings of mica schist. During deformation the surfaces between quartzite and mica schist assume a wave-like pattern. The result, seen where the schist is stripped away, is an undulating or fluted structure on the surface of the quartzite with superimposed finer ridges and troughs where quartz has moulded around edges of ribboned or shingled mica. Thin layers of quartzite sandwiched between mica schist commonly are fluted on both surfaces, producing rods, lenticular in cross-section, resembling boudinage.

(3) *Shingled mica.* Occurring with or instead of mica ribbons and ellipses, is a shingled arrangement of mica plates dipping at a slight angle to the foliation. In a section perpendicular to the foliation the mica flakes appear in *en échelon* arrangement. This type of lineation is particularly characteristic of schistose layers in gneiss and quartzite. It is recognized by the parallel arrangement of the upturned edges of the mica plates and the way in which light is reflected from rows of parallel flakes. The shingling may be stepped in one direction only or may alternate with shingling in the opposite direction giving a crenulated appearance on the surface. In normal crenulation, which is in fact a series of minute folds, the mica plates are bent and the folds continue across the layers parallel with the axial planes of the folds. Neither of these features appears on 'crenulations' produced by shingling. Where schist is in contact with quartzite layers, the shingling is generally combined with grooving on the quartzite, as explained above.

(4) *Trains and pods.* Minerals are commonly disposed on bedding and foliation surfaces as concentrations along parallel linear zones or in ovoid clusters either as separate oriented individuals or as aggregates. Such concentrations may contain almost any rock-forming mineral such as mica, sillimanite, hornblende, or garnet. They are apparently not due to the intersection of the exposed foliation with bedding, in so far as they occur where bedding planes and foliation coincide.

(5) *Augen.* Many of the severely sheared feldspar-bearing rocks carry augen-like structures containing recrystallized, feldspar-rich aggregates. The augen are actually elongated spindles and, when the rock is split along a foliation, the breaking tends to occur around the spindles resulting in a surface marked with discontinuous parallel ridges and grooves.

(6) *Crenulation.* Crenulation of a pre-existing foliation is rarely encountered in gneisses of the Monashee group, but is common in the less highly metamorphosed schists and slates. Most known occurrences belong to disturbances of the Younger deformation for the axial planes of the crenulate folds cross the general trend of layering at a high angle, whereas the axial planes of almost all folds belonging to the Older deformation lie parallel with the layering. As crenulation is formed by intersection of a layer with the axial planes of the crenulation folds it is placed in class B of Figure 21.

(7) *Intersection of quartz parting with mica cleavage.* In some muscovite-bearing quartzites the elongated and flattened grains of quartz are aligned parallel with a plane slightly divergent from the plane in which the disseminated mica plates are aligned. The intersection of these two planes forms a ridged or grooved lineation.

(8) *Fold rodding.* In the crest of the Fosthall Mountain anticline the beds are rolled into giant crenulations. The rock resembles a pile of neatly stacked posts or rods in the outcrop with their long direction parallel with the main fold axis (*see* Plate VIII A). Although this is the only occurrence known in the map-area, it is a striking example and apparently continues for the length of the fold.

Lineations most commonly seen in the Monashee group in order of decreasing abundance are (1) mineral orientation, (2) mica shingling, (3) grooved and ridged surfaces, (4) mineral trains, and (5) quartz rods.

Although lineations in the high-grade metamorphic rocks of the Monashee belong predominantly to class A of Figure 21 it is possible that the intersection of planes (class B) played a part in their formation and that the planes themselves were later destroyed by recrystallization.

Orientation of Lineation

With the exception of occasional *a*-lineation and possibly some crenulation, all lineations in the Monashee group are parallel with the axes of recumbent drag-folds of the Older deformation. Lineation, except for the rodding in the Fosthall Mountain fold, has developed independently of drag-folds and is as pronounced where folds are absent as it is on the sharpest crests. Undoubtedly, both structures stem from the same source but the rotational movement of drag-folding is not the direct cause of the lineation. All principal lineations in the Monashee group were, however, formed at the same time as the shear foliation and recumbent drag-folds during the Older deformation.

In high-grade metamorphic rocks of the Monashee group lineations in directions other than the regional trend are rare, but in low-grade metamorphic rocks two or three directions of lineation are common in a single specimen. Presumably the latter rocks yielded readily to stresses of the Younger deformation whereas the former were so stiffened by their metamorphism that they yielded only to the most intense later deformation.

All lineations recorded from the Monashee group south of the Canadian Pacific Railway line through Eagle Pass are diagrammatically represented in Figure 9. No attempt was made therein to distinguish between lineations of different ages. Lineations forming the highest concentration in Figure 9 lie horizontally near north 70 degrees east, but those forming the low concentrations form an incomplete horizontal girdle. Lineations in the main central area of the Monashee group are in general about north 70 degrees east, but south of latitude 50 degrees 30 minutes a gradual change takes place until the general direction of lineation is east or, in some places, even slightly south of east. All are in every other respect identical and belong to the Older deformation.

An abnormally large number of anomalous lineations, many trending parallel with the Columbia River fault, appear in the Monashee group adjacent to Columbia River. These lineations are, however, clearly attributable to the Younger deformation as they are, in many places, superimposed on lineation with a normal, northeast trend. Older lineation is, however, commonly obscured where Younger lineation is strongly developed. In quartzite or very quartzose gneiss, the Younger lineation appears as wide-spaced undulations, and in mica-rich gneiss, as crenulations. Lineation by crystal orientation is rare despite the fact that the Younger deformation was in some places accompanied by high temperatures, as indicated by pegmatite fillings of fissures formed at that time.

LINEATION IN THE MOUNT IDA GROUP

Although lineation in the Mount Ida group is morphologically different from that in the Monashee group, its tectonic significance is similar. The Mount Ida lineations belong predominantly to class B in Figure 21 instead of class A and are generally less well developed and scarcer than those in the Monashee group. Mineral orientation is not important because inequidimensional minerals were rarely formed. Moreover, thin films of sericite coat shear planes on which lineation might be expected to appear. Notwithstanding the poorness of lineation in rocks of the Mount Ida group compared with that in rocks of the Monashee group, it is a ubiquitous and valuable structure.

Types of Lineation

In the Mount Ida group the only common type of lineation is that formed by the intersection of cleavage and bedding. This is marked in some places by colour streaks on the cleavage and in others by slight undulations on the cleavage surfaces, where the rock has broken along alternate intersecting planes. These undulations are commonly coated by mimetic mica, mostly sericite, giving them the appearance of crenulations.

Crenulation and slip cleavage are, as White (1949) shows, so closely allied in their origins that they grade into each other. For this reason lineations produced by crenulation are placed in the same category as those formed by intersecting planes. Axial planes of crenulations are considered equivalent to cleavage and the intersection of either structure with an older layering produces a similar type of lineation.

The lineation of the Mount Ida group was produced by the same stress that produced the folds, and is parallel with the fold axes (*see* Figures 13 and 14). Unlike that in the Monashee group, however, the lineation is most pronounced in and near folds, because it depends upon the angular discordance of planes, such as axial plane cleavage and bedding. Rocks that contain no layering, for example lavas, bear no lineation unless the first shear planes are re-sheared in another direction. In that event, however, the lineation is not related to the first deformation but to the second. Absence of lineation on bedding cleavage in sedimentary rocks of the Mount Ida group does not necessarily indicate absence of deformation because cleavage and bedding commonly do not intersect. Moreover, films of mimetic sericite on the cleavage may have covered any lineation present.

Where the Mount Ida group is cut by numerous aplite and granite dykes, stocks, and batholiths, the resulting metamorphism produced rocks mineralogically like the gneisses of the Monashee group. The lineation so characteristic of the Monashee group is, however, absent and one must conclude that these rocks were metamorphosed subsequent to the Older deformation and that the linear structures were largely destroyed by contact metamorphism and recrystallization.

Although lineations in the Mount Ida group have the same structural affiliations as those in the Monashee group their directions are more haphazard (*see* Figure 14). Despite relatively poor alignment, the lineations have two main directions, north 30 degrees east and north 45 degrees west, which correspond closely with those of the axial trends of folds (*see* Figure 13). The lineations and axes that trend in the northeast direction are nearly parallel with those of the Monashee group but the others are nearly at right angles to that direction.

The folds whose axes diverge from those of the Monashee group are, nevertheless, recumbent drag-folds and are results of the Older deformation.

Lying between the main area of the Monashee group and that of the Mount Ida group near the north boundary of the map-area, is the triangularly shaped Queest Mountain block. This block is composed of gneiss, schist, limestone, and quartzite the exact counterpart of the rocks of the Monashee group except that the principal lineations and the axes of most of the drag-folds, trend northwest parallel with those in the nearby part of the Mount Ida group. These structures are, therefore, nearly at right angles to their trend in the Monashee group elsewhere. The lineations are, however, of the type that is common in rocks of the Monashee group (class A, Figure 21) and rare in those of the Mount Ida. A second set of structures, closely parallel with those of the Monashee group, occurs in a small area within the Queest Mountain block and is interspersed with the stronger divergent set. In effect the Queest Mountain block belongs to the metamorphic province of the Monashee group but mostly to the tectonic province of the Mount Ida group, and serves to link the two groups.

LINEATION IN THE ROCKS ON EITHER SIDE OF THE SHUSWAP TERRANE

Lineation produced by the intersection of miscellaneous fractures and joints generally has a haphazard arrangement and is of little tectonic significance. This is the type of lineation prevailing in the younger rocks on either side of the Shuswap terrane except in the immediate neighbourhood of faults and on rare tight folds. The extreme rarity of systematically aligned lineation in these rocks is therefore a matter of note.

SUMMARY AND CONCLUSIONS

The value of lineation as a structural tool is well known, but the particular uses made of it as a guide to rock movement, chronology, and correlation in Vernon map-area are as follows:

(1) Once the tectonic significance of a certain type of lineation is known, it can be used for tectonic orientation where other indicators such as folds are absent. For example, in the Shuswap rocks the principal lineation is parallel with most fold axes. As lineation is easily found and easily recorded almost everywhere in the Shuswap rocks, it supplies structural data in areas where folds cannot be recognized. Lineation also provides a universal standard direction to which other structural orientation data can be referred. Furthermore, the plunges as well as the strikes of fold axes are conveniently indexed by lineation.

(2) In certain instances lineation is the only indication of rock deformation visible in the field. For example, both Mount Ida and Monashee groups

are foliated parallel with bedding, but the fact that there had been movement along the folia could not be recognized except through the presence of lineation.

(3) The fact of more than one deformation is most easily recognized by the presence of superimposed lineations. Lineation of most types is fairly resistant to mechanical destruction and disorientation and, therefore, preserves not merely the event of previous deformation but also its tectonic orientation. Associated folds and cleavage may, on the other hand, be obscured by later effects.

(4) The relative times of metamorphism and deformation are to some extent revealed by the disposition of metamorphic minerals to lineation. Minerals that are bent and broken by the development of lineation obviously formed before the deformation; minerals such as sillimanite, hornblende, and micas that are oriented so as to produce the lineation must have crystallized at the time of the deformation; and similar minerals that are not broken or bent and show no relation to the lineation probably formed later than deformation. If recrystallization is superimposed on and obscures the lineation obviously the metamorphism is later than the deformation. In this way metamorphism related to granitic rocks which intruded the Monashee group east of Okanagan Lake and the Mount Ida group in numerous places, is known to be later than the Older deformation that produced the lineation in nearby rocks.

(5) In a strictly empirical manner, lineation can be used as a supplementary means of ascertaining the relative age and structural history of adjacent geological provinces.

The Older deformation produced strong, widespread lineation while the Shuswap rocks were being metamorphosed. The Younger deformation also produced linear structures but these are mainly confined to low-grade metamorphic rocks. The rocks of the Mount Ida group belong, in part at least, to a tectonic province different from those of the main Monashee group, for both lineation and fold axes are oriented differently and their alignment in the former is not nearly as perfect. Possibly as the Mount Ida rocks were less deeply buried a different structural environment resulted. This in turn led to the development of structural differences. Later intrusion and metamorphism have in many places destroyed the characteristic lineation of the Shuswap rocks.

• BOUDINAGE

Brief references to structures that appear to be boudinage are common in the geological literature but papers devoted specifically to it are few. Boudinage is generally regarded as a minor and unimportant structural detail by geologists, but in the Shuswap terrane boudinage is of particular value as a clue to the structure and structural history.

The term 'boudinage' was first employed by Lohest in 1906 and Lohest *et al.* (1908) to describe certain sausage-like structures in the Bastogne region of France. Further contributions to the subject were made by Quirke (1923), Holmquist (1910, 1920, 1930, 1931), Corin (1932), Wegmann (1932), Read (1934), Walls (1937), and Cloos (1946). An excellent short summary of the important literature on boudinage with a brief discussion was given by Cloos (1947) in a paper on the subject published in 1947.

Writers differ on the tectonic implications of boudinage and have suggested the following means or some combination of them by which the structure may have been produced:

(1) longitudinal compression within the plane of the layer
(2) compression perpendicular to the plane of the layer
(3) shear tangential to the layer
(4) simple tension in the layer
(5) tension in the layer resulting from shear.

The shape of boudinage fragments and the pinch-in parts are points of varied contention. The alternate thicker and thinner parts have been attributed to compression and bulging to form the thick parts of the layer or to tension and plastic thinning to form the 'necks'. The relatively greater competency of the boudinaged layer to the surrounding rock is, however, one factor upon which all writers apparently agree.

TERMINOLOGY

The term 'boudinage' has been used in somewhat different senses by different writers, few adhering strictly to the original definition by Lohest. In all cases however the term has been restricted to the aggregate of a fragmented, sheet-like body where the fragments are disposed more or less in a plane.

The essential requirements for boudinage as used in this report are as follows:

(1) The parent body, prior to deformation, must have been sheet-like or layer-like (for example, a bed, a sill, or a dyke).
(2) The final structure must be the expression of a tendency for the original solid layer to increase its lateral dimensions in one or more directions by segmentation and dismemberment or by thinning and stretching at spaced intervals.

Boudinage, as it is defined above, does not necessarily imply 'sausage' structure as Lohest conceived it, but in transverse sections, so commonly observed, the structure generally has a marked resemblance to linked sausages.

In order to simplify description and to focus attention on the individual components of the structure certain terms are listed and defined below (*see* Figures 23 and 24). Most of these have already appeared in the literature but a few are new.

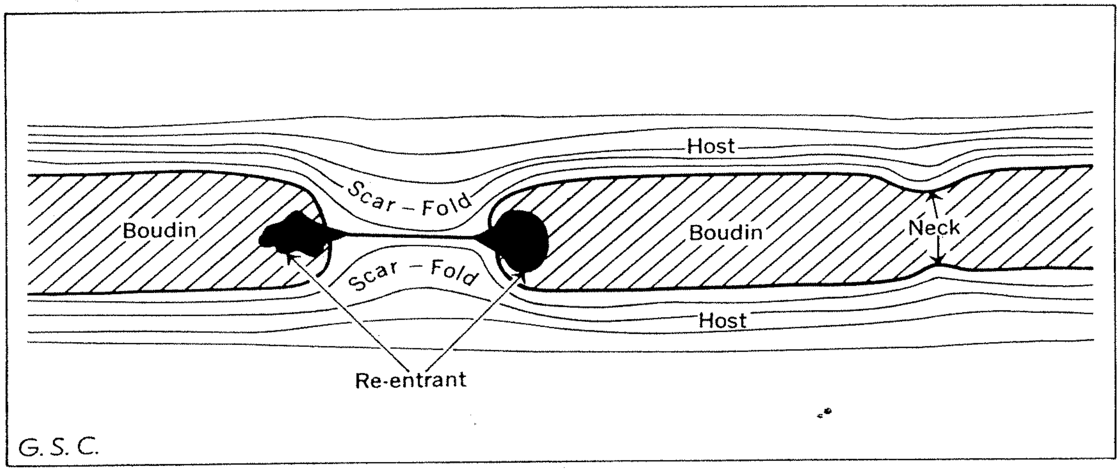


Figure 23. Nomenclature of structures related to boudinage.

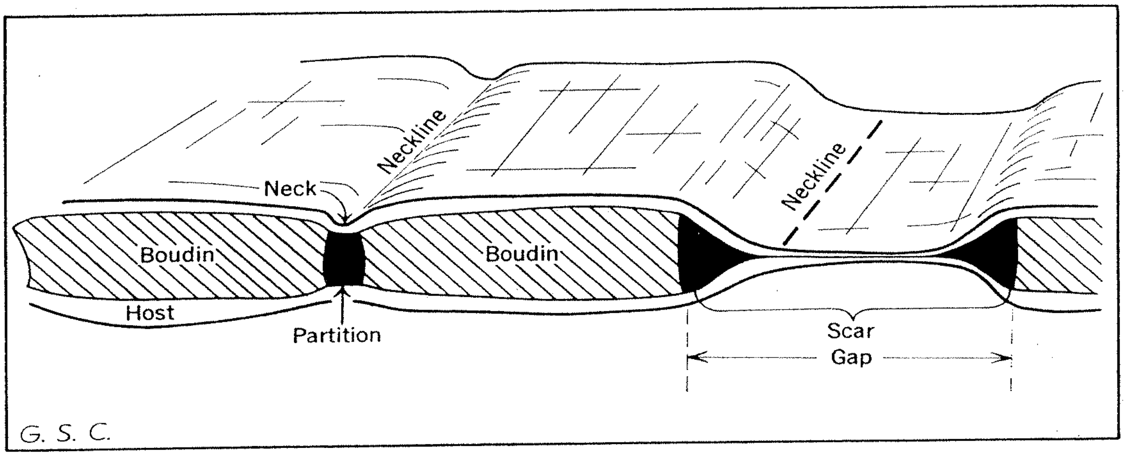


Figure 24. Nomenclature of structures related to boudinage.

Boudin: an individual segment of the original layer. In section it may appear lenticular, round, rectangular, or irregular and may be of any extent or shape in the third dimension.

Host: the mass of rock material that bounded the original layer and contains the subsequent boudinage.

Neck: the place where a layer has been thinned, the place at the broken end of a boudin, or the place where host layers close between boudins.

Neckline: the line along the neck of a boudin, or along its broken edge, or along the crest-line of a scar-fold. More than one set of parallel necklines may be present.

Scar (Wegmann's 'cicatrice'): the filled or closed-in space vacated by the boudinaged layer.

Partition (Read): the mineral filling in the interfragmental space; a completely mineral-filled scar.

Re-entrant: a concavity (slight to pronounced) in the broken end of the boudin so that its surface layers enclose like jaws a part of the filled scar or interfragmental space.

Scar-fold: the fold in host layers resulting from the host flowing into the scar void left by separation of boudins.

Gap: the space separating boudins. This distance is a measurement of the extension undergone by the rock but may be only a part of it if the boudins themselves are plastically stretched.

BOUDINAGE IN THE SHUSWAP TERRANE

Boudinage in parts of the Monashee group is ubiquitous and complex. It is indeed one of the commonest of the minor structures, and is undoubtedly an important key to the geological history.

The rocks involved are highly metamorphosed and the assemblage contains coarsely granular schist and gneiss as well as marble and quartzite with garnet, amphibole, and sillimanite as common constituents. Beds, sills, and dykes all show boudinage everywhere, at least to some extent. Boudinage is commonest in amphibolite, produced by the metamorphism of gabbroic sills. These sills are especially numerous in the northeast part of the map-area particularly in the belt from Three Valley Lake south and east across Tilley, Blanket, and Cranberry mountains, and all show boudinage. The striking contrast in colour between the black amphibolite and the lighter surrounding rock displays the structure well, and this belt is particularly favourable for studying boudinage (*see* Figure 25). Elsewhere in the area sills of pegmatite, veins of quartz, beds of quartzite, or gneissic quartzite comprise the boudins but are not so conspicuous although abundant. Host rocks include various gneisses, schist, quartzite, limestone, and silicated limestone, in many cases surprisingly similar in appearance and composition to the boudin material.

Although the fact of major horizontal movements is amply demonstrated by drag-folds and other phenomena, the underlying cause of the deformation is obscure. Boudinage is closely allied to the folding in origin and orientation and was evidently produced by the same deformational process. Structural information gained from a study of boudinage can therefore be expected to supplement that supplied by other features.

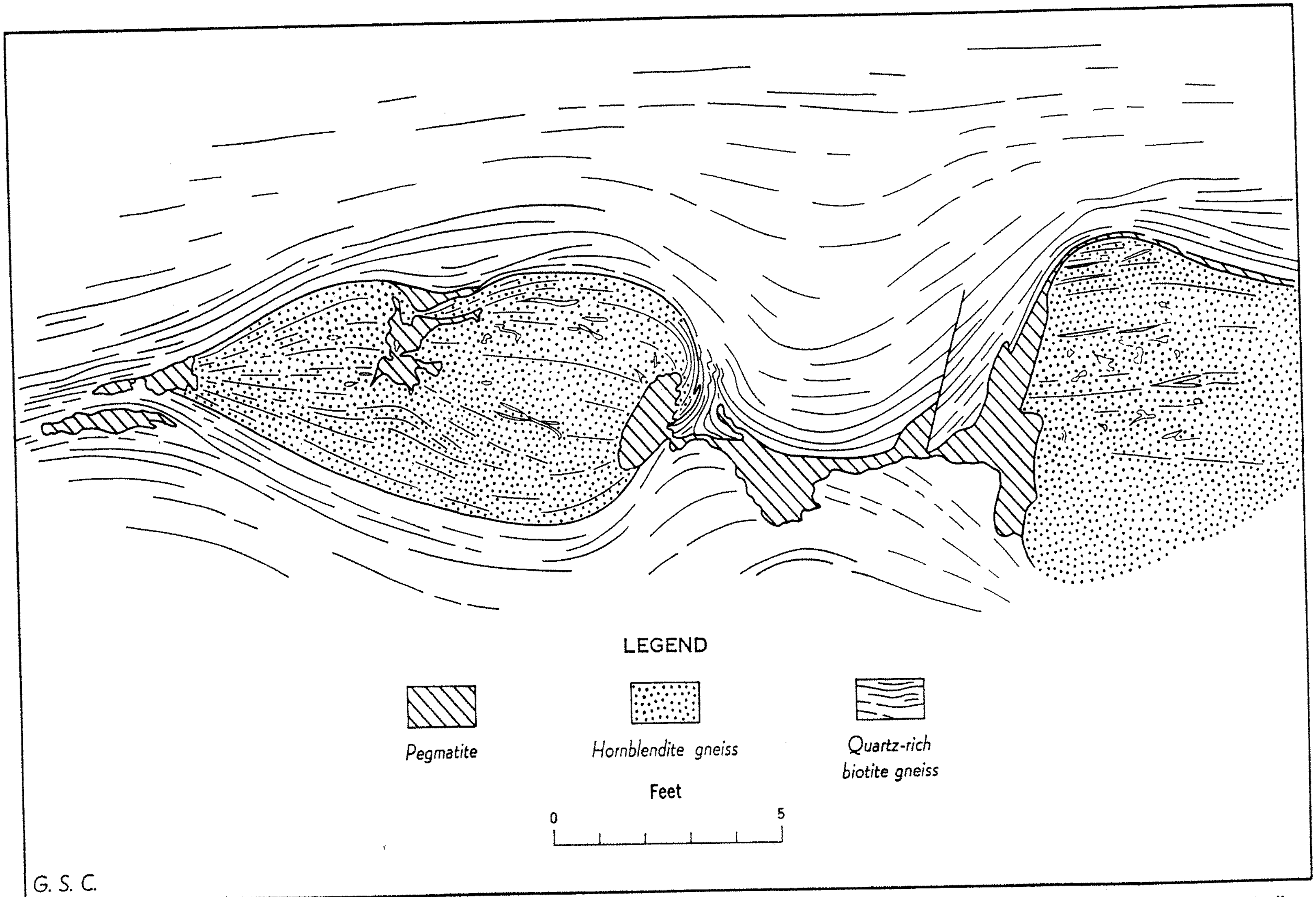


Figure 25. Boudinage of hornblendite in biotite gneiss, with pegmatite filling the scars and partly replacing the boudins and host. Boudinaged layer was originally a continuous gabbroic sill, Three Valley Lake. Sketch is from photographs.

The boudinaged layers are, on the whole, flat lying and the boudins are therefore disposed essentially horizontally. They are most commonly observed in vertical sections in cliff faces and, therefore, only a two-dimensional view is normally obtained. A horizontal view is uncommon and it is rarely possible to determine the trend of necklines. A true, three-dimensional picture of the complete shape of the boudin is consequently rarely determined. Nevertheless, it is certain that few boudins have the columnar, sausage shape of Lohest's boudins, but are more or less rectangular tablets.

The outline of a boudin in vertical section ranges from sharply rectangular to markedly lenticular, and in places, the boudinage is a swarm of broken fragments (*see* Plate X B). The average boudin in vertical section, regardless of scale, is about five times as long as thick, although this proportion varies widely. In a single boudinage a mixed assemblage of irregular, rectangular, and lenticular shaped fragments of different sizes is not uncommon. There are two regular sets of necklines, approximately at right angles to each other and within 20 degrees (rarely 30 degrees) of being parallel with or perpendicular to lineation and fold axes. As pointed out above, few necklines are exposed but the consistent arrangement of those seen makes the foregoing statement reasonably certain.

Although a horizontal view of boudinage layers is rarely seen it appears as if the shape of boudins is not as regularly rectangular as might be expected. Furthermore, the distribution of boudins within the layer lacks any regimented pattern, like that of city blocks. The following example (*see* Figure 26) is believed to be representative of the geometry of Shuswap boudinage. The data are taken from a hand specimen of hornblende-biotite-garnet gneiss that encloses a boudinaged layer of hornblendite. The slab was cut with a diamond saw along two sides, one perpendicular to, and one parallel with, the lineation and then lengthwise through the centre of the boudinage layer parallel with the foliation. Two sections so exposed are figured. The following important facts may be noted:

(1) Two sets of necklines are present but are not consistently at right angles to each other nor are the necklines ridgedly parallel within each set.

(2) The set of necklines roughly parallel with lineation presents a meshed or linked pattern.

(3) Only the necklines nearly at right angles to lineation have carbonate scar-fillings.

(4) Most boudins are roughly rectangular in plan, but some are triangular and nearly all have irregular edges.

The shape of the boudins in section rarely shows whether the section is perpendicular to or parallel with the local fold axes. In general, although not as a strict rule, the greater the gap between boudins the more rounded are their ter-

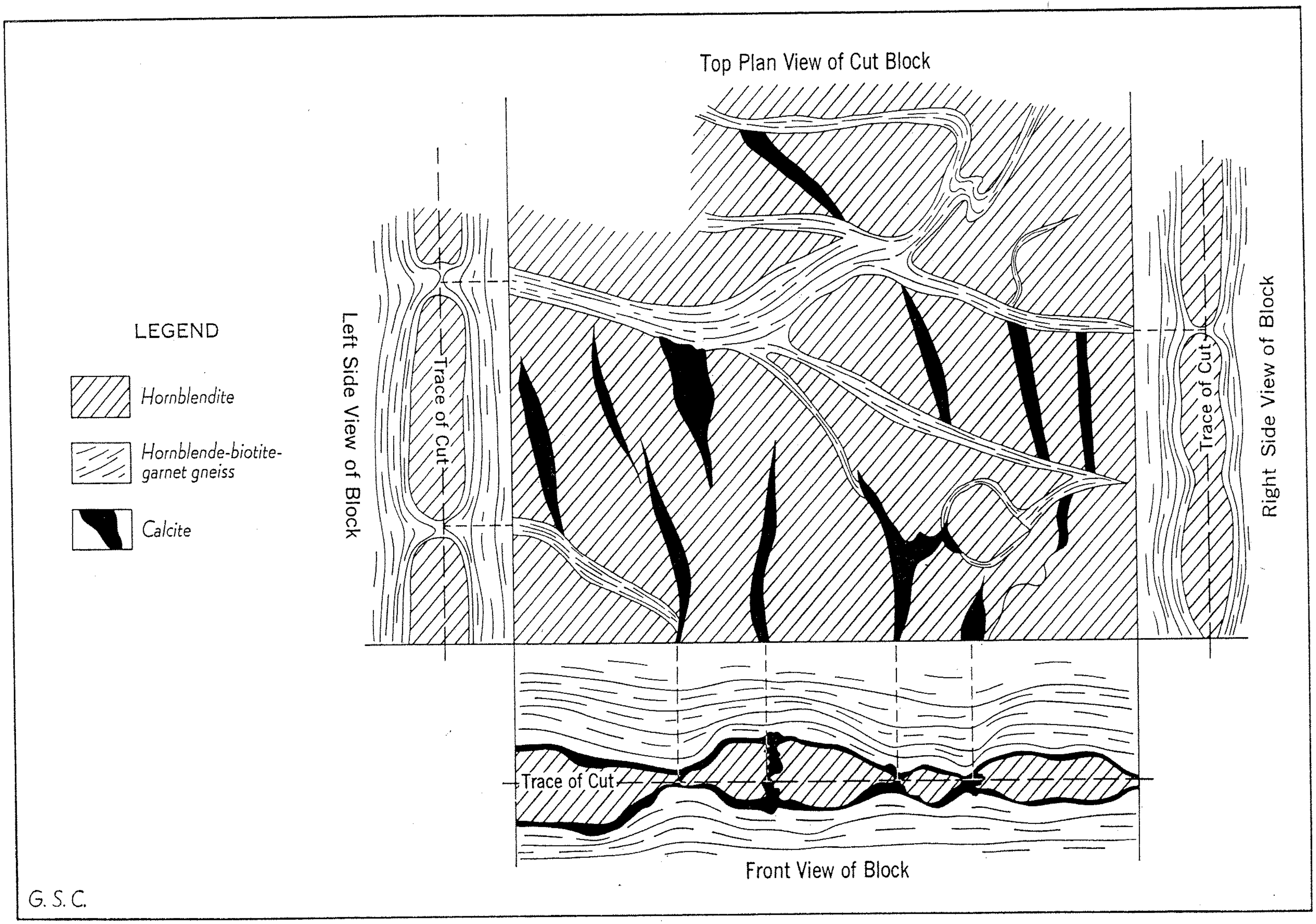


Figure 26. *Boudinage of hornblendite sketched from cut specimen. Top of block is view of boudinaged layer after it is cut parallel with the layer along the tracelines shown on the end views of the block. Lineation in the host rock lies exactly parallel with the front face of the block, normal to the side faces.*

minations, and, as greater separation between boudins is ordinarily in sections perpendicular to fold axes, the ends of boudins in these sections are generally more rounded or tapered than in sections parallel with fold axes (*see* Plate XI A, B). In the direction perpendicular to fold axes, the extension of the boudinaged bed as determined from the gaps usually exceeds 25 per cent and commonly attains several hundred per cent, whereas in the direction parallel with fold axes the extension is a few per cent or rarely exceeds 100 per cent.

The material filling the scar is quartz-feldspar pegmatite or vein quartz. Other minerals rarely accompany the quartz and feldspar and then only in minor quantity. Muscovite, biotite, garnet, and hornblende are the commonest accessories.

Most scars are mineralized but many are not. In some boudinage all scars are filled, in others only some scars or some sets of scars are filled, and in still others all scars are barren and tightly closed by the host. The filling may occupy the whole scar from one boudin to the next, or may be only at the end of the boudin or in a re-entrant. Where the filling is only at the end of a boudin it is commonly triangular-shaped, as pointed out by Wegmann. Short, completely filled scars or partitions are numerous but lenticular or spindle-shaped scars of the classical Bastogne examples are rare. The ends of boudins next to partitions may have re-entrants but more commonly are rectangular or slightly irregular.

Open-space filling was doubtless the principal means by which scars formed, nevertheless there is evidence that substantial amounts of chemical replacement took place. In the scar between the rectangular ends of some boudins the pegmatite filling is studded with scattered fragments of the host rock in the form of 'domino breccia'. Apparently the host rock collapsed under high pressure into an empty space or, at most, into a space filled with a tenuous liquid. Small vugs 1 inch to 3 inches across, lined with comb quartz occur here and there, supporting the above conclusion, although re-solution might account for the phenomenon. Replacement of boudin rock by scar-filling pegmatite is not uncommon and in some places has proceeded to a considerable degree (*see* Plate X B and Figure 25).

Above and below the scars the layered host rock has been deformed into scar-folds. Such scar-folds may be symmetrical (*see* Figure 27) or asymmetrical (*see* Figure 28), but in either case die out a short distance away from the boudin layer. The folds represent flowage of the host rock towards the scar void (or potential void) as pressure was reduced in that place. The flowage was sometimes arrested before the host filled the void because other material, such as pegmatite or quartz, was introduced. Some scar-folds have small subsidiary drag-folds in the limbs (*see* Figures 25 and 29). It is interesting to note that the axial planes of these subsidiary folds are not parallel with that of the main scar-fold, showing that material has migrated from a lateral direction as well as from above or below for upper and lower scar-folds, respectively. The scar-folds die out so rapidly away from the boudin layer that some writers have assumed that the rock extension must be confined to the stratigraphic layers that are affected by scar-folds. The reason scar-folds die out in such a short distance seems to be that the materials are drawn radially to fill the scar and the source of supply consequently increases rapidly outward from the scar.

The subsidiary drag-folds on the limbs of scar-folds, in sections parallel with the main tectonic axis, commonly show opposite sense of drag above and below the same boudin termination (*see* Figure 29). This feature demonstrates that the host on both sides of the boudin flows in towards the scar. On sections perpendicular to the major tectonic axis the subsidiary drag-folds on opposite sides of the boudin commonly have the same shear-sense (*see* Figure 28).

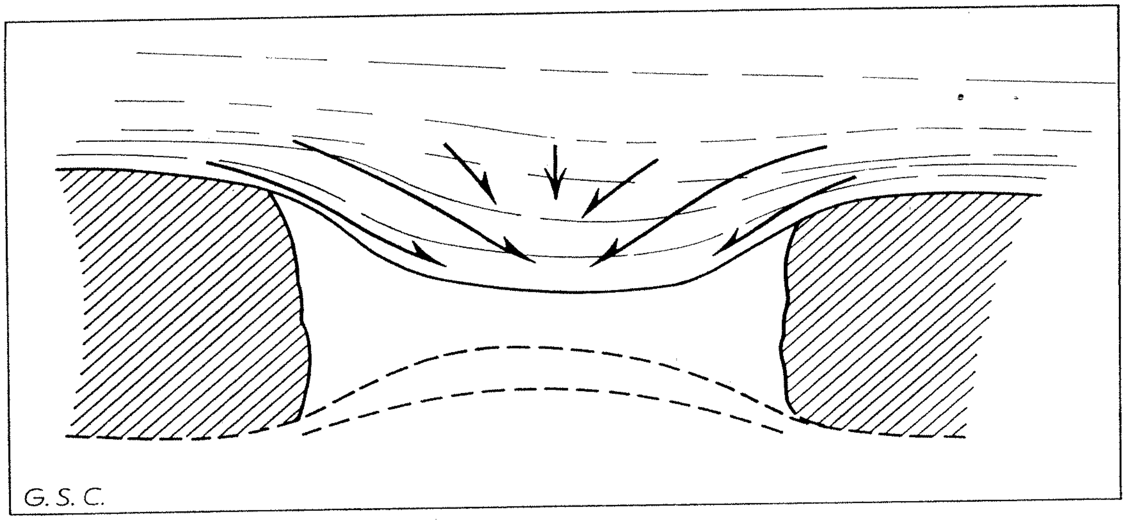


Figure 27. Symmetrical scar-fold.

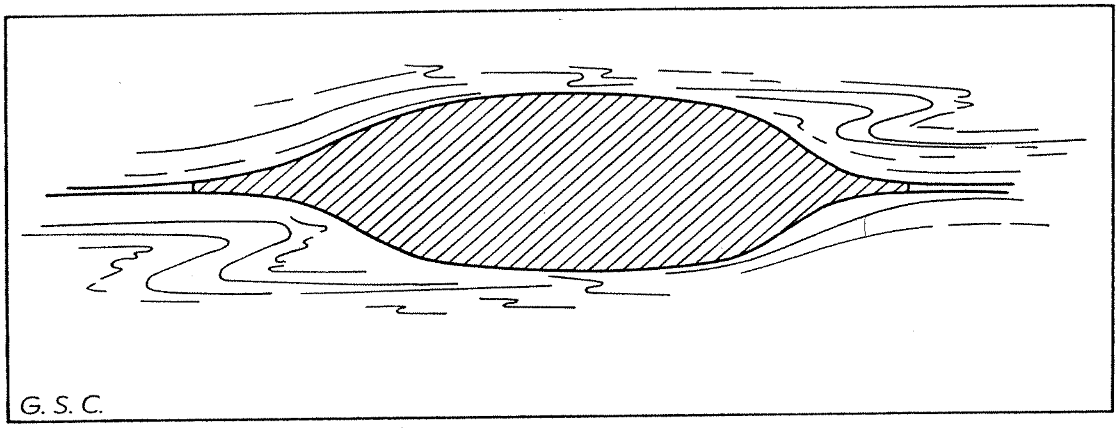


Figure 28. Asymmetrical scar-fold.

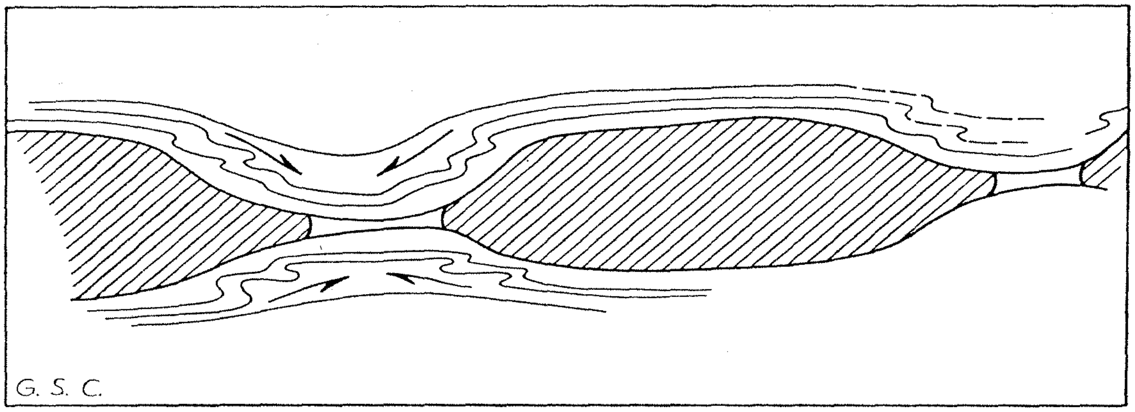


Figure 29. Drags on limb of scar-fold showing direction of host rock flowage.

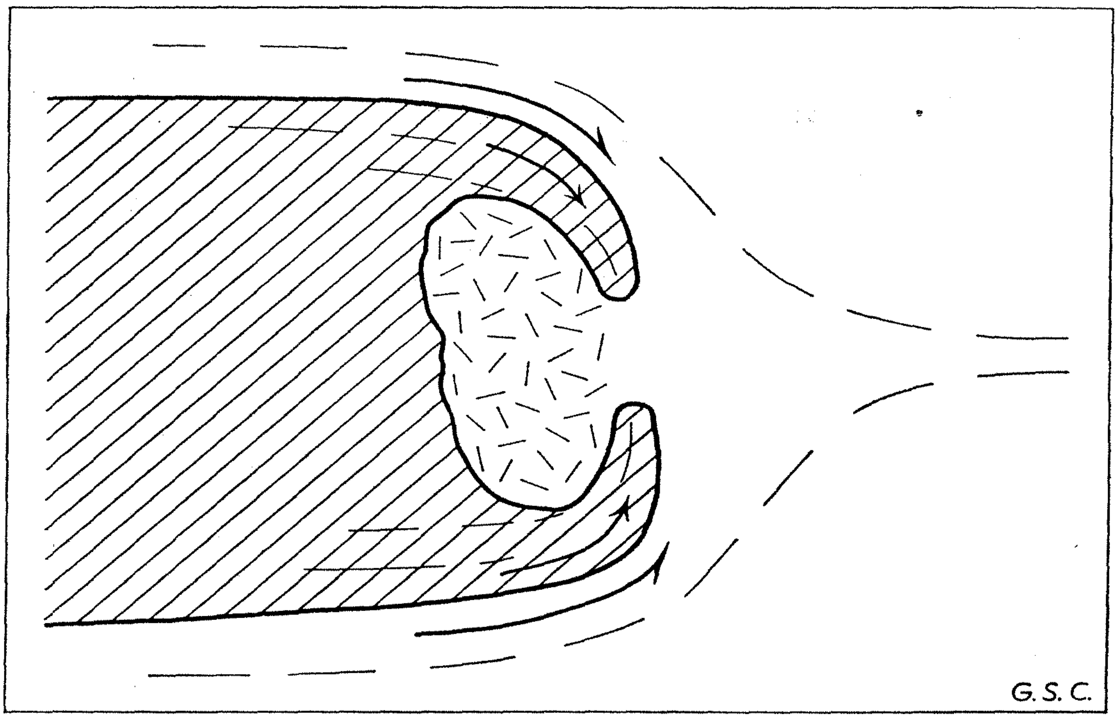


Figure 30. Formation of a re-entrant by outer layers of boudin drawing around scar-filling.

The movement of host past the boudin also affects the boudin. Boudins that were originally homogeneous in structure and composition throughout commonly exhibit a pronounced layering or foliation near their margins (*see* Plate XII A) due to this cause, and, in places, pegmatitic material has entered the slip planes so produced. This material originates in the same way as that in the scars and may be continuous with it, as a thin film or envelope around the edge of the boudin. In boudins formed of already foliated rock the shearing takes advantage of the slip planes in the rock and is commonly more pronounced. The same movement that creates the marginal foliation tends to elongate the outer layers and draws them towards the scar (*see* Figure 30). The result is a re-entrant at the end of the boudin (*see* Plate XII A, B). The re-entrant is thus another result of a tendency to fill the scar void.

The forces that produce boudinage must be transmitted through the host and not through the boudinage layer. A boudin separated from its neighbours can exert neither compressive nor tensile force upon them. Clearly, boudinage in Shuswap rocks is due to the extension of the boudin layer in two principal directions mutually at right angles effected by plastic flowage of the host, which carried with it the dismembered, more brittle enclosed layers. This plastic flow of host rock in the Shuswap terrane is ordinarily not merely a thinning of layers but includes the slipping of layers past one another, as proved by the presence of drag-folds, strong lineation, and foliation parallel with bedding. The evidence for the shear-slip motion appears in both host and boudin.

Strong internal movements of the host rock and the effect of metamorphism on rocks of different competency are clearly shown by the example of an amphibolite boudin tightly enclosed by pure quartzite (*see* Plate XII A). A statistical analysis of the orientation of quartz in the quartzite shows that the optic *c*-axes are aligned within folia, parallel with the direction of drag-fold movement and perpendicular to lineation (*see* Figure 31). Lineation, consisting of muscovite ribbons and shallow, fine grooves and ridges on the quartz, lies parallel with drag-fold axes in the immediate vicinity.

It has been shown that boudinage of beds and sills is the result of differential rock movement along planes parallel with bedding, and the only movement of such nature universally recorded in the Shuswap rocks is shearing along bedding planes. Further evidence for the genetic link between boudinage and shearing is (1) parallelism or near-parallelism of necklines with lineation and drag-fold axes, (2) marginal foliation in the once homogeneous boudins, (3) folded and shear-foliated dykes that were 'feeders' to boudinaged sills, and (4) orientation of rhombic boudins. In the extreme example, where boudins are strewn along folia the origin by shearing is obvious. Compression perpendicular to the boudinage layer cannot be demonstrated as the motive force because a random pattern of necklines and hexagonal plan-shape of boudins would have resulted. Hexagonal or polygonal shaped boudins might be expected to form, for instance, under load metamorphism.

Some rock layers have broken along transverse fractures oblique to the margins and the resulting pieces are rhombohedral in section. When these spread by shearing through the layered host the rhombs are rotated into a stable position with the long diagonal parallel or nearly parallel with the foliation (*see* Plate XIII A). The shape of boudin depends upon whether the layer

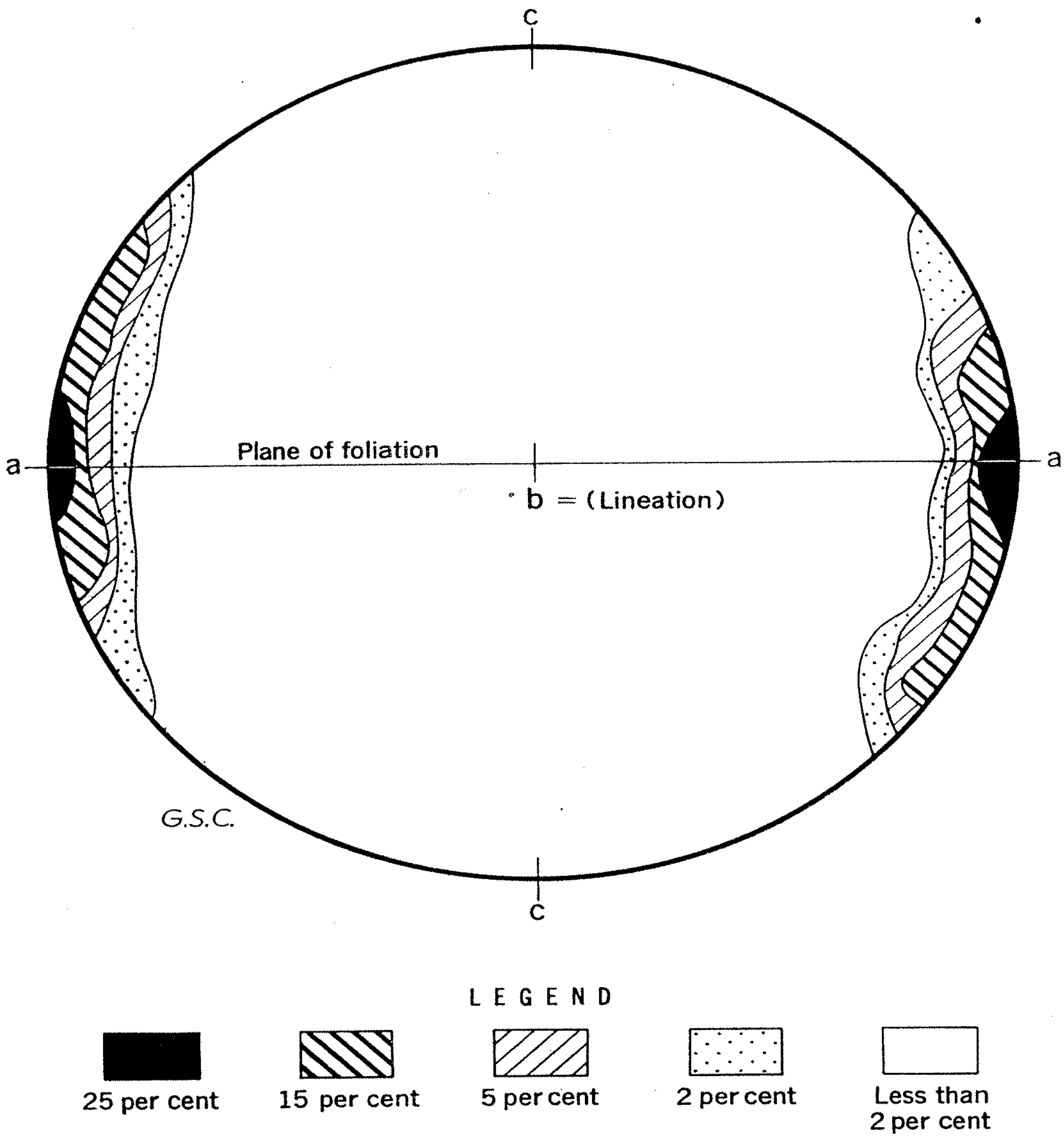


***Figure 31**. Equal-area lower hemisphere projection showing orientation of quartz c-axes in quartzite with respect to the plane of foliation (ab) and lineation (b). Two hundred poles are plotted; contour areas represent 25%, 15%, 5%, 2%, less than 2%.*

breaks along shear fractures or tension fractures, either of which may form under the same shear stress depending on the physical conditions of the rock and its environment. If shear fractures result a small amount of rotation would bring the resulting boudin into the stable position (*see* Figure 32A), but if tension fractures result a much larger amount of rotation is necessary to achieve the same result (*see* Figure 32B). Without knowing whether the rhombs formed by shear or tension fractures it is impossible to determine the shear-sense from their orientation.

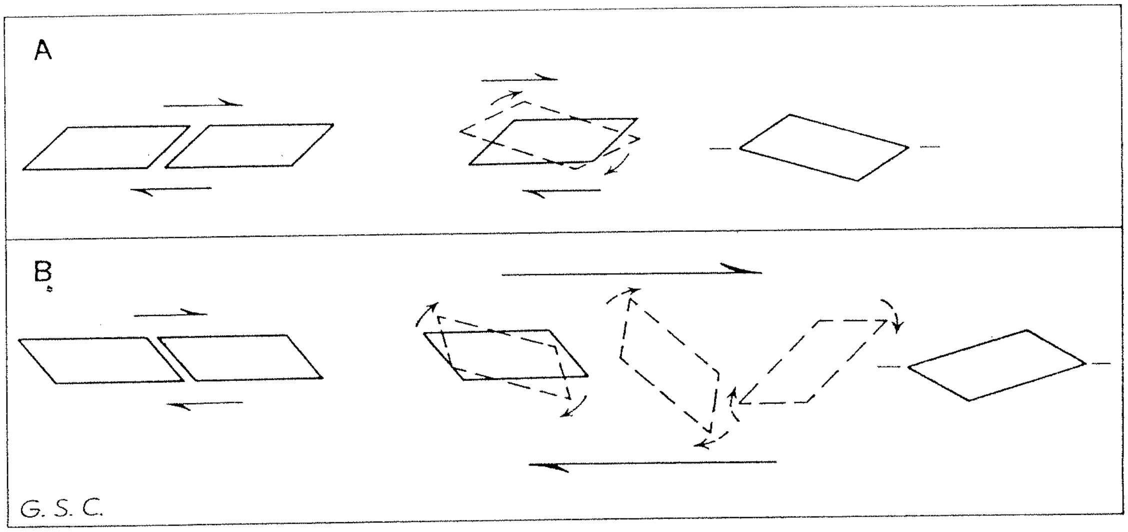


***Figure 32.** Mechanism of theoretical orientation of boudinage rhombs broken by shear (A) and tension (B).*

It has been shown that the principal direction of stress lies in the direction of shearing. Failure of the boudinage layer under this stress resulted in fractures closely perpendicular to this direction and parallel with *b*-lineation. Once the fractures opened, the principal stress was relieved. The secondary direction of boudinage extension lies parallel with fold axes and lineation. When the principal stress was relieved, the stress in the secondary direction became dominant and was relieved by fractures normal to lineation and fold axes.

The cause of the secondary extension cannot be explained as readily as that of the primary. Nevertheless, if one considers a pile of stratified rock as being moved by shearing of layer over layer it is reasonable to suppose that all parts of the moving front do not advance the same amount. A lateral extension can result in this way and account for the necklines approximately perpendicular to lineations and fold axes. A similar situation might arise if the boudinaged layer were not everywhere displaced the same amount by the shearing movement of the host.

MISCELLANEOUS LENTICULAR STRUCTURES

Lenses of granite, pegmatite, or vein quartz from an inch to several feet in length and mostly less than half that in width are common in rocks of the Monashee group. Good evidence is lacking in most cases as to whether or not these lenses are dismembered layer-like bodies. Some of them may have assumed their present shape prior to deformation, but the writer inclines to the opinion that they are the result of boudinage.

A layer of pegmatite that pinches and swells, but is nowhere completely discontinuous, is illustrated in Plate XIII B. The shape of the thick parts and the orientation of the necklines resemble those of boudinage nearby. There is no means of determining if the pegmatite in the thinner parts is later than that in the thicker parts, but vague marginal foliation present in the bulges and absent in the thinner parts suggests that the latter is relatively undeformed scar-filling between pegmatite boudins.

Plate XIV A shows lenses of light coloured granite in dark biotite-amphibole schist, the cliff section being essentially parallel with lineation and drag-fold axes in the schist. These lenses have two sets of necklines, one parallel with and the other perpendicular to lineation. A slight foliation within the lenses may be attributable to shearing, but no scar-filling is present. The necklines parallel with lineation certainly formed at least in part by shear. Peach and Horne (1907) give an illustration (Plate XXIX) of "phaccoidal structure in biotite gneiss and pegmatite" attributed to deformation. A striking resemblance exists between this phaccoidal structure and the lenses of gneiss illustrated in Plate XIV A.

Here and there throughout the area the rocks contain swarms of small quartz bodies. The host rock in some places is limy quartzite and in others biotite gneiss or quartzitic schist. The bodies range in shape from regular, symmetrical, concordant lenses to ragged, somewhat discordant slivers, crudely lenticular in outline. The quartz material is milky to clear with little apparent granularity and resembles vein quartz. In vertical section the ratio of length to width varies from 2 to 1 to 10 to 1 or even greater, and the lengths range from a quarter inch to 2 feet. Typical examples of these are at Summit Lake, in the railway-cuts 8 miles west of Revelstoke. The long dimensions lie in or close to the foliation of the enclosing gneiss. In detail many of the bodies are folded with the gneiss into hook-shapes and many cross the foliation at low angles. Several limestone beds are also present. Although the gneiss contains numerous, tiny, sharp drag-folds, indicating intense shearing, the limestone beds appear to be undeformed except for gentle pinches and swells. Evidently, the internal bedding of the limestone is so tightly folded that it is largely obscured. Thin layers of harder material in the limestone are pulled apart in miniature boudinage, whereas layers not so hard are sheared into sharply crested isoclinal folds.

The writer believes that most of the quartz bodies discussed in the previous paragraph are dismembered pieces of veins, although some may be beds of clear or milky quartzite, examples of which may be found near Summit Lake and elsewhere. There is, however, also the possibility that the quartz was segregated from the host rock by some process of metamorphic differentiation and was subsequently deformed into the existing shapes.

SUMMARY AND CONCLUSIONS

The shape and disposition of boudinage in the Shuswap terrane show that the rocks have suffered considerable extension in two principal directions, namely perpendicular to and parallel with the tectonic axis. The secondary foliation and the principal direction of rock flowage lie parallel with both the boudinaged layers and bedding.

Evidence that compression, either in the plane of the boudinaged layer or normal to it, was a principal motive force in creating boudinage is entirely lacking, and the scheme of alternate compression and tension outlined by Quirke and supplemented by Holmquist cannot apply to the Shuswap structures.

The bulged appearance of the Shuswap boudins is not due to compressive thickening of the layer at that point, but to constrictive thinning of the necks during tension, that is, the boudins are no thicker than the layer from which they were formed. Notably, also, constrictive thinning of layers in the Shuswap terrane does not necessitate actual disruption of the layer (*see* Plate XIV B).

Shear-slip movement of host past the margin of boudins is universal and is proved by the separation of boudins, rounding of ends, marginal foliation, re-entrants, and evidence for bedding plane slip in the host itself.

The degree of metamorphism seems to have little bearing on the shape of boudins or the nature of the boudinage, the principal factor being the relative competence of host and boudinaged layer. Boudinage in the Shuswap terrane is a structural situation whereby active, incompetent rocks impose a remarkably well-ordered deformation on the passive, minor competent members that are enclosed.

The Shuswap boudinage (1) shows evidence of extension in directions both parallel with and perpendicular to the tectonic axes, (2) is directly or indirectly a result of shearing parallel with foliation, (3) provides a measure of the minimum extension, (4) is so consistently associated with other structures of shearing and extension in host rocks that it provides tectonic information in places where such other data are lacking, (5) provides some indication of the direction and nature of relative rock movements near boudins for correlation with petrofabric analysis, (6) gives insight into the relative competency of different rocks under the conditions of metamorphism (for example, amphibolite boudins in a pure quartzite), (7) provides another structural tool for study of the regional tectonics and (8) provides evidence on the availability and composition of 'ichor' type solutions that have filled unconnected scars.

• MICROSCOPIC STRUCTURES

The microscopic structures referred to herein are restricted to the dimensional and optical arrangements of quartz in quartz-rich rocks, and do not include the host of small-scale features that might be considered under this heading.

The rocks chiefly concerned are quartzites, quartzitic gneisses, vein quartz, and, to some extent, granites and granitoid gneisses. In all these rocks quartz is a major, if not dominant, mineral component. Besides the larger masses of these rocks, certain thin seams, lenses, or veinlets of quartz contained in other rocks are also considered.

In megascopic appearance the rocks in question may not seem to be shattered or crushed but coarsely crystalline. They do, nevertheless, always display faint to pronounced foliation and always have lineation on the surfaces of folia.

In thin section most individual quartz grains are seen to be notably inequidimensional and to be strikingly aligned, both optically and dimensionally. The boundary of most grains is highly sutured and each grain is tightly interlocked with its neighbours. In thin sections cut at right angles to the foliation the quartz grains appear as elongated slivers, most of which are rather crooked. To learn the true shape of the quartz grains, three sections were cut at right angles to one another from single specimens. The sections were cut (1) parallel with the foliation, (2) perpendicular to foliation and parallel with lineation, and (3) perpendicular to foliation and perpendicular to lineation. The shape of the grains, as so determined, is somewhat like that of an ordinary building brick, having one long dimension, one intermediate, and one short, but, unlike a brick, has highly irregular, sutured boundaries, crooked shapes, and tapered ends. The ratio of the greatest dimension to the smallest is in the order of 6 to 1 or more.

The long dimensions of all are parallel with one another and with the lineation, and the long and intermediate dimensions lie in the plane of the foliation. The optic axes (c) of the quartz lie closely parallel with the intermediate dimension of the grains, that is, in the plane of foliation at right angles to lineation. This is called 'Class I' type of orientation by Fairbairn (1942). The degree of parallelism of the axes has been determined for many specimens by means of the universal stage and by plotting on equal-area nets. The c-axes, which have been plotted as points on such nets, show remarkably high concentrations ranging up to 25 per cent and have single maxima (*see* Figure 31). In some diagrams, however, a slight dispersion of points from the maximum in the great circle containing *a* and *c* suggests an incipient girdle in that direction.

In more or less pure quartzites the optical alignment of the quartz grains is nearly perfect. In quartzose gneisses, granitoid gneisses, and some granites, the feldspars are commonly scattered along the foliation planes or are collected in augen-like lenses and the grains themselves are generally broken and surrounded by feldspar chips that create the cataclastic texture known as mortar-structure. The quartz in these rocks is concentrated in thin discontinuous streams that undulate and interlink with one another and pass around the feldspars in a sheath-like manner that closely resembles the way in which the water in a river flows around islands. Each stream of quartz is comprised of close-packed, inequidimensional grains. In sections normal to the lineation the long dimension of these grains is parallel with the borders of the stream. The shape of quartz grains and the dimensional and optical orientation are the same as in the purer quartzites described, but because of the wavy borders of the quartz streams, there is a greater dispersion of the optic axes into incipient *ac* girdles. The stream-like aspect of the quartz in these rocks has led the writer to use the term 'fluidal structure' for this texture.

Micaceous minerals, which include muscovite, biotite, and chlorite, are rarely either bent or broken and lie within or beside the quartz in orientations that are normally concordant with the fluidal structure. In some places, however, the micas lie in parallel planes that diverge as much as 20 degrees from that marked by the parallel elongation of quartz grains. In such examples two foliations are present which intersect in the line of lineation.

The orientations of quartz described above are confined to the high-grade metamorphic rocks of the Monashee group but are found everywhere in them, regardless of position or rock type. They clearly belong to the Older deformation and, like megascopic structure of that time, are commonly obliterated by the effects of the Younger deformation. In places, however, despite extensive recrystallization, the earlier optic alignment of the quartz is still visible.

The following are the principal facts that emerged from the study of the quartz (1) quartz reacted to the stresses during deformation apparently without breaking whereas feldspar was crushed, (quartz lamellæ, as described by Fairbairn (1942), were detected in only one thin section of Shuswap rocks); (2) the quartz in some rocks became concentrated in stream-like units, fluidal structure; (3) quartz is moulded around mica flakes which are rarely bent; (4) the direction of the optic axis of a single, unbroken quartz grain with undulating extinction may vary as much as 35 degrees; (5) no girdle of optic axes appears in the equal area plot to indicate rotation about the *b* tectonic axis except for a slight dispersion of axes in *ac* due to undulating extinction in quartz grains or to waves in quartz streams; (6) the quartz in quartzite has commonly achieved a high degree of crystallographic parallelism, possibly approaching that of a single quartz crystal.

The most widely accepted theory to explain the alignment of quartz (according to the Sander School) involves (1) splintering of the original quartz grains along appropriate crystallographic directions, (2) mechanical orientation of the inequidimensional splinters by rotation and gliding, and (3) recrystallization causing the disappearance of the fragmental aspect and the development of crystals with the preferred optic orientation. Evidence from the Shuswap rocks is inconclusive, but the writer believes that the fluidal structure of the quartz and its concentration in certain layers and streaks strongly suggest that, under the existing environment, quartz was relatively mobile. Undulating extinction up to 35 degrees proves that quartz crystals can be greatly distorted without actually breaking. The writer believes that the quartz was reoriented by the forces resulting in rock movements during the regional shearing of the Older deformation, without having been fractured or splintered but probably by a process of solution and recrystallization under stress.

Fairbairn (1942) reports that this type of quartz orientation has been found only in connection with slickensides. Perhaps this is also true of the Shuswap rocks if the bedding foliation was induced by an infinite number of closely spaced slip-planes or faults.

• FAULTS

The Older deformation was, in general, a relatively well-ordered interlayer movement of horizontal strata, and faults then incurred were mostly low-angle thrusts. The Younger deformation was more complex and probably involved several phases, among the last of which was high-angle faulting or block faulting. Only the latter is represented on the map (*see* Figure 2). Although, from the tectonic point of view, this period of later faulting was relatively unimportant, it had the greatest effect on the present day topography. It is interesting to note that the Younger faults are clearly formed under conditions of low confining pressure and temperature in contrast with the Older structures which developed under high confining pressure and high temperature.

OLDER FAULTS

The Older deformation was imposed solely on the Shuswap terrane and, owing to its nature, faults that developed at that time are limited to near-bedding types and are therefore difficult to recognize. Bedding slip or near-bedding slip occurs to some degree throughout the Shuswap terrane and is akin to fault movement. Faults, at least on microscopic scale, may therefore be considered to have occurred in all the rocks and many foliation planes are indeed tiny faults. Some of the aspects of these 'micro-faults' have been discussed under the heading of planar structures, and this section will be devoted to larger, though similar, features.

As the effect of Older deformation was principally a grand scale slipping of horizontal beds, one over the other, it is clear that any layer was potentially a fault plane. The rock movement was in many places fairly evenly distributed throughout the stratigraphic column, but in others it was mainly concentrated along certain horizons which thereby constituted bedding faults. Many layers within which movement was concentrated were thick — possibly up to 400 feet — and the rocks therein were crushed and almost simultaneously recrystallized. The stratigraphic zones in which movement was concentrated were naturally the weaker ones. Those rocks in which crushing or mylonitization dominated recrystallization appear homogeneous and aphanitic with small augen of feldspar. They are characteristically dense and tough, almost cherty, and are highly foliated and lineated but do not necessarily split easily. More commonly, however, recrystallization kept pace with mylonitization and the rock is a relatively coarse-grained augen-schist or gneiss.

The limbs of many recumbent folds are cut off by faults parallel with the axial planes, particularly where the folded bed has overriden the one below. This feature is commonly seen on small scale in the outcrops but is thought to exist also on larger scales.

In many places pegmatite was introduced or developed along a fault while it was active causing the whole zone of movement to become an abnormally feldspathic augen-gneiss containing lenticular and twisted units of pegmatite and country rock.

The amount of slip movement on faults of the Older deformation is difficult to estimate because the faults are so nearly in the plane of the bedding and horizon markers are largely absent. The general intensity of a fault may, however, be estimated from the intensity of lineation, the abundance of broken, dismembered, and folded inclusions of schist, gneiss, and pegmatite, and from the association of the zone as a whole with auxiliary drag-folds.

Zones that are believed to be faults following or nearly following bedding are common and may be as much as 400 feet thick. Although the writer was not able to trace any of them out in entirety, such faults do represent a type of rock failure common throughout the Shuswap terrane.

YOUNGER FAULTS

Faults illustrated on the map represent some of the latest deformation in Vernon map-area. Although the faults themselves are rarely exposed, the course of most is clearly expressed by the topography. Evidently, the shattered rock in the fault zone eroded easily and left a linear depression commonly marked by streams, long lakes, and saddles. The presence of faults in many of these linear features is proved by the differences in the succession of beds on either side. Undoubtedly, many faults exist that are not shown on the map or whose presence may not even have been suspected in the field.

The amount of movement on these faults is not known nor is there more than a hint here and there as to the direction of movement. The nearly flat-lying strata near the east flank of Mount Macpherson, southwest of Revelstoke, turn sharply down to the east near the Columbia River fault. This suggests that strata of the Monashee group were thrust up with respect to the rocks to the east and their ends dragged down along the fault. The fault that passes on the east flank of Cranberry Mountain has a large synclinal drag on its east side indicating, again, that the west side has moved up relative to the east.

Except for the two mentioned below, all faults are thought to be vertical or very steeply dipping, because of the straightness of their traces crossing mountains and valleys. Two faults, however, seem to have dips as low as 45 degrees. They are (1) the fault trending southeast from Sugar Lake separating highly metamorphosed Monashee rocks on the east side from less metamorphosed Monashee and Cache Creek rocks on the west; and (2) the southeast end of the fault trending southeast from Three Valley Lake beyond Shuswap River Valley, where it is dying out. Although most faults are comparatively straight, their interlinking nature and the irregular fault boundaries between major rock groups signify that movements are mainly vertical rather than horizontal.

The most important faults are shown on Map 1059A and, of these, the most significant is the Vernon-Sicamous fault. This fault is probably a system of subparallel, linked faults rather than a single break and the major displacement is transferred from one to another as the system is traced longitudinally. The fault has a length in Vernon map-area of about 70 miles and extends beyond both north and south boundaries. The writer believes that the fault actually continues south for the complete length of the Okanagan Valley in Canada and may extend for a total distance of over 170 miles. The main geological aspect of the fault in Vernon map-area is that it separates the Monashee from the Mount Ida group.

Another important system of faults trends northwest from Armstrong and separates the Mount Ida group from the Cache Creek group.

The Columbia River fault system separates the Shuswap terrane on the west from the Windermere and younger rocks on the east. The line of principal displacement follows the Columbia Valley south from Revelstoke to the head of Upper Arrow Lake and there turns south along the lake. About half-way down the lake it edges into the west shore and heads for the vicinity of Whatshan Lake where it disappears into granite.

Although some faults evidently pre-dated the intrusion of the large granite bodies, others formed later or at least had some post-granite movement. Thus some faults disappear entirely on entering granite, whereas the paths of others are clearly marked by crushed granite. All the faults examined pre-date the Tertiary lavas, but some may have had some post-lava movement. Tertiary lava flows are mostly and characteristically confined to plateau-like cappings of the hills but along the line of the Vernon-Sicamous fault, numerous remnants of basaltic flows are at or near the level of the valley bottom. In one place, where the crush-breccia of the fault is exposed, pieces of basalt were mixed with fragments of granite and gneiss, suggesting post-lava movement on the old Vernon-Sicamous fault. The sequence of events on this fault is interpreted to be as follows:

(1) Creation of the fault in pre-Tertiary time
(2) Erosion of a valley along the fault
(3) Filling of the valley by lava in Tertiary time
(4) Renewed movement along the fault
(5) Renewed erosion along the line of the old fault valley, leaving remnants of the lava flows.

Hydrothermal activity along the faults may date from the time of Tertiary vulcanism as well as that of granite intrusion.

The principal effect of the regional faulting is believed to be a general uplift of the whole Shuswap terrane. The main or central block was the massif of the Monashee group bounded by the Vernon-Sicamous fault on the west and the Columbia River fault system on the east. The alpine topography of the Monashee massif as compared with the relatively flat surrounding of the Interior Plateau is probably more the result of this uplift than the difference in hardess of the rocks underlying the two regions.

The Monashee rocks, being stiffened by metamorphism, acted essentially as a unit and were less faulted than the weaker rocks of the Mount Ida and Cache Creek groups to the west. The initially horizontal strata of the Mount Ida group are progressively more disrupted and upturned by faults as they near the contact with the Cache Creek group. The Cache Creek group is the most severely dissected of all the major geological units, and reacted as a relatively thin, incompetent layer mashed against the uplifted Mount Ida group block. East of Vernon, members of the Cache Creek group are partly in unconformable contact with the Monashee group and partly as block faulted inliers.

• CONCLUSIONS

The salient features of the Shuswap structures have been summarized in the introduction to this chapter, but some of the more general and genetic aspects of the structural problem have yet to be discussed. The descriptions that have been presented so far have been detailed and directed in large measure towards emphasizing the importance and pervasiveness of small-scale structures in the Shuswap terrane and pointing out that they represent a deformation that affected even the microscopic textures of the rocks.

The parallelism of schistosity with bedding is the result of shearing parallel with bedding. This type of rock movement was conducted while the stratified series was essentially horizontal and left its most obvious mark on crosscutting units such as dykes and veins, by foliating them parallel with the wall-rock foliation, by folding them, or by dismembering them. Planar parallel alignment of grain and multiple grain units of all kinds and sizes was developed principally by the laminar type of flowage. The direction of laminar flowage is marked in the rocks of higher metamorphic grade by linear, parallel alignment of grain and multiple grain units normal to the direction of slip. The rock movement was penetrative and affected minerals normally of equidimensional habit by deforming them into inequidimensional shapes, and by orienting them physically and optically. The optic axes of quartz grains in certain quartzites of the Monashee group, for instance, were so perfectly aligned that the whole bed almost assumed the optic characters of a single crystal.

In view of the new data, the evidence for static metamorphism as offered by Daly is no longer tenable. Brock (1934) suggested that the schistosity might have developed parallel with bedding by the forceful doming of flat-lying Shuswap strata by igneous masses resulting in radial stretching and slipping of beds during contact metamorphism. This hypothesis, however, cannot be supported for there are no radial or concentric arrangements of the tectonic or structural axes and the metamorphism is not directly associated with intrusive rocks.

Any general explanation of the regional deformation must account for the following (1) the generally flat-lying foliation that lies essentially parallel with the major bedding, (2) the recumbent drag-folding and its drag-sense, (3) the lineation, and (4) the boudinage in two directions. Above all, the theory must be compatible with the immensity of the area concerned and the intensity of the deformation impressed on the rocks.

The most difficult of the minor structures to fit into an overall structural picture are the drag-folds. Figure 2 shows the prevailing senses of drag-folds within the major fault block units by means of large arrows. Although drags of opposite senses are present, they are few in number and occur on the middle limbs of larger folds.

The rocks of the Monashee group, exclusive of those of the Queest Mountain block in the northwest corner, are folded on axes oriented principally along northeast or east directions but are divided into three irregular blocks or 'fields', each of which contains a consistent drag-sense that contrasts with that of its neighbours (*see* Figure 2). These fields are outlined by block faults that are younger than the deformation that produced the drag-folding. It is believed that the rocks within the three main fields were, after Older deformation and before Younger, essentially horizontal, stratified sheets that bore the marks of intense, penetrative rock movements embracing shearing parallel with major bedding and recumbent drag-folding in unique directions. The largest drag-fold so far identified in the region is the Fosthall Mountain fold, and the writer believes that larger folds are not present.

The continuity of shear-sense direction in each of the fields indicates that the rocks therein were subjected to an essentially uniform structural environment. For each individual field, the internal structure can be reasonably accounted for by processes of thrusting whereby great layers moved over (or under) one another, resulting in low-angle thrust faults, bedding faults, bedding shearing, and recumbent drag-folds. Drag-folds on the middle or overturned limbs of larger drag-folds are opposite to the normal direction of shear-sense, but are apparently only of local importance and do not affect the general picture.

The chief difficulty is to account for the fact that the shear-sense of one of the fields is different from that in the other two. As all three fields belong to a single structural environment, to account for the opposite shear-sense in adjacent fields a structure must be at least as large as the fields themselves. One whole block could be in the overturned middle limb of an immense drag-fold brought into its present position by later block faulting but this would presuppose a drag-fold with a middle limb at least 50 miles long, which is difficult to imagine.

Another, though equally improbable explanation, would be to suppose a central horizontal thrust among the middle members of a horizontal stratified series. In effect, layers below these members would be overthrust and layers above underthrust thus producing drag-folds of opposite shear-sense at different levels. There is, however, no way to account for such movement.

The writer has no alternative adequate explanation to offer, but it seems certain that all three fields must have assumed the drag-folds and related structures of the Older deformation while they lay at different levels in the earth's crust because no tectonic process could have developed in them such contrasting directions of intense rock movement while they lay in their present relative positions.

Correlation of structures in the Mount Ida group with those of the Monashee group presents a somewhat similar problem. Although rocks of the Mount Ida group have suffered only low-grade metamorphism, they exhibit deformational structures that are identical in all important respects to those in the Monashee group and both are considered to have been formed by the Older deformation. The important structural difference between the two groups is the direction in which these structures are oriented.

In the Monashee group the tectonic axes are oriented predominantly to the northeast or east whereas in the Mount Ida group they are oriented predominantly to the northwest or north, almost at right angles. In the Mount Ida group the tectonic axes are less closely aligned than those in the Monashee group but both are marked by drag-fold axes and *b*-lineation. The sense of drag-folding, except for minor local exceptions, is as if upper layers sheared to the east or northeast over the lower layers. No strata are repeated to suggest the presence of large folds.

In accounting for the difference in direction for the tectonic axes of the two groups, both hypotheses cited for the Monashee group might be applied, but seem just as unlikely. It is probable that, because of the much lower degree of metamorphism of the Mount Ida rocks, they were never as deeply buried as those of the Monashee group. Deformation, therefore, could have taken place at very different levels in the earth's crust. Possibly the Mount Ida group rocks were deformed at a slightly later stage of the Older deformation than those of the Monashee by forces acting in a different direction but, if so, the structural effects are so similar that probably the movements are parts of the same tectonic period. The two groups could later have been brought to the same level by movements along the Vernon-Sicamous fault. The matter must rest unsolved until further work brings new data to light.

Accounting for the structures of the Younger deformation is easier, even though several phases are involved and they lack the continuity of the Older deformation structures.

Some of the Younger structures are closely linked with the intrusive bodies and are, apparently, local adjustments in nearby softened rocks. Here and there, for instance in the large region of gneisses south of the Vernon-Lumby Valley, metamorphism and Younger deformation have been superimposed on, and have all but obliterated, the effects of the Older deformation. Younger folds are also associated with certain massive pegmatite bodies. Block faults are, in general, the latest structures and, associated with them, are a few large folds.

Structures of the Younger deformation are the only ones that appear in the younger rocks on each side of the Shuswap terrane, and, although they are similar in every respect to those in the Shuswap rocks they are much more extensively developed because of the relative softness of the rocks.

• AGE AND CORRELATION OF THE SHUSWAP TERRANE

The problem of the age of the Shuswap terrane is actually the double problem of the age of the sedimentary assemblage and the age of the superimposed metamorphism. In the writer's opinion the Shuswap sedimentary rocks are older than the Cache Creek rocks of Permian age and are probably older than the Windermere rocks of Proterozoic age. They may be early Proterozoic, possibly in part equivalent to the Purcell series, or they may be Archæan. The principal and widespread metamorphism that is typical of the Shuswap rocks is also believed to be pre-Permian and probably pre-Windermere age and is considered to be unrelated to the Mesozoic intrusions.

The opinion on the Shuswap terrane currently in vogue, supported by what might be called the 'Cairnes School' of thought, is that it represents a *metamorphic condition* of Mesozoic age superimposed on any rocks of earlier age. The opinion of the writer, which agrees with what may be called the 'Dawson School' of thought, is that there is a definite *stratigraphic position* for the Shuswap terrane. Despite the abundance of new information that has resulted from the survey described herein the writer's conclusions as to age of the terrane are not without weaknesses but, as a result of these studies, the contesting arguments have changed in both nature and weight and warrant recapitulation. The arguments of both 'schools' of thought are summarized below; those that support the 'Dawson School' are derived from earlier parts of this report and are listed in order of their apparent importance.

ARGUMENTS FOR THE 'DAWSON SCHOOL' OF THOUGHT

(1) *The Shuswap terrane is structurally and tectonically distinct.* In the preceding part of this report much space has been devoted to describing structures formed during the Older deformation, which are easily recognized, are characteristic of the rocks, and are found everywhere in the Shuswap terrane unless locally obliterated by later recrystallization. They do not occur in rocks of the Cache Creek group and have not been seen in rocks of Windermere age. Furthermore, the tectonic orientation of structures derived from the Shuswap Older deformation are, for the most part, distinctly anomalous to the provincial Cordilleran trend. The change between areas bearing the two trends is *abrupt* and marked by faults that post-date the Older deformation. The Mount Ida group contains two principal tectonic directions of Older deformation and one of them is parallel with the Cordilleran trend but all the structures concerned are typical of the penetrative Shuswap deformation. Although the special structures of the Older deformation are restricted in occurrence to rocks of the Shuswap terrane the ordinary structures of the Younger deformation, which conform in all respects to the Cordilleran orogeny, are prevalent in the rocks of the Shuswap as well as in those in the neighbouring regions.

Evidently, therefore, the special forces of the Older deformation existed exclusively within the vast Shuswap terrane whereas the more ordinary forces of the Younger deformation were regional. The logical conclusion, then, is that the rocks of the Windermere, Cache Creek, and other neighbouring formations were deposited *after* the occurrence of the deformation so characteristic of the Shuswap terrane.

(2) *The Shuswap terrane is unconformably overlain by rocks of the Cache*

Creek group. The 'Cairnes School' holds that the Cache Creek group is included in the Shuswap terrane disguised by Mesozoic metamorphism, but that premise cannot be correct if unmetamorphosed Cache Creek rocks rest unconformably on the metamorphosed Shuswap rocks. In the text above five unconformities that are believed to separate rocks of the Shuswap terrane from those of the Cache Creek group are described; Salmon River unconformity, Dome Rock unconformity, Lavington unconformity, B. X. Creek unconformity, and Glenemma unconformity. In all but the Glenemma unconformity, which is obscured by dynamothermal processes, the unconformable nature of the contact is clear. It remains to be shown, therefore, that the rocks above and below the unconformities are Cache Creek and Shuswap, respectively. At Dome Rock unconformity fossils of Cache Creek type were found in the overlying rocks but, unfortunately, the underlying rocks belong to the Chapperon group whose identity with the Shuswap is not absolutely certain. In the other four localities the rocks overlying the unconformity are separated from fossiliferous Cache Creek rocks by faults, but are lithologically identical to them. Except for unmistakable, distinctive Tertiary strata no rocks younger than the Cache Creek group have been detected in the region of the unconformities. Triassic rocks of the Nicola group occur, so far as is known, only in a small area in the northwest corner of the map-area and are not likely to be present in the small widely scattered localities of the unconformities. The possibility that Jurassic and Cretaceous rocks are represented at the unconformities must also be considered, but they are not known to occur either within or near the map-area. Furthermore all Jurassic and Cretaceous rocks known in southern British Columbia are lithologically dissimilar to those overlying the unconformities. Although direct proof is lacking, it is almost certain that the overlying rocks at the unconformities are of the Cache Creek group and the natural conclusion is that rocks of Permian and perhaps Carboniferous age do not pass into the Shuswap rocks but overlie them unconformably.

(3) *The Shuswap terrane is lithologically distinct.* Discounting metamorphism, neither the Mount Ida nor the Monashee group corresponds in stratigraphy or lithology with the Cache Creek group. Although the Cache Creek group has been assumed by the 'Cairnes School' to grade into the Shuswap 'condition' no volcanic rocks or equivalents of them have been found in the Monashee group despite the fact that one-third or more of the Cache Creek group is andesitic and basaltic volcanic rocks. Both high- and low-grade rocks of the Monashee group are practically devoid of types that could have originated as volcanic rocks even where thick volcanic sequences in the Cache Creek group are adjacent to, and strike towards, the area of the Monashee group, as for instance south of Cherry Ridge. The Mount Ida group contains rocks of probable volcanic origin but neither the stratigraphic sequence nor the thicknesses and nature of associated members corresponds with that of the Cache Creek group.

(4) *The Shuswap terrane is metamorphically distinct.* One of the tenets of the 'Cairnes School' is that the Shuswap rocks, everywhere, are the results of metamorphism around the margins of Mesozoic granitic intrusions. The metamorphic rocks in many areas, such as around the south end of Kootenay Lake, are almost assuredly derived from the effects of granitic intrusion but do not, for this writer, deserve the name 'Shuswap' which he feels should be reserved for the definite and distinct assemblage of rocks defined in this report. Metamorphism in the Shuswap rocks, whether it be relatively low-grade metamorphism like that in the Mount Ida and Chapperon groups or extremely high-grade like that in much of the Monashee group, is widespread and uniform over large areas in which typical intrusive type granitic rocks are largely absent. This is utterly unlike the metamorphism in the Cache Creek group, which is restricted solely to the immediate vicinity of granitic rocks, except for shearing along fault zones. The type of metamorphism in rocks east of the Shuswap terrane also is like that in the Cache Creek rocks. In addition to the contrast in its association with intrusions there is also a difference in the type of metamorphism. The metamorphic rocks in the Cache Creek to the west and other groups east of the terrane are products of recrystallization and metasomatism and are practically devoid of secondary structures. On the other hand, the rocks of the Shuswap terrane were metamorphosed simultaneously with the Older deformation and exhibit orderly, penetrative secondary structures. Although both high- and low-grades of metamorphism are represented in the Shuswap rocks there is no consistent relation between the grade and the boundaries of the terrane; indeed, unmetamorphosed Cache Creek rocks in many places lie in direct contact with sillimanite gneisses of the Monashee group. Aside from the matters of genesis and appearance, the Shuswap metamorphism is assuredly older than the Mesozoic metamorphism in so far as it is simultaneous with the Older deformation (*see* Statement 1).

ARGUMENTS FOR THE 'CAIRNES SCHOOL' OF THOUGHT

(1) *The pre-Permian unconformities have not been proved by fossils.* The age of the rocks lying unconformably on known Shuswap rocks is not absolutely proved despite the lithological similarity of the rocks to Cache Creek strata.

(2) *Shuswap deformation and metamorphism may be early Mesozoic.* The Older deformation and allied metamorphism characteristic of the Shuswap rocks could, despite their dissimilarities to recognized Mesozoic processes, conceivably belong to early deep-seated phases of the general Cordilleran tectonic and intrusive period. Later, faults could have brought them into adjacency with other rocks that show the effects of orthodox, shallow-seated Cordilleran agencies.

In review, the arguments for a pre-Permian age for the Shuswap terrane are the most impressive and conclusive in contrast with those for a Mesozoic age which are negative in quality and largely strike at gaps remaining in the chain of information. The new data supplied by this report have materially changed the status of the debate and one should note that many of the arguments offered or summarized by Cairnes (1939) are no longer applicable. Much of Cairnes' evidence was derived from areas remote to the Shuswap terrane in southeastern British Columbia and in the Kettle River West Half map-area where aureol metamorphism and allied phenomena occur in association with the numerous large Mesozoic granite intrusions. The rocks in these areas should not, in the writer's opinion, have been called Shuswap. Some of Cairnes' evidence was, however, drawn from within the Vernon map-area but is also considered by the writer to be in error for the following reason. The two regions of low-grade metamorphism in the Monashee group that occur northeast of Vernon and on Cherry Ridge east of Lumby (*see* Map 1059A) were mistakenly mapped by Cairnes (following Dawson) as 'Nisconlith' formation which is the lower part of his Cache Creek group or a conformable formation underlying the Cache Creek. Both of these regions of misidentified rock fortuitously lie in fault contact with fossiliferous Cache Creek strata, but in so far as the faults were unrecognized it was inevitable that Cairnes considered the unmetamorphosed rocks of the Cache Creek to be transitional with the low-grade rocks of the Monashee group. The true gradation from low- to high-grade metamorphism within the Monashee group completed the steps so that Cairnes thought he saw an unbroken sequence from unmetamorphosed Cache Creek rocks into the highly metamorphosed Shuswap complex. In reviewing the old evidence further in light of the new facts, it is clear that the controversy regarding the unconformity at Albert Canyon, east of Revelstoke (Gunning, 1929) is no longer related to the problem inasmuch as the rocks involved are not part of the terrane.

Outside the Vernon map-area probably little or none of the true Shuswap terrane has been mapped in sufficient detail to contribute information on the age and origin of the terrane. Nevertheless, the Shuswap rocks probably have a great areal extent, especially to the north of the present map-area. In 1951 the writer mapped a small area at a dam site near Mica Creek on Columbia River near the 'top' of the Big Bend, and was impressed by the similarity between the rocks there and those of the Monashee group. The rocks at Mica Creek are quartzites, biotite-muscovite gneisses, and mica-garnet-kyanite schists. The structure is dominated by recumbent, isoclinal drag-folds, on axes trending northeast, identical in form, intensity and orientation with Older structures in the Monashee group. The writer has no doubt that the rocks at Mica Creek are members of the Shuswap terrane and probably represent part of a 90-mile uninterrupted extension northward from Vernon map-area. Especially noteworthy at this point, however, is the close proximity of these rocks to the main Rocky Mountains. Only the width of the Rocky Mountain Trench separates these typical Shuswap metamorphic rocks of northeast tectonic trend from unmetamorphosed Palæozoic rocks of standard northwest trend.

Although the conclusions presented above as to the relative age of the Shuswap terrane seem reasonably certain, the actual age remains largely a matter of conjecture. There are three possibilities, first, that the Shuswap terrane is of Windermere and early Palæozoic age, second, that it is equivalent to the Purcell series of late Proterozoic age, and third, that it is Archæan or early Proterozoic and older than any formation hitherto recognized in British Columbia.

(1) *Windermere and/or early Palæozic age.* Reasons have already been given for presuming that the Shuswap terrane is older than the Windermere, or at least than that part of it nearby to the east. The abrupt change in metamorphism and structure at the boundaries of the terrane in the Vernon map-area and again near Mica Creek, at the Rocky Mountain Trench are strong arguments in themselves for a younger age for the Windermere and Palæozoic rocks.

(2) *Late Proterozoic age.* A late Proterozoic age for the Shuswap rocks would make them equivalent to the Purcell series. The Purcell series is a thick assemblage (about 40,000 feet) of fine quartzite and argillite and is the oldest known assemblage of rocks in British Columbia. Dioritic igneous bodies known collectively as the Purcell intrusions or Purcell sills are included in the series and may also be of Precambrian age. The correlation of the Purcell series with the Monashee group has much to commend it. The Monashee group is lithologically similar to the Purcell series for, although the Purcell rocks are mostly unmetamorphosed, their known outcrops are sufficiently distant from the Shuswap terrane that metamorphic disparity is no difficulty in correlation. The Purcell sills, moreover, have ready counterparts in the pre-tectonic sills and dykes (the Three Valley intrusions) of the Monashee group. On the other hand, the lithological succession in the Mount Ida group has no counterpart in the known Purcell series. The considerable amount of volcanic rock in the Mount Ida is hard to account for, although the presence of the Purcell lava, and, more particularly, the Irene volcanic rocks indicates some volcanic activity in Purcell or post-Purcell time.

(3) *Archæan age.* An Archæan age for the Shuswap terrane would place it older than any other formation hitherto recognized in British Columbia. This hypothesis is not supported by any direct evidence, of course, but would accommodate all the known facts and would introduce no impossible features. Best of all it would account for the strange, anomalous tectonic trend and relegate its genesis to an age prior to the development of the Cordilleran geosyncline, which seems to have controlled the younger tectonic trends in the province. A serious drawback to any of these age hypotheses is the tremendous gap represented by

the unconformity between the Shuswap and the Cache Creek and the relation of that gap to the stratigraphic record in southeastern British Columbia. Little (1949) reports that the stratigraphic column in the Nelson West Half map-area contains rocks of Windermere, Cambrian, Ordovician, Carboniferous, Permian, Triassic, and Jurassic ages that are nowhere separated by an unconformity of any consequence. In consideration of the proximity to the Vernon map-area it is puzzling that the erosion which immediately pre-dates deposition of the Permian (and Carboniferous?) Cache Creek group is not apparent in the stratigraphic sequence of the Nelson West Half map-area. One must not forget, however, that only the upper part of the Cache Creek group (Unit C) has yielded fossils and that the lower succession which is up to 16,000 feet thick may be equivalent to the lower Palæozoic strata recognized elsewhere in the province. The only established important unconformity in the Nelson West Half map-area is represented by the base of the Toby conglomerate formation which separates the Purcell series from the overlying Windermere. Although no great angular discordance is apparent between the Windermere and Purcell series (except locally in the Windermere map-area) the Toby conglomerate contains boulders and pebbles of such size and angular shape as to indicate rapid erosion from a relatively nearby source. Some hint of pre-Windermere granitic rocks or gneisses is given by the report of biotite granite by Daly (1912) and of granite or arkosic quartzite by Rice (1941) in pebbles of the Toby conglomerate.

The assembled arguments indicate with a high degree of certainty that the Shuswap terrane and its metamorphism are at least older than the Cache group of Permian age and are probably of Archæan or partly Proterozoic age. The Windermere and early Palæozoic strata were either never deposited on the terrane or were removed by erosion before the Cache Creek rocks were deposited. Considering the lack of coarse clastic sedimentary rocks among the late Precambrian and early Palæozoic series to the east one must conclude that the Shuswap terrane did not contribute a significant amount to the sediments of those rocks. The terrane may be regarded, nevertheless, as a part of the great western land-source of Cordilleran sedimentary rocks.

All things considered, the writer believes that the Shuswap terrane ranks in age and origin with the Archæan Grenville series of Eastern Canada, and, if this opinion is substantiated, the geological status will have completed a circle, returning the age of the terrane to that which was assigned when it was first described by Dawson and Daly.

• SEQUENCE OF GEOLOGICAL EVENTS

(1) Synclinal deposition and burial of the Monashee, Mount Ida, and Chapperon groups (Shuswap terrane).

(2) Intrusion of diorite or gabbro sills in the Monashee group (Three Valley intrusions).

(3) Deformation and metamorphism of the Shuswap terrane. The Monashee group folded on axes trending mostly northeast or east and the Mount Ida group simultaneously or successively folded on axes trending mostly north-northeast or northwest. Intrusion of pegmatite and granite (Silver Star intrusions).

(4) Intrusion of peridotite dykes into Chapperon and Mount Ida groups (Old Dave intrusions).

(5) Period of erosion and deposition through late Precambrian (Windermere) and early Palæozoic time; Shuswap terrane probably mostly a low, positive area west of present Columbia River-Arrow Lake system; synclinal sedimentary deposition concurrently taking place to the east and southeast.

(6) Deposition of the Cache Creek group on the eroded and down-warped Shuswap terrane during Carboniferous and Permian time; continued sedimentation in the basin to the east of the terrane with local unconformity marking the base of the Milford group of Carboniferous-Triassic age; sedimentary accumulation lasting at least to Jurassic time east of the terrane and at least to Triassic time immediately west of it.

(7) Block faulting, followed or accompanied by

(8) Intrusion of granitic rocks in late Mesozoic time; contact metamorphism near intrusions.

(9) Renewed or continued block faulting.

(10) Erosion in Early Tertiary time and deposition of fresh water sediments in local basins.

(11) Outpouring of basaltic lavas in oligocene or Miocene time.

(12) Minor movement resumed on certain faults.

(13) Erosion, glaciation, and development of modern topography.

CHAPTER IV

MINERAL DEPOSITS

Unlike much of British Columbia, the Vernon map-area has never been an important mining area. Most of the prospecting was done before the turn of the century and few mineral claims have been staked since then. Today, only a few prospects are being investigated and only one mine — the Falkland gypsum quarries — is producing regularly. Mining in the future may, however, have a greater place among the industries of the map-area and the future possibilities of certain phases of the mineral industry are outlined in this chapter.

Most of the mineral deposits in the north Okanagan district were described in some detail in 1931 by Cairnes (1932). Little exploration has been done on most of these properties since then and Cairnes' report is still the principal source of detailed information. As this report is now out of print the writer has quoted from it freely.

• METALLIFEROUS DEPOSITS

PLACER GOLD DEPOSITS

References

1. Barnes Creek: B.C. Dept. of Mines, Bull. 1, p. 100 (1931); Ann. Repts., Minister of Mines, B.C.: 1935, p. 36; 1951, p. 206.
2. Cherry Creek: Ann. Repts., Minister of Mines, B.C.: 1874 to 1895 in tables; 1874, p. 15; 1876, pp. 410 and 423; 1877, p. 404; 1879, p. 241; 1881, p. 398; 1882, p. 362; 1886, p. 213; 1887, p. 277; 1889, pp. 291 and 292; 1890, p. 378; 1891, p. 575; 1892, p. 543; 1893, p. 1073; 1894, p. 753; 1895, p. 706; 1901, p. 1127; 1905, p. 192; 1914, pp. 359, 360; 1920, p. 187; 1921, p. 196; 1922, p. 145; 1923, p. 160; 1925, p. 184; 1926, p. 200; 1927, p. 213; 1930, p. 208; 1931, p. 116; 1934, p. 34; 1935, p. 15; 1940, p. 97; 1941, p. 91; Bull. 2, 1930, p. 53; B.C. Dept. of Mines, Bull. 20, p. 24.
3. Harris Creek: Ann. Repts., Minister of Mines, B.C.: 1892, p. 543; 1936, p. 43.
4. Moffat Creek: Ann. Rept., Minister of Mines, B.C.: 1932, p. 144.
5. Naswhito (Siwash) Creek: Ann. Repts., Minister of Mines, B.C.: 1889-1894; 1915, p. 252; 1916, p. 263; 1917, p. 20; 1918, p. 21; 1924, p. 140; 1925, p. 200.

6. Putman Creek: Ann. Rept., Minister of Mines, B.C.: 1936, p. 48.
7. Scotch Creek: Ann. Repts., Minister of Mines, B.C.: 1885, p. 496; 1886, p. 212; 1887, p. 276; 1895, p. 696; 1896, p. 565; 1897, p. 613; 1898, p. 1101; 1935, p. 49.
8. Whiteman and Bouleau Creeks: Ann. Repts., Minister of Mines, B.C.: 1915, p. 253; 1920, p. 187; 1921, p. 196.
9. Winfield Placers: Ann. Repts., Minister of Mines, B.C.: 1933, p. 197; 1934, p. 34; 1935, p. 15; 1936, p. 46.

The placer deposits of the Vernon map-area have never produced important amounts of gold, but have been of local interest over a long period of time. With the exception of the placer mining at Scotch Creek, on the north edge of the map-area, all activity of any consequence has been near the north end of Okanagan Lake or east of Vernon near Lumby and Monashee Pass.

Whiteman, Bouleau, Siwash, Equesis, Moffat, and Newport Creeks

Cairnes (1932) reports: "Within the map-area placer mining has been conducted with some success on a number of streams tributary to the main valleys. Those of principal interest include Whiteman, Naswhito (Siwash), Equesis (Six-mile), and Moffat. Of these streams the first three occupy prominent valleys draining easterly into Okanagan Lake. Moffat Creek is comparatively small and empties into a depressed area occupied by several small lakes that have an underground seepage northwesterly into Salmon River. Placer gold has also been found in small quantities along many of the smaller creeks of the area, particularly those draining from the west and south into Okanagan and Salmon River Valleys. The valleys of the larger streams are typical of those intersecting the plateau country of British Columbia. They cut deeply across the rock structures and the streams following them flow over rock-bottomed stretches separated by intervals of gentler grade where stream wash has accumulated.

"In their lower courses the stream beds are flanked by high banks of sorted bench materials rising to heights of several hundred feet. Some attempts have been made to hydraulic these bench materials, but for the most part efforts have been confined to working the creek gravels. On Naswhito (Siwash) creek operations of the latter sort were attempted years before the settlement of Okanagan valley and have continued to attract some attention. The principal producing years of which there is any record extended from 1889 to about 1895, during which period a yearly output of from \$1,200 to \$2,000 is reported. Since 1914 hydraulic operations have been undertaken by different companies, with some success, at a point about 2 miles from the mouth of the creek. Here bedrock is exposed at the base of about 200 feet of gravels, sand, and clay the lowermost beds comprising several feet of rusty-weathering gravels. The important values are concentrated near and mostly on bedrock. The disposition of the overlying heavy cover is a difficult problem.

"At Moffat creek, on the other hand, encouraging values are reported to have been obtained from the entire deposit of unconsolidated bench materials accumulated near its mouth on either side of the Canadian National Railway. Considerable exploratory work including attempts at hydraulic operations was done on this property many years ago by Ross Mahon and others, and some coarse gold is reported to have been obtained. The chief practical difficulties there relate to disposition of waste and to securing an adequate supply of water. At one time it was proposed, and negotiations were in fact put under way, to tap Pinaus Lake, in the valley of Equesis creek, by a rock tunnel, to be driven from the upper, southern slope of Salmon River valley, and flume the water from thence to the diggings.

"Some placer mining has been conducted from time to time on Whiteman, Bouleau, and Equesis creeks. These operations have been chiefly concerned with the recent stream gravels and though hydraulic leases are reported to have been acquired on the two first-mentioned creeks, there is no record of operations of this sort. Nor is any data available as to the output from these creeks except that it was small as compared with that of Siwash creek. Good values are reported to have been obtained locally from Equesis creek, particularly in the vicinity of its junction with Musgrave creek, a northern tributary entering the main stream about 6 miles from its mouth. A little work has also been done on this tributary.

"Placer gold has been found in the gravels of Newport (Deep) creek and, in fact, on most if not all of the streams draining the western slopes of the northern Okanagan valley. There are no reports of gold having been found in the streams draining the country east of this valley, though B.X. creek, since it cuts across an area of rocks carrying auriferous quartz veins, should hold gold if any of the streams on this side do."

Winfield Placers

The Winfield placers are east of Wood Lake (the south end of Long Lake) about 4 miles northeast of the railway station of Winfield. They are situated at various places along the base of a succession of horizontal lava flows of the Kamloops group. The lower part of the Kamloops group there consists of buried alluvial deposits of various kinds that lie on an old, irregular land surface. On this old land surface is a sinuous, gravel-filled stream channel that here and there emerges at the surface, from under the lava, the present slope of the hill giving a cross-section. These gravels consist of white quartz pebbles and garnet sand, and carry gold. Small adits have been driven along the bottom of the channel at various places, and a total of 75 ounces of gold is reported to have been recovered between the years 1933 and 1945, with a value of $1,658.

Harris Creek

Harris Creek is about 16 miles east of Vernon and flows into Bessette Creek about 3 miles south of Lumby. The placer mine is about 2½ miles from the Vernon-Lumby highway at a place where Harris Creek takes a sharp bend shortly before entering the broad Lumby Valley and joining Bessette Creek. The gravels in which the gold occurs form a bench that extends up to 220 feet above the level of the present stream, and fill an abandoned stream channel which is thought to extend about 2 miles towards the west. The gold is mostly contained in the lower parts of the deposit, among poorly sorted or unsorted debris which contains many large boulders and pebbles of Shuswap gneiss and garnetiferous sands. The gold is coarse, and nuggets up to 1¾ ounces have been found. The deposit has been worked intermittently since 1936 with the aid of a small monitor and sluice-boxes, and is reported to have yielded 455 ounces of gold with a value of $14,522.

Putman Creek

Putman Creek flows east into Trinity Valley from Silver Star Mountain, and is about 5 miles north of Lumby. Gravels in the vicinity of this creek are extensive but so far attempts to work them for placer gold have not been successful. In 1936 a total of 5 ounces was recovered, valuing $155.

Cherry Creek

The Cherry Creek placer deposits are 16 to 20 miles east of Lumby on the main stream ('North Fork of Cherry Creek') on Monashee Creek ('South Fork of Cherry Creek'), and on some tributary streams such as Rembler ('Porcupine') Creek which flows northeast into Monashee Creek. The valleys were filled with gravel after the retreat of the ice and remnants of these gravels in benches up to 300 feet high have been left by the recent entrenching of the stream. The best placers have been found on Cherry Creek, although most of the streams have been extensively mined. The deposits have been worked by hand, by an elaborate system of flumes, and by hydraulicking since the early 1870s and in the past two decades with the use of gasoline shovels. The gold is fairly coarse and nuggets up to 6½ ounces have been recovered. The Cherry Creek placers as a whole have yielded more gold than any other placers in the map-area, totalling 5,210 ounces for all creeks with a value of $80,332. Most of the placer mining was done between the years 1874 and 1895, but hydraulicking operations are reported to have yielded gold to the value of $20,000 in more recent years.

Barnes Creek

The Barnes Creek placers are about 10 miles west of Whatshan Lake on Eureka and Holding Creeks, which are tributaries of Barnes Creek. The leases that are currently being worked are on Holding Creek and are reached by 6 miles of rough road from a point 5.3 miles west of Inonoaklin crossing on the Monashee highway. The stream gravels, which lie on both sides of the creeks, comprise benches up to 30 feet high, although the parts that are being worked are only 5 to 6 feet high. The current operation employs two workmen, a bull-dozer for stripping, a hose and pump for moving pay gravel, and sluice-boxes. The leases are being held by Barnes Creek Mining Association Ltd. Between the years 1931 and 1945 a total of 103 ounces valued at $3,074 was recovered from all placers on creeks tributary to Barnes Creek.

Scotch Creek

Scotch Creek flows southward and enters Shuswap Lake near its western end, opposite Sorrento. The placer gold deposits that made Scotch Creek renowned in the 1880s are almost all north of the map-area but some of lesser importance are included along the lower reaches of the stream. For the most part the best gravels comprise high-level benches up to 400 feet above the present stream. The working of such high deposits by hydraulicking requires either large-scale pumping of the water from Scotch Creek or the fluming of water from tributary creeks above the deposits. The first operation has proved to be prohibitively costly, and the supply of water for the second is very limited. Mining has consequently been on a relatively small scale. Between the years 1885 and 1945 the Scotch Creek placers as a whole produced 1,999 ounces valued at $40,693 but mostly from outside Vernon map-area.

LODE DEPOSITS

Gold and silver prospects are more numerous than those of the base metals. Within a radius of 8 miles of Vernon are many deposits in which gold is the main metal and from 8 to 15 miles from Vernon most deposits contain silver, accompanied by some lead, zinc, and gold. The most important copper prospects are near Shuswap Lake and north of Siwash Creek on the west side of Okanagan Lake. Nearly all are vein deposits and lie in or near fault fissures. A few are bodies of disseminated minerals near the contact of granite bodies. The chromite deposits of the southwest corner of the map-area are segregations in ultramafic dykes and differ from all other mineral deposits in the area. When the area was being studied, none of the deposits was being mined and not many have shipped more than a few tons of either ore or concentrate. Work on most prospects was stopped because the continuity of the ore could not be established; although the grade of the ore in most prospects is high its distribution is erratic and spotty.

The geological factors having a bearing on the vein deposition of the ore are:

(1) *Faults.* Few fault zones are without attendant mineralization, indeed the presence of mineralization can almost be accepted as evidence of faulting nearby.

(2) *Zoning*. Mineral deposits are concentrated around the north end of Okanagan Lake and exhibit a rough concentric zoning of metallic content. The localization and zoning of the deposits may be partly a consequence of the convergence of the faults in the area whereby the rocks were shattered more than elsewhere producing unusually favourable conditions. The proximity of Cretaceous or Tertiary granite intrusions may also have been a contributing factor.

(3) *Host rocks*. Rocks of the Cache Creek group contain most of the known mineral deposits of the map-area. This fact has, in the past, been explained by the hypothesis that temperature and pressure conditions were more favourable in the Cache Creek group than in the nearby Shuswap terrane, which, it was assumed, was being subjected to intense metamorphism under high temperature and pressure during the mineralization period. In view of the fact that the metamorphism in the Shuswap is now believed to have taken place long before the mineralization this hypothesis can no longer be accepted. Actually mineral deposits do occur in the Shuswap but it is probable that their scarcity is due mainly to (1) the rarity of suitable fault zones and, (2) the rarity of intrusions of Mesozoic and (?) Tertiary granitic rocks, both common features in the Cache Creek rocks.

The following table lists most of the lode deposits in the map-area and presents their principal features in summary form. The most important metals in the deposits are in italics.

LODE DEPOSITS OF THE METALLIC MINERALS IN THE VERNON MAP-AREA

No.	Name	Location Latitude; Longitude	Metals	Production	Remarks	Reference
1[1]	Annex group	50°54′; 119°02′	gold	nil	Narrow quartz veins in chlorite, mica schist, and quartzite; pyrite	1932, p. 146[2]
2[3]	Bachelor group	50°13′; 119°22′	*gold,* copper	nil	Quartz veins 3½ feet wide in granite; pyrite and copper sulphides	1896, p. 579 1899, p. 747
3	Beverley group	50°19′; 119°18′	*gold, silver, lead,* copper, antimony	nil	Network of veins 10 inches to 30 feet wide; erratic assays	1934, p. 32
4[4]	Big Ledge	50°29′; 118°10′ to 117°55′	*zinc,* lead	nil	(*See* descriptions)	
5	Black Hawk (Peoitch)	50°25′; 119°22′	*gold, silver,* copper, lead	nil	Quartz vein 5 feet wide in volcanic rock and slate; much calcite; some pyrrhotite, pyrite	1899, p. 747 1900, p. 887 1902, p. 189 1919, p. 184 1922, p. 144
6	Bluebird	50°12′; 118°57′	*gold,* silver	nil	Small quartz veins in sedimentary and igneous rocks; low grade	1949, p. 137

[1]Number appearing on map
[2]All references to Ann. Repts. B.C. Min. Mines, unless otherwise stated
[3]Described by Cairnes (1932)
[4]Described more fully below

Lode Deposits of the Metallic Minerals in the Vernon Map-Area—*Continued*

22	Blue Bell	(*See* Goodenough group)				
7	Blue Hawk group	50°00′; 119°32′	*gold,* lead	5 tons shipped in 1935	Series of faulted quartz veins up to 4 feet wide in altered tuff, breccia, cherty argillite; near granite body; pyrite, galena	1933, p. 196 1935, p. 13 1937, p. 23 1938, p. 36
8	Blue Jay	50°18′; 119°17′	*gold,* arsenic, lead, antimony	nil	Quartz vein 4½ feet wide in volcanic breccia; pyrite, galena, arsenopyrite, tetrahedrite	1897, p. 609 1899, p. 747 1934, p. 32
9	Bon Diable	50°18′; 119°13′	*gold,* silver	1 ton shipped in 1899	Several small quartz veins in faulted quartzite; average grade low	1897, p. 609 1899, p. 747 1901, p. 1125
10	Bonnie Brae	50°41′; 119°17′	*silver,* lead, zinc	nil	Quartz lenses and veins up to 6 inches wide in schist, pyrite, galena, sphalerite, pyrrhotite	1926, p. 188 1930, p. 183
11	Brent	50°20′; 119°18′	*copper,* lead, silver, gold	nil	Quartz vein 3 to 4 feet wide, in schist	1923, p. 161 1925, p. 184
12	British Empire	50°15′; 119°22′	*gold,* copper	Few tons of concentrate	Quartz veins up to 2 feet wide; disseminated pyrite, chalcopyrite; erratic spectacular assays, average grade low; stamp mill	1901, p. 1125 1902, p. 189 1903, p. 178 1905, p. 192 1906, p. 172 1925, p. 184 1927, p. 213

25	Buckthorn	(*See* I.O.U.)				
13	Cartwright	50°15′; 119°24′	?	nil	Quartz vein several feet wide	1897, p. 609
30	Chance group	(*See* Kalamalka)				
14	Chrome-Vanadium group	50°01′; 119°52′	*chromium*, iron	nil	(*See* description)	
41	Cochrane	(*See* Mitchell)				
15	Copper Chief	50°53′; 119°20′	copper	nil	Disseminated copper sulphides in wide zone in schist	1930, p. 183
16	Copper Cup	50°53′; 119°20′	*copper*, lead, zinc	nil	Silicified zone in chlorite schist, small bodies of chalcopyrite in quartz lenses; sphalerite, galena	1928, p. 210 1929, p. 217 1930, p. 183
17	Copper Island	50°54′; 119°24′	*copper*	nil	Copper disseminated in chlorite schist	Geol. Surv., Canada, Rept. Prog. 1877-78
18	Copper King group	50°03′; 119°13′ (approx.)	copper	nil	Reported copper mineralization including native copper; little or no work	1929, p. 249
25	Copper Queen	(*See* I.O.U.)				
22	Dawson	(*See* Goodenough)				

LODE DEPOSITS OF THE METALLIC MINERALS IN THE VERNON MAP-AREA—*Continued*

19	Densy group	50°15′; 119°23′	*gold,* copper	nil	Three narrow veins, one up to 6 feet wide	1897, p. 609 1899, p. 746
20	Eagle	50°17′; 119°40′ (approx.)	molybdenum	nil		B.C. Dept. of Mines, Bull. No. 9, p. 132, 1940
3	Edith	(*See* Beverley)				
21	Falcon	50°17′; 119°18′	*gold,* copper, lead, arsenic	nil	Quartz vein 1 foot wide in argillite and tuff; arsenopyrite in vein and wall-rock; spotty high assays for gold; chalcopyrite, pyrite, galena	1899, p. 747 1921, p. 191 1932, p. 143 1934, p. 30
22	Goodenough group	50°18′; 119°28′	*copper,* lead, gold, silver	nil	Disseminated sulphides in host rocks at and near contact of granite and volcanic and sedimentary rocks; alteration of granite and host rocks; pyrrhotite, chalcopyrite	1900, p. 886 1902, p. 189 1904, p. 228 1921, p. 191 1924, p. 140 1929, p. 247
25	Gem	(*See* I.O.U.)				
23	Grand Times and Hidden Treasure	50°23′; 119°28′	gold	nil	Quartz vein	1896, p. 1129 1899, p. 747
24	Grandview group	50°40′; 119°8′	*gold,* silver, lead	nil	Quartz veins in fault zones in quartzite; pyrite, galena	1928, p. 211 1930, p. 184
33	Hic Jacet	(*See* Klondike group)				1898, p. 1130

23	Hidden Treasure	(*See* Grand Times)				
63	Homestake	(*See* Zion)				
25	I.O.U. group	50°18′; 119°28′	*gold*, copper	nil	Quartz vein 6 feet wide	1899, p. 746
26	I.X.L.	50°18′; 119°17′	?	nil	Quartz vein 6 inches wide, in argillite; disseminated sulphides	
27	Iron Cap	50°15′; 119°22′	copper	nil	Two narrow quartz veins with chalcopyrite	1897, p. 609
28	Iron Pot	50°58′; 119°27′	gold, lead, zinc	nil	Quartz veins with pyrrhotite, sphalerite, galena	1930, p. 184
29	Jumbo	50°18′; 119°17′	gold	nil	Several small quartz veins in slate and tuff; disseminated pyrite	1928, p. 220 1929, p. 248 1930, p. 208 1931, p. 116
30	Kalamalka (Chance)	50°12′; 119°06′	gold, silver, lead, zinc	1941—917 tons 1942—433 tons (Small shipments not recorded)	(*See* description)	1897, p. 609 1934, p. 32 1935, p. 13 1937, p. 31 1938, p. 36 1940, p. 71 1941, p. 60 1942, p. 59

Lode Deposits of the Metallic Minerals in the Vernon Map-Area—*Continued*

31	Kenallan and Yokahama	50°27′; 119°49′	molybdenum	nil	Contact deposit in silicated limestone; spotty, high grade	
32	Keystone	50°18′; 119°18′	copper, zinc, lead	nil	Quartz veins up to 3 feet wide; chalcopyrite, sphalerite, pyrite, galena	
33	Klondike	50°15′; 119°28′	copper, gold	nil	Quartz veins at contact of granite and dykes with sedimentary rocks; disseminated sulphides	1898, p. 1130 1899, p. 746
34	Lake View	50°18′; 119°17′	*gold, silver,* copper	nil		1896, p. 579
35	Last Chance	50°43′; 119°03′	gold	nil	Quartz veins; silicification; pronounced fracturing	1926, p. 188
36	Little Duncan and Panorama	50°21′; 119°22′	*gold, silver,* copper, lead	nil	Quartz vein 2 to 5 feet wide; pyrite, galena	1899, p. 746
3	Marie	(*See* Beverley)				
37	May	50°26′; 119°18′	gold, silver, lead	nil	Quartz vein	1899, p. 747
38	Metal Crest	51°00′; 119°27′	lead, zinc	nil	Quartz veins; spotty galena, sphalerite	1929

39	Milligan group	50°12′; 119°18′	gold	nil	Zone of quartz in limestone	1902, p. 188
40	Mission Hill	50°12′; 119°18′	*silver,* gold, copper, lead	nil	Series of disconnected quartz veins in granite; disseminated pyrite, chalcopyrite, galena; calcite	1928, p. 221
41	Mitchell and Cochrane group	50°18′; 119°22′	*silver,* lead, copper, zinc	nil	Two parallel quartz veins 6 to 8 feet wide, in argillites; pyrite, galena, chalcopyrite, sphalerite	1922, p. 145
42	Monashee group (St. Paul)	50°07′; 118°30′	gold, silver, lead, zinc, copper, antimony, arsenic	2,729 tons since 1890; yielded 503 ounces gold, small amount of silver; intermittent small shipments not recorded	Discontinuous quartz veins up to 10 feet wide; galena, pyrite, pyrrhotite, magnetite, jamesonite, tetrahedrite, arsenopyrite, stibnite, chalcopyrite, sphalerite	1897, p. 609 1900, p. 886 1901, p. 1128 1902, p. 188 1903, p. 178 1914, p. 359 1915, p. 252 1916, p. 263 1921, p. 191 Geol. Surv., Canada, Sum. Repts. 1930, pp. 116-121; 1933, p. 155; 1934, p. 11; 1935, p. 13; 1940, p. 71; 1945, Dept. of Mines, Bull. No. 20, pt. 3, p. 24
43	Morning Glory	50°14′; 119°23′	*gold,* copper	Test run only	Quartz vein 6 feet wide, in granite; arsenopyrite	1896, p. 579 1897, p. 608

LODE DEPOSITS OF THE METALLIC MINERALS IN THE VERNON MAP-AREA—*Continued*

44	Mount Ida group	50°38′; 119°14′ (approx.)	*silver,* lead	nil	Quartz veins 18 inches to 7 feet wide; galena	1913, p. 198
45	Octagon group	50°22′; 119°22′	*silver,* copper, antimony, lead, zinc	nil	Quartz vein; tetrahedrite, sphalerite, pyrite	1923, p. 161
46	Ophir	50°17′; 119°23′	*copper, silver,* lead, zinc, gold	nil	Quartz vein 3 to 4 feet wide; chalcopyrite, malachite, pyrite, galena, sphalerite	1923, p. 161 1925, p. 184 1926, p. 200 1927, p. 213 1928, p. 220
47	Paladora group	50°03′; 118°25′	*gold,* silver, lead, zinc	Less than 200 tons shipped	Parallel quartz veins in granite; pyrite, galena, sphalerite	1899, p. 748 1900, p. 856 1902, p. 165 1916, p. 207 1927, p. 232 1949, p. 343 1930, p. 263 1938, p. 40
36	Panorama	(*See* Little Duncan)				
48	Paradise and Renown	50°05′; 118°28′	gold, silver	nil	Quartz veins in granite; pyrite	1930, p. 263
49	Pay Roll	50°19′; 119°22′	*silver, lead,* gold	nil	Quartz vein in argillite 2 to 3 feet wide; smithsonite, galena	1929, p. 247 1930, p. 208

3	Peggy	(*See* Beverley)				
5	Peoitch	(*See* Black Hawk)				
22	Pheonix	(*See* Goodenough)				
50	Polar Star	50°08′; 119°33′	?	?	?	1898, p. 1130
22	Porteous	(*See* Goodenough)				
22	Queen group	(*See* Goodenough)				
51	Rex (Three Tramps)	50°16′; 119°22′	*gold*, copper	nil	Quartz veins 1 foot to 1½ feet wide in crushed zone; pyrite, chalcopyrite	1897, p. 609 1899, p. 746 1901, p. 1125 1905, p. 192
52	Rita	50°14′; 119°19′	*silver*, copper, gold	nil		1914, p. 360
53	Ruby Gold	50°15′; 119°24′	gold	nil	Quartz veins in schist 10 to 12 feet wide; pyrite	1897, p. 608
42	St. Paul group	(*See* Monashee group)				
54	Shuswap	50°57′; 119°26′	lead	nil	Quartz vein in schist 6 inches wide; galena, pyrite	1934, p. 29

LODE DEPOSITS OF THE METALLIC MINERALS IN THE VERNON MAP-AREA—*Concluded*

55	Silver Creek	50°35′; 119°02′	silver	nil	Quartz veins	1877
56	Silver Star group	50°23′; 119°03′	*silver, lead, zinc,* gold, molybdenum	A few tons picked ore	Quartz vein in argillite 3 to 4 feet wide; galena, sphalerite, pyrite, molybdenite	1898, p. 1130 1926, p. 200 1948, p. 120 1949, p. 137 1950, p. 116 Geol. Surv., Canada, Sum. Rept. 1930, p. 122
57	Skookum	50°22′; 119°23′	*silver,* gold	nil	Quartz vein 2 to 4 feet wide, highly fractured; pyrite, tetrahedrite, chalcopyrite, malachite, galena	1933, p. 196 1941, p. 60
58	Sugar Loaf	50°40′; 119°08′	*gold,* lead	nil	Quartz vein 7 feet wide, in quartzite; pyrite, galena	1929, p. 228 1930, p. 184
59	Sunset	50°41′; 119°16′	*silver,* lead	nil	Quartz veins; galena	1930, p. 184
51	Three Tramps	(*See* Rex)				
60	Victory	50°47′; 119°02′	zinc	41 tons of ore shipped	Disseminated mineralization; sphalerite in garnet gneiss	1927, p. 197 1930, p. 184
61	Vimy	50°53′; 119°20′	*copper,* gold, silver	nil	Quartz veins in silicified zone	1928, p. 211

62	White Elephant and Yellow Rose	50°08′; 119°33′	*gold*, silver, tungsten	Small shipments of concentrate	Quartz plug 50 to 70 feet wide containing central ore shoot 15 to 25 feet wide, in granite; pyrrhotite, bismuth telluride, scheelite; small mill	1921, p. 192 1922, p. 144 1923, p. 159 1924, p. 140 1927, p. 213 1928, p. 220 1929, p. 248 1930, p. 207 1932, p. 143 1933, p. 196 1950, p. 115
31	Yokahama	(*See* Kenallan)				
63	Zion	50°08′; 119°39′	gold	nil	Quartz vein	1907, p. 128

Big Ledge Group

References: Ann. Repts., Minister of Mines, B.C.: 1908, p. 111; 1909, p. 127; 1910, p. 114; 1916, p. 207; 1917, p. 197; 1918, p. 199; 1923, p. 235; 1927, p. 330; 1947, 174; 1949, p. 193; 1950, p. 151.

The Big Ledge group of claims is near the crest of a prominent bare ridge that lies immediately south of Mount Odin, on the western edge of the map-area. The crest of the ridge is mostly above timber-line (6,000 feet) and rises to over 7,000 feet at Mount Symonds. When the property was visited in 1953 the Consolidated Mining and Smelting Company Ltd. held an option on the claims and were conducting extensive exploration. A geological examination of the Big Ledge deposits was made by Cairnes and Gunning (1929) and their report gives the most detailed account available.

The rocks in the vicinity are gneiss, schist, quartzite, marble, and pegmatite, typical of the high-grade metamorphic members of the Monashee group. The mineral content of the rocks, the differences from layer to layer across strike, and the continuity of layers along strike prove that they are of sedimentary origin. The pegmatite occurs as small sills or dykes cutting the layers at low angles. The gneiss and schist are composed of relatively few minerals but the proportions of these minerals in different layers and the widths of the layers themselves vary widely. The minerals include quartz, plagioclase, biotite, sillimanite, garnet, orthoclase, amphibole, diopside, and muscovite.

The strata at and near the Big Ledge are in an overturned monocline and strike east parallel with the ridge and dip south at 20 to 40 degrees. Small drag-folds are widespread. The beds that form the wall-rock of the Big Ledge are part of the overturned middle limb of the Fosthall Mountain fold (*see* section on structure) and consequently all the small drag-folds are inverted. The zone of mineralization is a few inches to 60 feet wide, and follows a single bed about 135 feet thick. Alteration has largely obscured the original nature of this bed but Cairnes and Gunning believe it to have been calcareous.

The sulphide minerals are mainly pyrrhotite, pyrite, and sphalerite, in that order of abundance. Galena is present, but only in small amounts and consequently zinc is the only important metal. The sulphides are disposed in lenses and bands within the ledge, either as disseminations or as replacement bodies of nearly pure sulphide. The distribution of zinc in the ledge is erratic and the average grade low, although certain sulphide-rich bodies are high grade. The ledge can be traced for over 6 miles but sulphides are not everywhere visible. Dithozone geochemical tests, conducted by the present lessees, have, nevertheless, shown that zinc is present almost continuously along the Ledge and have enabled it to be traced eastward as far as Upper Arrow Lake despite heavy overburden[1]. The deposit has been explored by a few short tunnels, many open-

[1]Malcolm, D.C.: Consolidated Mining and Smelting Company Ltd., personal communication.

cuts, magnetometer and geochemical surveys, and over 13,000 feet of diamond-drilling.

Cairnes and Gunning considered the deposits to be formed by selective replacement of certain favourable, probably calcareous, beds. These beds should recur in the upper and lower limbs of the large Fosthall Mountain fold and outcrop in parallel zones both north and south of the Big Ledge. The sulphide deposits are apparently later than the main period of deformation, for they do not show the schistosity and lineation so prevalent in the host rocks. The ore-bearing beds in the other limbs of the fold should, however, be equally favourable and, as they are relatively inaccessible, may not have been thoroughly prospected.

On the other hand, some factor that may have controlled the localization of sulphide deposition in the Big Ledge may have been absent along the projection of the beds. Such a factor might be a bedding fault in the Ledge stratum. The Fosthall Mountain fold and the strata concerned therein do not extend eastward beyond a fault that lies approximately along the course of Pingston Creek. The Big Ledge zone of mineralization however continues across Pingston Creek to Upper Arrow Lake, despite the change in strata. This suggests that the mineralization occurred along a fault that crosses the Pingston Creek fault with little or no displacement and which lies parallel or nearly parallel with the bedding.

Kalamalka (Chance) Mine

References: Ann. Repts., Minister of Mines, B.C.: 1897, p. 609; 1934, p. 32; 1935, p. 13; 1937, p. 31; 1938, p. 36; 1940, p. 71; 1941, p. 60; 1942, p. 59; B.C. Dept. of Mines, Bull. No. 20, pt. 3, p. 24; Federal Bureau of Mines, pub. 771, pp. 81-86.

The Kalamalka gold mine, formerly known as the Chance prospect, is about 2 miles south of Lavington and 11 miles east of Vernon. The deposits occur as quartz veins near the contact of a small diorite plug with argillaceous sedimentary rocks of the Cache Creek group. The veins are as much as 4 feet in width but are lenticular and discontinuous, owing to numerous faults that cut them at small angles. Sulphide mineralization is scanty but includes pyrite, pyrrhotite, and galena. The mine was developed on three main levels through one main adit, although several short adits and exploratory drifts were driven into the zone of the vein from the hillside. The mine was closed down in 1944, as the severe faulting and marginal grades made it difficult to develop sufficient ore. A total of 1,350 tons of ore reported to have good fluxing qualities was shipped to the smelter during 1941 and 1942, and smaller shipments were made in other years but not recorded. The smelter returns on 917 tons of ore were: 502 ounces of gold and 247 ounces of silver.

Chrome-Vanadium Group

Reference: Ann. Rept., Minister of Mines, B.C.: 1929, p. 249.

The Chrome-Vanadium group of claims is on the headwaters of Nicola River near the southwest corner of the map-area at an elevation of 4,800 feet.

Of the detailed geology and mineralogy of these deposits Cairnes (1932, p. 94A) says:

"Interest in the Chrome-Vanadium group is centred chiefly on the occurrence of segregated chromite in a belt of serpentinized peridotite which extends across Nicola valley in a general north 25 degrees west, direction. This belt was followed to the southeast of the river for over half a mile and in the opposite direction for about a mile and picked up again over a mile farther northwest. In this total distance the belt maintains a remarkably straight course and apparently steep dip. On either side of Nicola river it has an observed width of about 400 feet and is doubtless somewhat wider, as its northeast contact is nowhere exposed. On the southwest side the belt is in contact with, and apparently intrudes, both granitic rocks and argillaceous sediments. In shape, structure, and contact relations this belt resembles a broad dyke and such it is presumed to be.

"This chrome-bearing dyke is composed mainly of dark green serpentine which commonly weathers a deep orange-red, but in places is coated instead with a thin, semi-transparent, whitish, talcose film. The serpentine has resulted from the alteration of an intrusive composed very largely of olivine. Microscopic studies reveal different stages of alteration ranging from those in which abundant small grains of olivine occur in a meshwork of serpentine to others in which no traces of unaltered olivine remain. Other minerals present include partly to completely altered crystals of pyroxene, talc, chlorite, magnetite, asbestos, chromite. The chromite is dark brown and almost opaque in thin section. It is an abundant constituent at one locality. At most other places the rock carries disseminated magnetite occurring either in crystals or in lumps and small, irregular streaks. At different places the serpentine was observed to contain small veinlets of cross fibre asbestos varying in thickness from that of a mere thread to 1/4 inch. Where shearing or slickensiding is pronounced, lenses of partly-developed, slip-fibre asbestos have formed. In a comparatively narrow, steeply inclined belt of this sort, however, important deposits of asbestos are hardly to be expected. Small lumps and stringers of pearl grey, semi-transparent talc are abundantly scattered through some sections of the peridotite belt.

"The principal discovery was made less than 100 yards southeast of, and a few feet above, the left bank of the river, at a point nearly 450 feet from the southwest contact of the serpentine belt. Here a small segregation of high-grade chromite ore was discovered, apparently mostly dug out. It occurred in part as closely spaced kidneys of chromite 1/2 inch to one inch in diameter, and in part as a heavy dissemination of small, granular aggregates occupying up to 75 per cent or more of the rock volume. The enclosing rock is a dull green, massive, partly serpentinized dunite in which some further alteration to talc and chromiferous chlorite has occurred. Little or no magnetite appeared to be present. Though not of itself economically important, this discovery suggests the possibility of other occurrences in this serpentinized belt. Little clue is furnished as to where to look for such deposits. The rock in the belt is a type that under favourable conditions might prove a valuable source of both chromite and asbestos and, perhaps, rarer minerals such as platinum. The belt should, consequently, be followed in both directions and particular attention paid to it at places where it either widens materially or changes in its general structure or appearance."

The sedimentary rocks in which the peridotite dykes appear are members of the Chapperon group and extend as a narrow belt towards the northwest. Since Cairnes' report many other showings of the serpentinized peridotite dykes (Old Dave intrusions) have been discovered along the belt. A little asbestos occurs in some of these rocks but no chromite segregations comparable to those of the Chrome-Vanadium claims have been seen. At the north end of the belt of Chapperon rocks the age of the peridotite dykes is indicated as pre-Cache Creek by the Salmon River unconformity. Ultramafic rocks are known elsewhere in the map-area but in every place they intrude rocks that are older than the Cache Creek group. The search for deposits in rocks of this type should therefore be confined to areas underlain by members of the Chapperon, Mount Ida, or Monashee groups.

• NON-METALLIC DEPOSITS

GYPSUM

References: Ann. Repts., Minister of Mines, B.C.: 1947, p. 214; 1948, p. 188; 1949, p. 255; 1950, p. 220; 1951, p. 219.

The only commercial occurrence of gypsum known in the Vernon map-area is at Falkland. The deposits were first staked in 1894 but have been mined extensively mostly during the last two decades. The mines, operated by Gypsum, Lime, and Alabastine Co. of Canada, Ltd., are 500 to 800 feet above the valley bottom, on the hill-slopes north and northeast of the village. The gypsum is mined in surface workings, hauled approximately 1 mile from the quarries to a crusher in the village, and stored in bunkers ready for shipment in railroad cars to a processing plant at Port Mann near Vancouver. Among the products manufactured from the Falkland gypsum are: wall-board, lath, plasters, building tile, plaster of Paris, and refractory and thermal insulating materials. The operation produces 300 to 400 tons of gypsum per day and employs about 30 men at Falkland.

The gypsum-bearing bodies are vertical, roughly lenticular units up to 300 feet in diameter and 50 feet thick. The bodies are more or less concordantly enclosed in argillaceous and tuffaceous sedimentary rocks of the Cache Creek group that are of relatively uniform composition and are layered in units of an inch to a foot thick. The strata dip nearly vertically in most places and are, together with the enclosed gypsum bodies, so complexly and closely faulted that none can be traced more than a few hundred feet. These faults are part of the great fault system that crosses South Thompson River at Pritchard and thence passes southeastward through Falkland to Vernon. Most gypsum bodies terminate longitudinally against faults.

Anhydrite is abundantly intermixed with the gypsum in most places and constitutes the chief impurity. The gypsiferous rock varies from massive glistening white to banded greyish white, streaked with dark argillaceous seams and layers. Where uninterrupted by faults the bodies of massive gypsum grade outward into more and more banded types until the peripheral rock can be considered a gypsiferous argillite. Small amounts of pyrite and chalcopyrite commonly accompany the gypsum as disseminated grains or filling cracks.

The gypsum deposits have generally been regarded as of sedimentary origin by previous examiners and by those engaged in the mining, nevertheless the writer believes them to have been formed from hydrothermal solutions. No gypsum has been found anywhere else in the Vernon map-area except north and south along the same fault system. No other evaporites have been found in the map-area, despite abundant exposures of Cache Creek strata. In the vicinity of Falkland, however, and along the fault for a distance of a few miles, both sedimentary and volcanic rocks contain numerous fissures and cavities filled with gypsum. Although the layered appearance of the gypsiferous rock in the mines suggests a sedimentary origin, in places argillite beds can be seen to grade into banded gypsum along strike, the gypsum apparently having replaced the argillite. All these factors and the association of gypsum with sulphide mineralization suggest that these deposits are the results of wholesale replacement and minor vein filling by hydrothermal solutions, following along the system of faults from a centre near Falkland. Renewed movement on the faults later fractured the deposits.

The Falkland gypsum deposits are mineralogically and geographically unique in the Vernon map-area and may therefore have an origin and age different from that of most of the mineralization. Tuktakamin and Estekwalan Mountains are thick piles of volcanic lava and breccia that are remnants of a dissected Tertiary volcano. The main central pipe or conduit of that volcano lies just west of Falkland. Gaseous and hydrothermal emanations associated with the outpouring of lava and tuff may have ascended along the adjacent fault zone during that period of volcanic activity and possibly were the agents of mineralization.

TALC

Reference: Ann. Rept., Minister of Mines, B.C.: 1951, p. 227.

The Sonny, Barbara-Ann, and Bluff groups of claims are owned by Mountain Minerals Ltd. and are 3¼ miles northeast of Armstrong, 1,000 feet above the valley level. Workings on the claims consist of a small quarry, some stripping, and numerous test pits. The talc occurs as an alteration product of a body of serpentinized peridotite, which appears to be a sill in the series of quartz-mica schist, hornblende gneiss, and limestone. The rock is generally iron-stained and contains some carbonate, actinolite, and tremolite. An analysis of a sample of ore returned 71 per cent talc, 14 per cent magnesite, 2½ per cent calcite, and 6¼ per cent magnetite. Small shipments have been made on an experimental basis.

MICA

Reference: Ann. Rept., Minister of Mines, B.C.: 1950, p. 226.

The Bret and Bird group of claims lies north of Sneezby Creek, 1 mile east of the crossing of the highway and railway north of Armstrong. The workings consist of small open-cuts and a short adit. The mica is muscovite in an irregular body of pegmatite that cuts across the layering of the intruded gneiss. The sheets of mica are 1/16 inch to 5 inches in diameter and are mostly greenish, twinned, and fractured. During the last two decades about 100 tons of ore have been shipped for the extraction of scrap mica.

Muscovite schists that are potential sources of scrap mica occur in several places in the western half of the map-area. Some of the more highly metamorphosed parts of the Silver Creek and Mara formations, in particular, contain highly micaceous schists. Some of these schists were seen at the following places: the hills immediately west of Enderby; the hills flanking the Salmon River Valley, 8 miles south of the city of Salmon Arm; and the shores of Salmon Arm.

Most of the pegmatites in the Monashee group are relatively devoid of mica. In a few places, however, some contain enough muscovite to make the extraction for scrap mica worth considering. Such pegmatites occur in the hills east of the Vernon-Enderby highway, in the south end of the Silver Hills, and in the hills east of Sugar Lake. Books of amber sheet-mica up to 8 inches across have been seen in pegmatites on Mount Griffin, 6 miles west of Three Valley, but the amount is small and the mica is fractured and twinned, and has inclusions.

PALAGONITE

Reference: Ann. Rept., Minister of Mines, B.C.: 1946, p. 207.

The crest of Tuktakamin Mountain is reported to consist of palagonite breccia which, like perlite, might be used as expanded insulating material.
basis.

MARL

The Marlime Company of New Westminster, B.C., operated a marl pit at Solsqua, about 10 miles east of Sicamous, during the years 1948-50. The workings consisted of an open pit operated with a bulldozer and small power-loader, an ore cable-car on an incline track, and a mill in which the marl was crushed, kiln-dried, and bagged for shipment. The finished product was sold as a soluble agricultural lime. The marl or travertine occurs in a blanket-like deposit up to 10 feet deep, more or less on the surface but some parts contain much inorganic soil and are not commercial. The marl was evidently deposited from groundwater seepage that had picked up lime while seeping through calcareous rock. No limestone outcrops in the immediate vicinity of the deposit but it is known to be a plentiful component of the rocks in the region.

Smaller deposits of marl, similar to that at Solsqua, occur near limestone in many places in the map-area. One such occurrence, that might be worth investigation, appears in the highway-cuts about 2½ miles east of Canoe on the south shore of Salmon Arm.

CERAMIC CLAY

References: Ann. Rept., Minister of Mines, B.C.: 1920, p. 169; Geol. Surv., Canada, Mem. 24E-25, pp. 118-120.

Clays that might be used for ceramic purposes occur in many parts of the map-area but have been exploited in only a few. At least two brick-works have operated near Vernon, and others have been located at Enderby and Falkland. Most of the main valleys have benches of glacial clay along parts of their courses, but most of this glacial clay contains too much sand, silt and other impurities to be of much value.

Cairnes (1932) comments as follows: "Glacial and post-Glacial clay and silt are abundant in Okanagan valley and have been employed to some extent in the manufacture of brick. Probably the most successful and prolonged effort of this sort was made about a mile north of Enderby, on a branch line of the Canadian Pacific railway about 25 miles south of Sicamous and 9 miles north of Armstrong. Here the Enderby Brick and Tile Company developed a clay bed forming part of the Shuswap River terrace. This was a stratified, calcareous, yellow clay strongly impregnated with iron oxide, somewhat silty, and containing an abundance of mica scales. The bed is replaced laterally by sand. It made a good, hard, red brick of which some 331 M were kilned in 1920. The product was shipped south as far as Kelowna and east along the main line of the Canadian Pacific railway to Revelstoke.

"A number of years ago a brick plant was operated at Vernon near the junction of the Coldstream and Long Lake roads. This plant is reported to have manufactured brick from a section several feet thick, of rather silty, banded, glacial clays, an exposure of which may be seen in an old pit on the north side of the Coldstream road.

"In 1920 the Lakeside Clay Products Company, Limited, was formed to work a clay deposit near Okanagan Landing. During the summer a plant was installed for production of brick and some kilns fired. It was the intention of the company to manufacture drain and hollow tile as soon as developments warranted. Some good tile were made from samples of the clay, but, so far as could be learned, no production is reported."

FELDSPAR

Reference: B.C. Dept. of Mines, Bull. No. 30, 1952, p. 36.

The pegmatites that abound among the Shuswap rocks contain much feldspar, but none has been exploited so far. One, near Lumby, was found to have a low iron content, but nothing further seems to have been done with the deposit. Some apparently large pegmatites along the road west of Sicamous contain crystals of feldspar up to 1 foot across and are relatively free of mica.

FLUORITE

Reference: Geol. Surv., Canada, Rept. of Prog. 1877-78, p. 101.

Fluorite is found in small veins in the rocks surrounding Little Shuswap Lake. Although this mineral was reported many years ago no deposit of commercial size has been found.

GARNET

Garnetiferous rocks are ubiquitous among the gneisses of the Monashee group, but it is doubtful if any are of commercial interest in view of the limited market and the transportation difficulties.

GRAVEL AND SAND

Gravel and sand suitable for road metal and concrete aggregate are readily available in moderate quantities in most parts of the map-area. They are mostly fluvioglacial origin and generally occur in benches above the level of the present streams.

BUILDING STONE

References: Parks, W.A., Building and Ornamental Stones of Canada; Mines Branch, Dept. of Mines, Canada, vol. 5, pp. 66-70.

The only rocks in Vernon map-area that appear to be suitable for building or dimension stone are granite and gneiss. The slates are of poor quality and most of the sandstones, limestones, and volcanic rocks are cut by close-spaced, criss-crossing fractures. Although many of the gneisses of the Monashee group would be structurally satisfactory, they are not as attractive in appearance as many of the granites. Among the best stones for ornamental purposes are the pink granites that lie on the eastern shore of Okanagan Lake and the porphyritic granite in the southeast corner of the map-area.

None of the quarries that have been worked in the area is operating at present. Cairnes (1932) described three granite quarries in the northern Okanagan as follows: "Three granite quarries have been opened up in the northern Okanagan valley, two on the east side of Okanagan lake a few miles south of Okanagan Landing and a third about 2 miles west of Armstrong, close to the Canadian National railway. The two quarries on the lake are in a coarse, pink and white granite which forms part of a body of Tertiary, granitic rocks. These quarries are fully described by Parks from whose report much of the following information has been obtained.

"The more northerly (Benjamin Lefroy) quarry, about 4 miles south of Okanagan Landing, is 50 feet long with a maximum face of 20 feet. Distinct sheeting is not shown, but the upper part of the face is cut by close-set, arching partings conforming to the contour of the hill. A strong set of vertical joints run north and south. Other vertical joints cross in a southeasterly direction. Though the site gives no promise of yielding really large blocks, the stone has a good rift and grain and is practically devoid of knots or flaws.

"The stone is a dull, light reddish granite, lacking in 'liveness'. It is rather coarse in grain, with feldspar crystals up to 8 mm. in diameter. Quartz is much less abundant than the feldspar and the dark mineral, biotite, is in relatively small amount. The microscope shows large orthoclase crystals in a semi-decomposed condition, some plagioclase, biotite, and a few grains of olivine. The specific gravity of the rock is 2.643. This rock has been employed to good advantage in the construction of such buildings as the railway station, post office, and Hudson's Bay Company store in Vernon, and the Church of England and the Royal Bank at Kelowna. The Vernon post office shows a uniform and pleasing pinkish tint without any sign of knots, flaws, or iron-staining.

"The more southerly quarry, about 6 miles south of Okanagan Landing, is operated by the Vernon Granite and Marble works, and was opened up subsequent to the Lefroy quarry, about 1910. It is about 75 feet long, parallel to the shore, about 50 feet wide, and 30 feet deep.

"The sheeting is irregular and poorly developed at the north end. Near the middle, at the top of the face, the sheets seem to dip east at about 30 degrees. The main joints strike north 20 degrees, west, dip 85 degrees westerly, and are widely spaced, thus permitting the quarrying of large stone. The rift of the granite is vertical at north 15 degrees east and is, therefore, not parallel to the main jointing. In the rear of the present workings some good outcrops were observed and doubtless many others could be found in the region.

"The granite in this quarry is, on the whole, brighter, fresher, and somewhat coarser than that obtained from the Lefroy property. Its mineral constituents are quartz, orthoclase feldspar, in crystals up to 10 mm. long, plagioclase, in less amount, and black mica or biotite with a little green chloritic matter. A little pyrite was also observed, but does not appear to have formed any rust spots.

"Much of the production from this quarry was used for the court house in Vernon. Small amounts have been used for monuments, chiefly for bases. The court house is a splendid building with a pleasing, slightly pinkish colour; it shows less disfiguration due to knots, veinlets, etc., than most of the granite structures in British Columbia. The building bears the date 1914.

"The Lumsden quarry near Armstrong is in a body of medium- to fine-grained, light grey granite. This stone has a good rift and grain, and is worked with facility. Unfortunately, it contains an undue amount of pyrite, with the result that all cut stone becomes badly spotted after a short period of weathering. A small amount of this stone has been used for monumental bases. It was employed for the base of the Bank of Montreal building, Vernon."

AGATE

Nodules of agate weather out of some of the Tertiary volcanic rocks that comprise the prominent hill known as Camels Hump, 10 miles east of Lumby. The agate is banded in shades of grey and black and is not attractive for decorative purposes, but, as it occurs in solid nodules up to 6 inches in diameter, it could be used for chemical laboratory instruments. Small veinlets of opal, also, are found here and there among the Tertiary lavas but are not of quality or quantity to be of value.

SILLIMANITE, KYANITE, AND STAUROLITE

Sillimanite is found throughout the gneisses of the Monashee group, but was nowhere seen to constitute more than a few per cent of the rock. Nevertheless, there may be layers of schist or gneiss containing sillimanite in commercial quantities. The mineral generally occurs as white fibres together with reddish brown biotite in thin schist layers between granitoid gneisses, but in a few places is in prisms up to an inch in length and ⅛ inch in diameter.

Kyanite is relatively rare as compared with sillimanite. It has, however, been recognized at the following localities; 2 miles southwest of Sugar Lake, 5 miles southeast of Sugar Lake, the hills east of Armstrong, and near Revelstoke. In each of these places it occurs as a minor constituent in schist, pegmatite, or vein quartz, although the individual, bladed, blue crystals commonly attain lengths of 2 inches or more.

Staurolite is the most spectacular of the three minerals as the large, dark crystals stand out conspicuously against the lighter coloured host rock. It occurs with kyanite at the localities mentioned above, thick prisms up to 3 inches long being common. The mineral is reddish brown to black and commonly exhibits the characteristic cruciform twinning. The amount of kyanite and staurolite in any of the rocks was not enough to suggest the possibility of commercial extraction, but richer deposits may exist in the area.

TOURMALINE AND BERYL

Many pegmatite dykes in the vicinity of Mount Begbie south of Revelstoke bear conspicuous amounts of black tourmaline (schorlite) in thick, prismatic crystals up to 3 inches long. One small dyke on the northeast side of the peak, on the lower edge of the great snowfield, carries not only schorlite but also green and red varieties of tourmaline, green beryl, red garnet, and lepidolite. The crystals of tourmaline are scattered and small (up to 1 inch long) and the dyke itself is nowhere more than 5 feet wide. Although this dyke does not appear to be of any commercial interest, larger and richer dykes may occur in the vicinity. Tourmaline-bearing pegmatites are especially abundant in and near the laminated quartzites that cap Mount Begbie and that appear in places as far south as Blanket Mountain. This quartzite also carries disseminated tourmaline as an accessory component and should, perhaps, be prospected for this and other minerals in pegmatites.

QUARTZITE

Pure, coarsely crystalline quartzite is common among strata of the Monashee group. These rocks are free from iron-bearing minerals, appear translucent white in hand specimen, and are so homogeneous as to be almost devoid of internal bedding or lamination. Such quartzite may be a potential source of silica for industrial uses where a high degree of purity is demanded. Relatively pure quartzites occur at; Clanwilliam (Summit) Lake, Victor Lake, the southeast foot of Mount Odin, and the ridge west of Upper Arrow Lake north of Pingston Creek.

CARBON DIOXIDE

A bubbling spring is located in Mara Lake just south of Black Point and has been active since early Indian times. The gas that issues from this spring is largely carbon dioxide. Rumour states that a company intends to capture the natural gas, compress it, and market it for industrial use.

COAL

References: Ann. Repts., Minister of Mines, B.C.: 1905, p. 193; 1911, p. 180; 1913, p. 179.

The coal prospects on Shorts Creek and near Enderby have been examined and described in detail by Cairnes, and similar small Tertiary coal deposits have been noted elsewhere in the map-area. The sedimentary rocks in which the coal deposits occur lie at the base of the Kamloops lava flows or between the flows. The areas of such rocks are small and it is unlikely that coal deposits of commercial size occur in them. About the deposits in general, Cairnes (1932, p. 100A) says:

"The question as to whether economic deposits of coal might not be found in northern Okanagan Lake district is one that has not only aroused some interest, but has resulted in the expenditure of considerable time and money in exploratory work. For many years it has been common knowledge that the Tertiary sedimentary rocks of the district carry some coal. After visiting a number of reported occurrences and discovering others, it appears to the writer that in most instances the deposits are seams varying from a few inches to over a foot in thickness, composed of alternating thin layers of coal and sandstone or shale. In other instances, the so-called coal seams are merely strata containing abundant, partly to completely, carbonized fossil remains of plants. In neither case are the deposits of commercial value, but the first type may represent horizons which elsewhere hold thicker, more valuable coal seams. At two localities where considerable exploratory work has been done, special conditions seem to have obtained, and although in one case the occurrence must be labelled as of doubtful, and the other as of even less possible value they each warrant further discussion."

• CONCLUSION

Although mining is not and has never been a major industry in Vernon map-area, there is some hope that it may increase in importance. The Big Ledge property has an excellent chance of becoming a large zinc mine, and, although none of the known precious metal prospects appears too promising, there is no known geological reason why better deposits may not yet be found. The faults that determine the loci of mineralization notably lie along wide valleys filled with alluvium and do not, for most of their lengths, have outcrop near them. It is very probable that many vein deposits are hidden by this overburden and some, at least, may be economically important. Placer mining, on the other hand, will probably never regain the place it once held during the gold rush days of Cherry, Siwash, and Scotch Creeks. All the best gravels have been already worked and are not extensive enough to warrant reworking by more efficient modern methods. Nevertheless, new, small deposits that can be profitably worked on a small scale will probably be found. The outlook for non-metallic deposits is more encouraging. If the high cost of transportation can be offset by establishing local processing plants and local markets it may be possible to exploit deposits of feldspar, mica, sillimanite, limestone, clay and the like.

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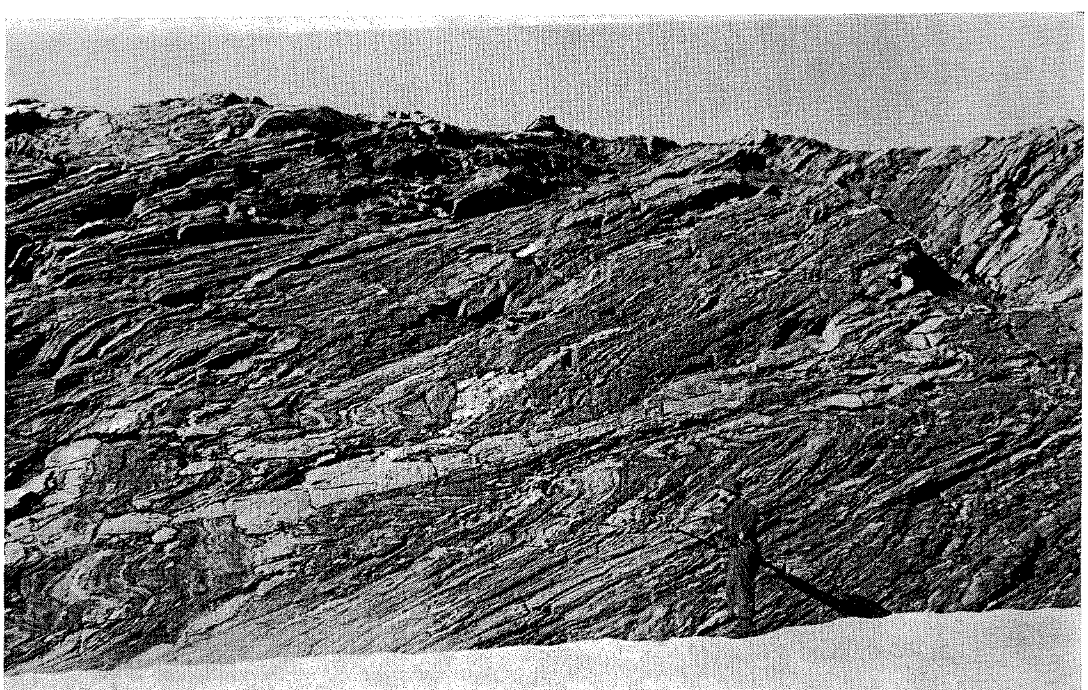
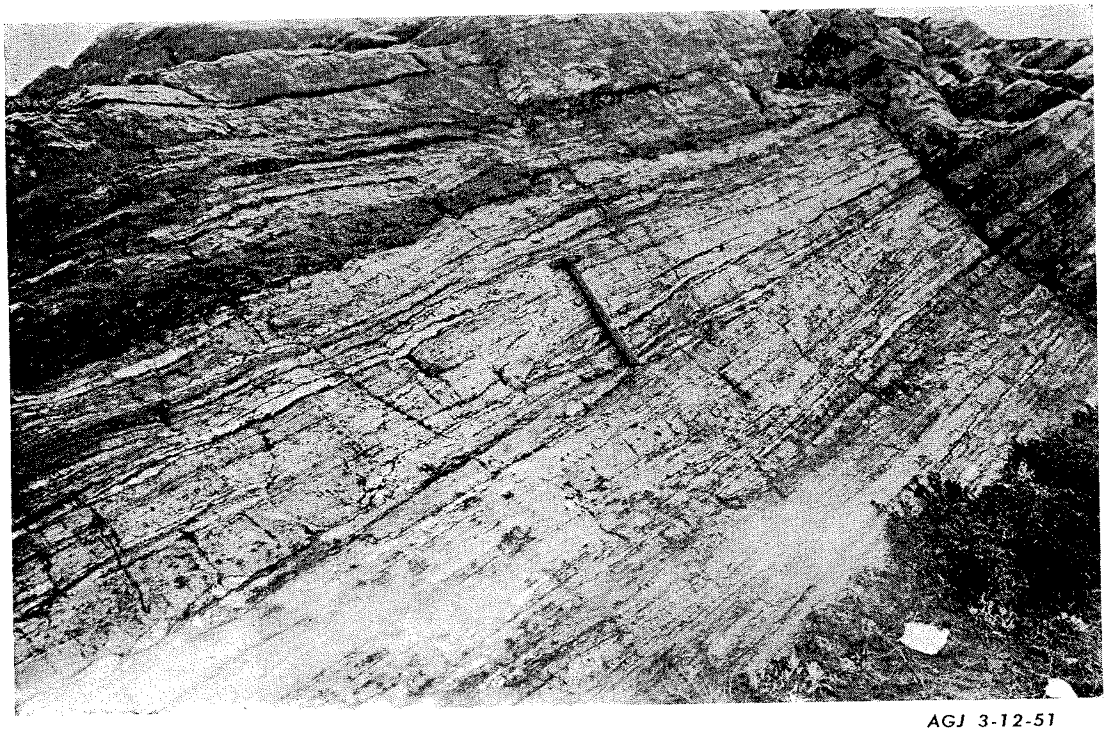
AGJ 23-8-49

Plate II A. *Typical view of Monashee Mountains. Looking south along Gold Range from Cranberry Mountain; farthest peaks visible are elements of the Pinnacle Peaks, almost 50 miles distant and lying in southeast quadrant of the map-area*

Plate II B. *Overturned recumbent folds in middle limb of the Fosthall Mountain fold, near Big Ledge mineral property. Pegmatitic granite dyke (white) belongs to the syntectonic Silver Star intrusions. Note that the dyke occupies one of the axial plane shears but is, itself, recumbently folded (above man's head).*

AGJ 8-10-51



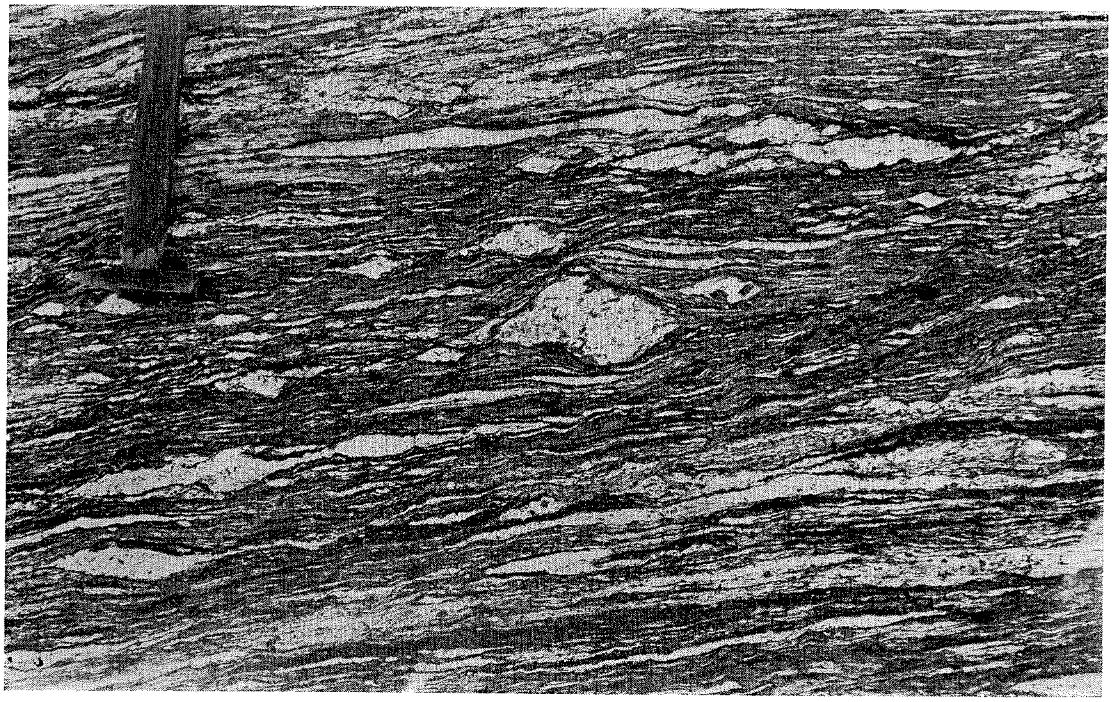


AGJ 3-12-51

Plate III A. Typical banded gneiss of the Monashee group. Note lenticular form of pegmatite units (white) and boudinage of garnetiferous hornblendite (dark).

Plate III B. Highly deformed calcareous gneiss and schist enclosing lenses of quartz and remnants of original bedding. Drag-folds are visible only on close inspection of outcrop.

AGJ 12-2-51

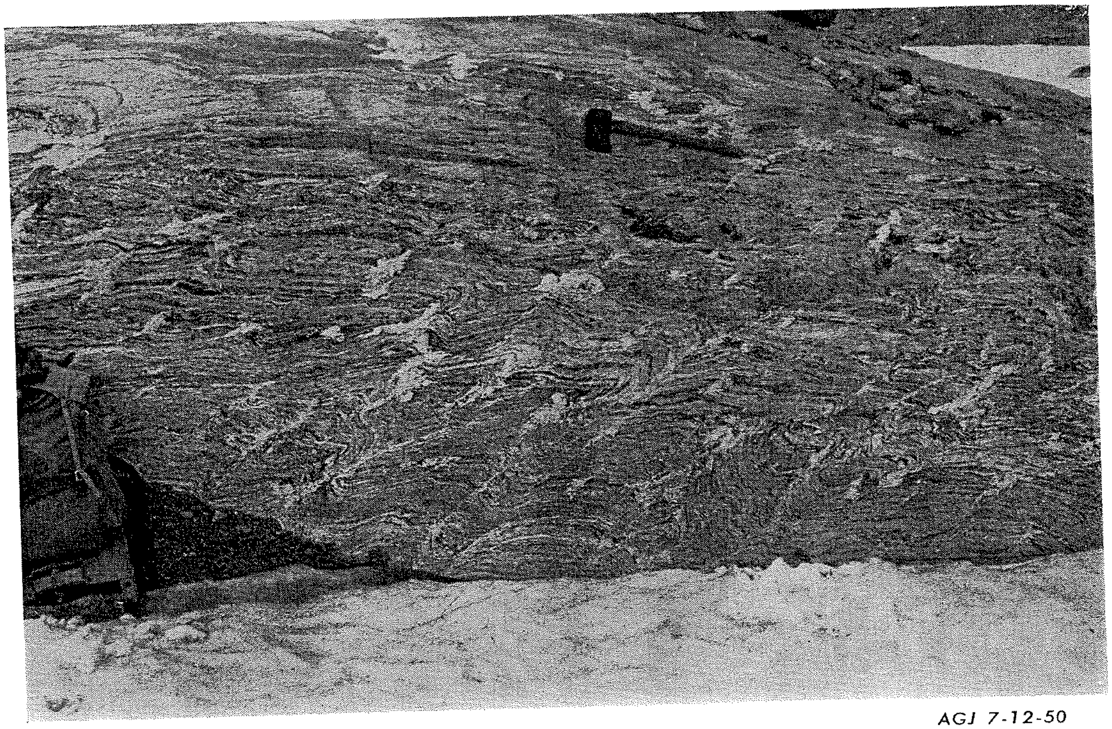


AGJ 9-3-51

Plate IV A. *Typical augen gneiss composed of sillimanite, biotite, quartz, and pegmatitic feldspar.*

Plate IV B. *Sill of sheeted pegmatite.*

AGJ 3-1-51

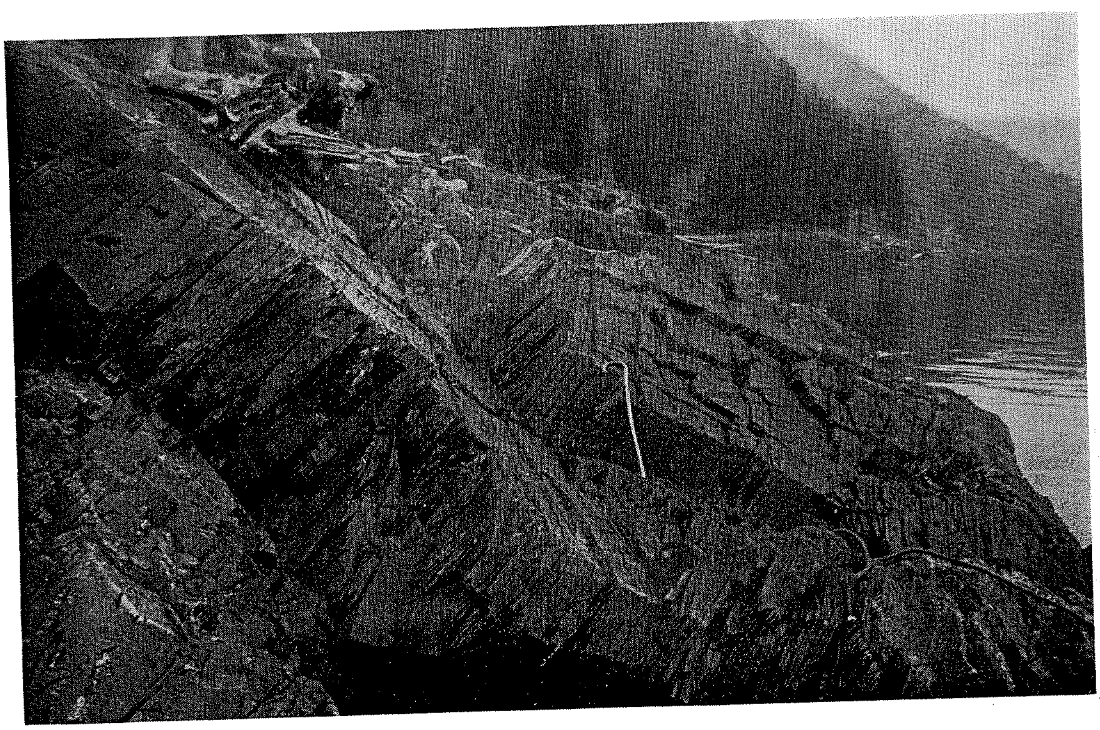


AGJ 7-12-50

Plate V A. Shear planes of the Younger deformation cutting obliquely across bedding and foliation of the Older deformation; fractures are partly pegmatite-filled; Blanket Mountain.

Plate V B. Typical "flow-cleavage" foliation in quartzitic argillite of the Eagle Bay formation; Shuswap Lake.

AGJ 24-1-49



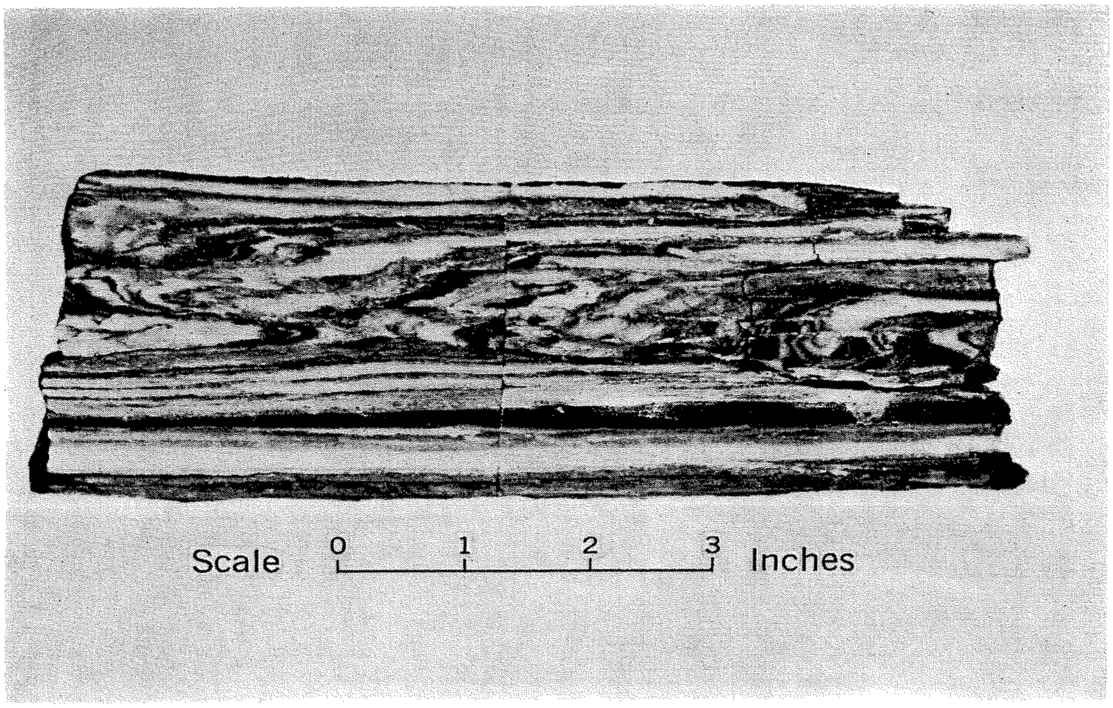


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Plate VI A. *Drag-folds and cleavage within a bedding plate of Sicamous limestone. Note that folding is confined to inside layer and that cleavage is parallel with bedding.*

Plate VI B. *Drag-folds in layered biotite gneiss. Note that middle layer is enclosed by unfolded layers of augen gneiss and that axial planes are parallel with main stratification; Mount Odin.*

AGJ 6-10-51

AGJ 24-10-49

Plate VII A. *Recumbent folds in quartzitic gneisses of the Queest Mountain block. Note that axial planes are parallel with the main stratification; east shore of Shuswap Lake.*

Plate VII B. *Recumbent drag-folds in marble, calcareous quartzite, and biotite gneiss; west of Blanket Mountain. Block is 2 feet high.*

AGJ 10-6-49

AGJ 9-8-51

Plate VIII A. *Rodded structure in biotite gneiss and quartzite in the core-zone of the Fosthall Mountain anticline. The rods are horizontal and parallel with the fold axis; south of Mount Odin. Cliff is about 40 feet high.*

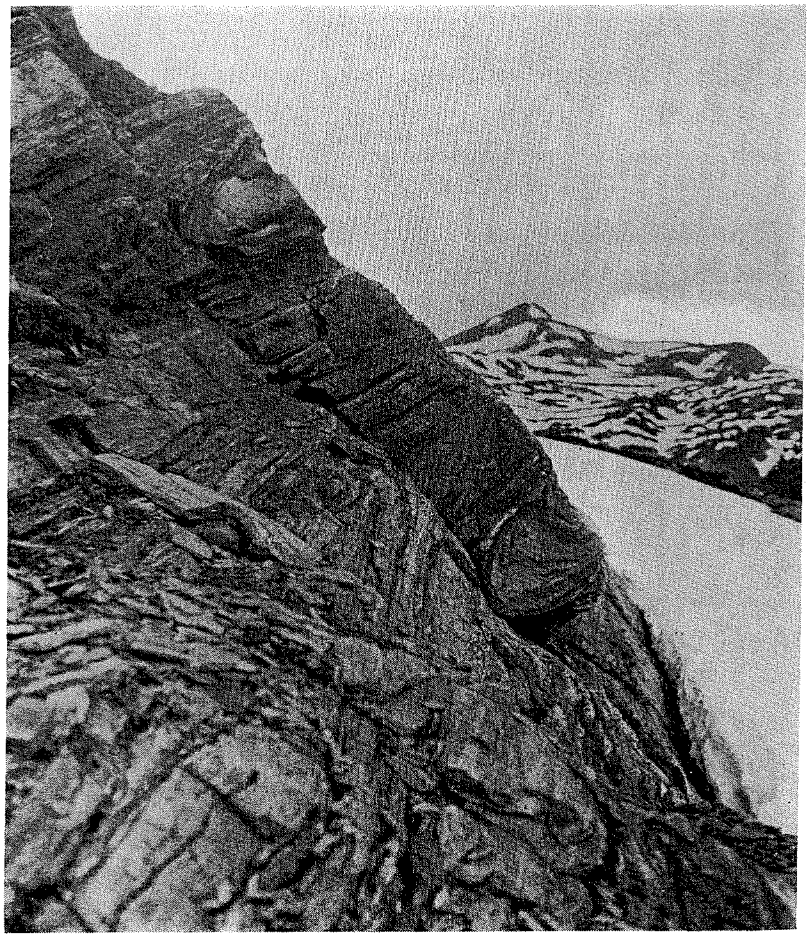
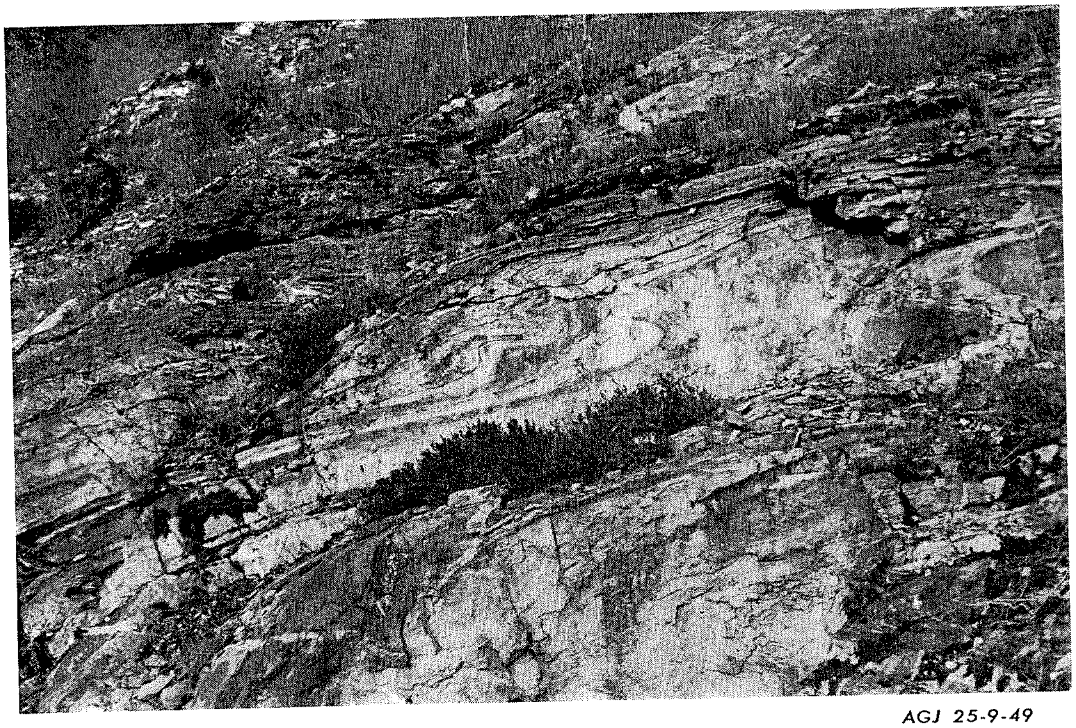


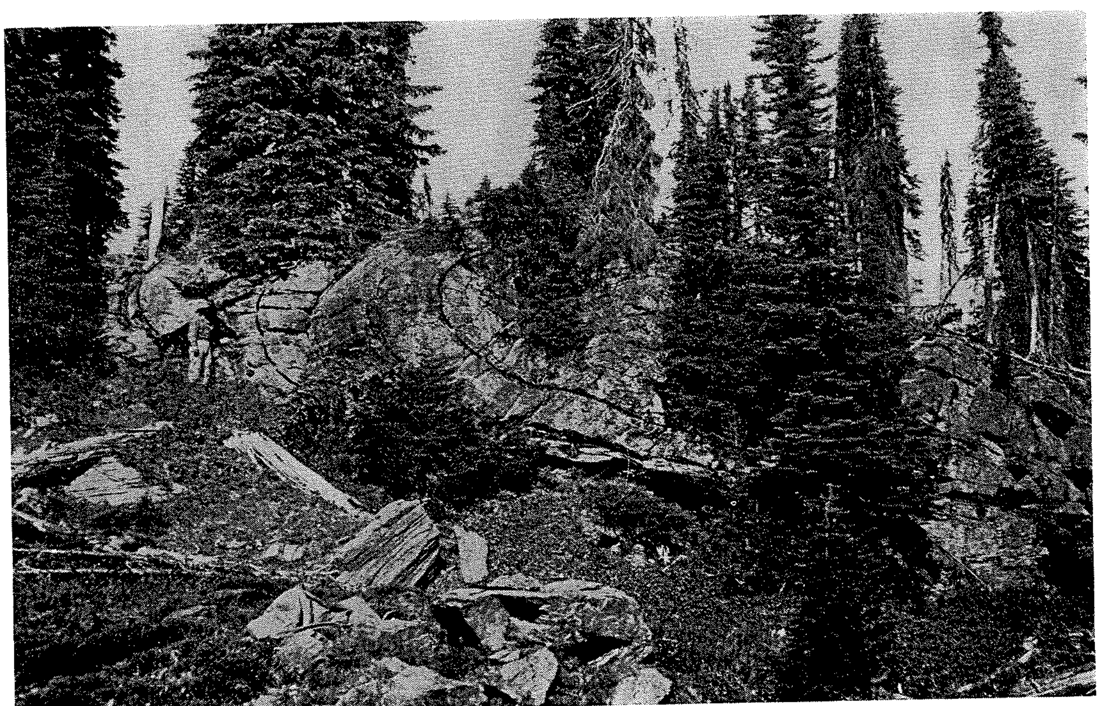
Plate VIII B. *Core-zone folds which give rise to rodded structure in Fosthall Mountain anticline. View is parallel with the fold axis, looking west, and Fosthall Mountain is in background, about 2 miles distant.*

AGJ 3-4-51



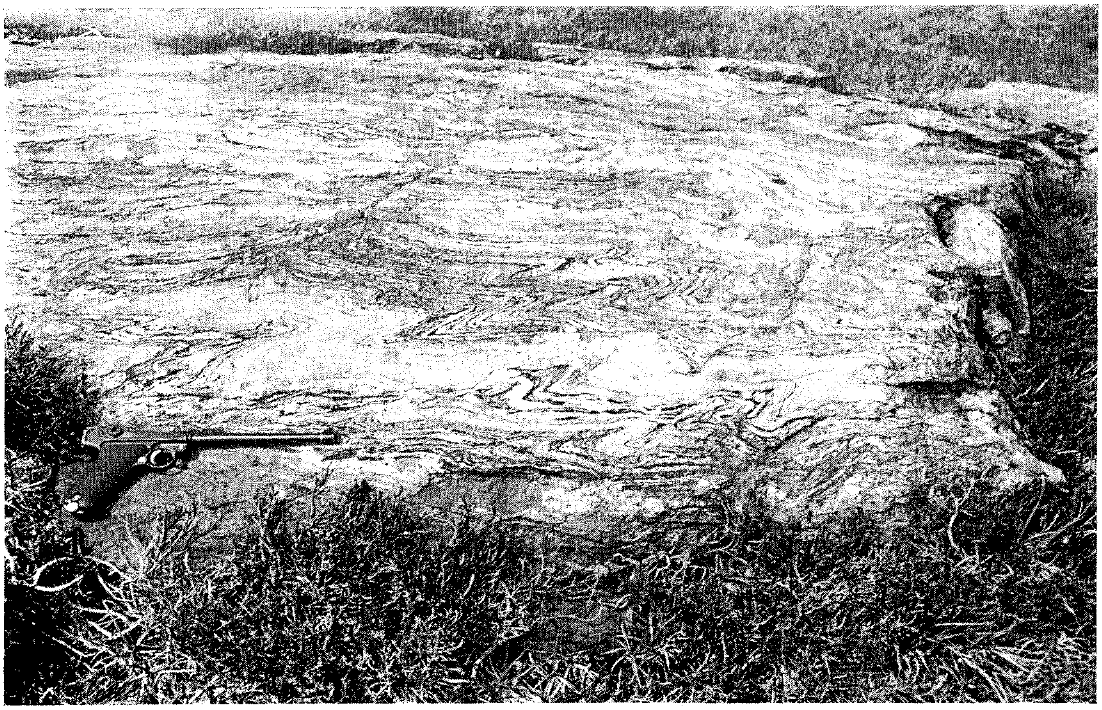
AGJ 25-9-49

Plate IX A. Recumbent drag-folds in biotite gneiss; Mara Lake.



AGJ 4-3-50

Plate IX B. Crest of recumbent fold in hornblende gneiss; Mabel Range.

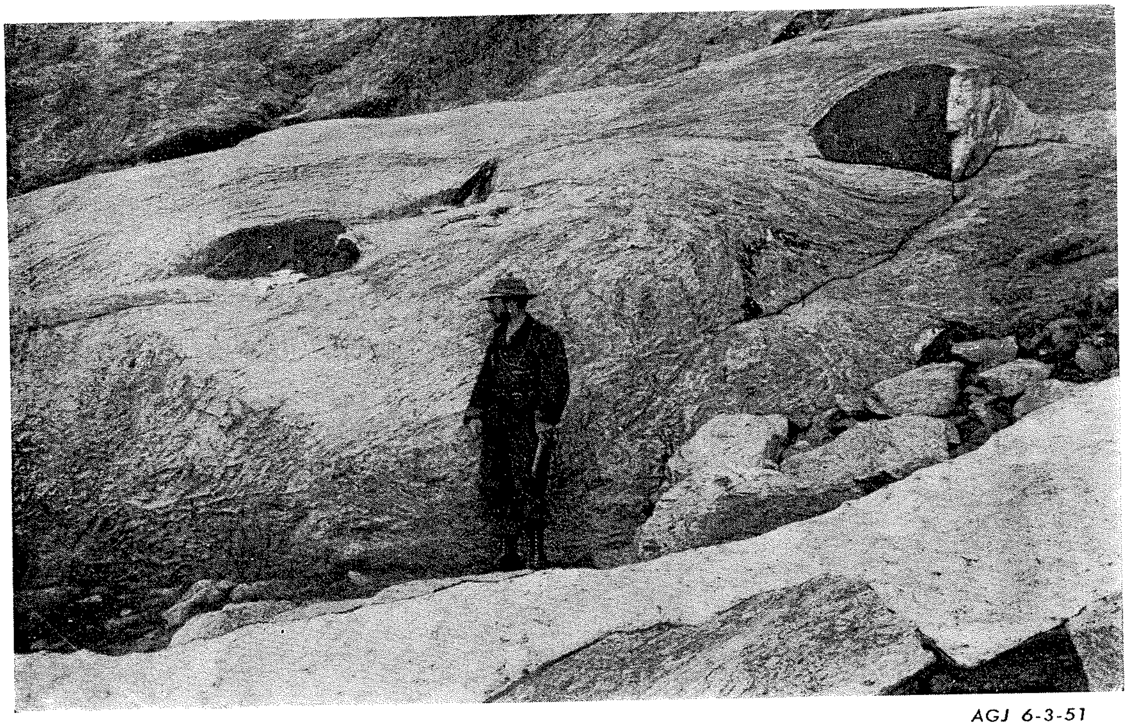


AGJ 7-9-50

Plate X A. *Shear-folding of the Younger deformation in biotite gneiss and schist; Blanket Mountain. Barrel of pistol is 7 ½ inches long.*

AGJ 10-1-49

Plate X B. *Boudinage containing a swarm of amphibolite fragments laced with pegmatite, surrounded by mica gneiss. Note that pegmatite appears to be replacing amphibolite along fractures.*

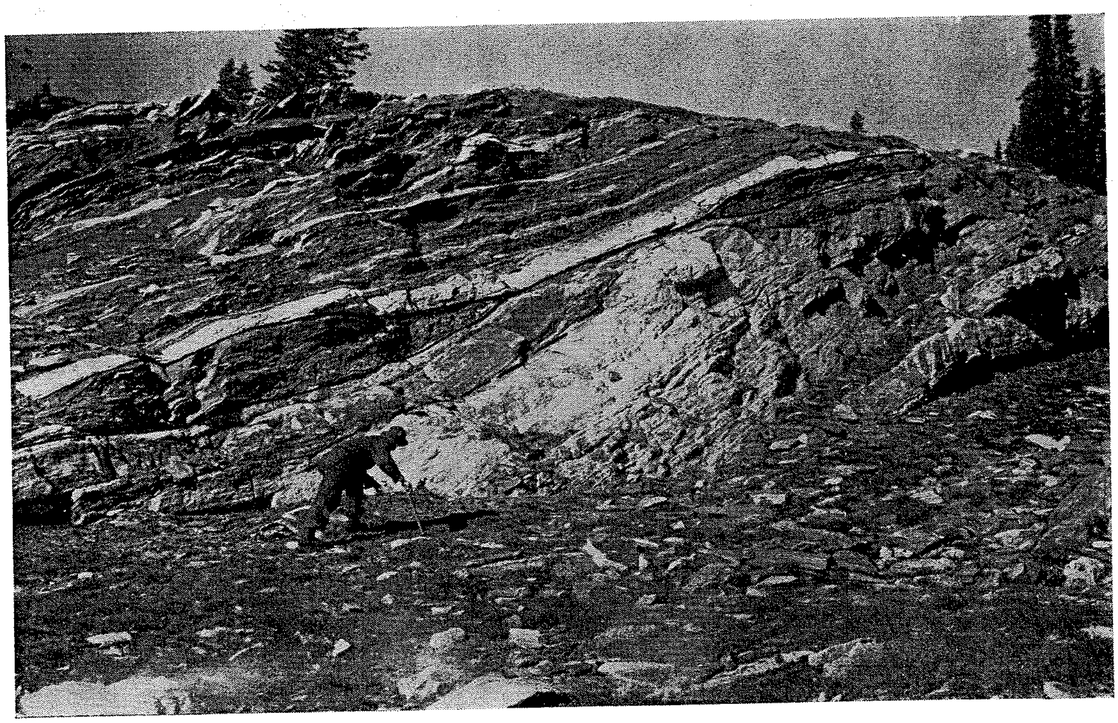


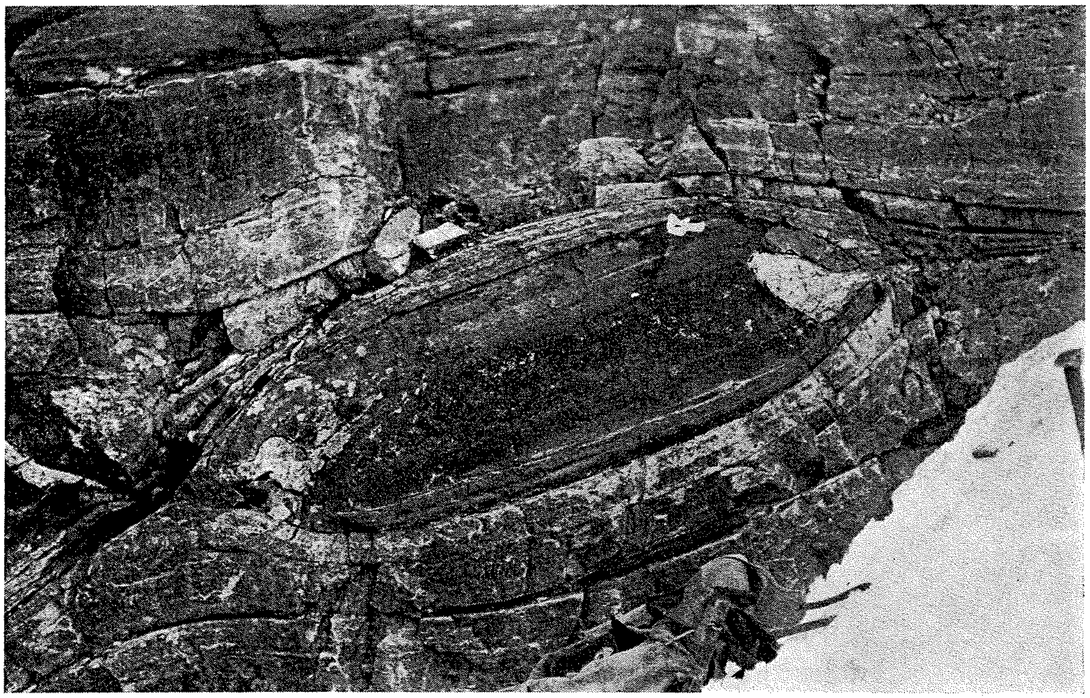
AGJ 6-3-51

Plate XI A. *Rounded hornblendite boudins with pegmatite scars in much-folded granitoid gneiss host; Mount Odin.*

Plate XI B. *Large boudins of hornblende-garnet gneiss enclosed in biotite gneiss and sillimanite schist. Note tapering ends to boudins; middle limb of Fosthall Mountain fold south of Mount Odin.*

AGJ 8-7-51



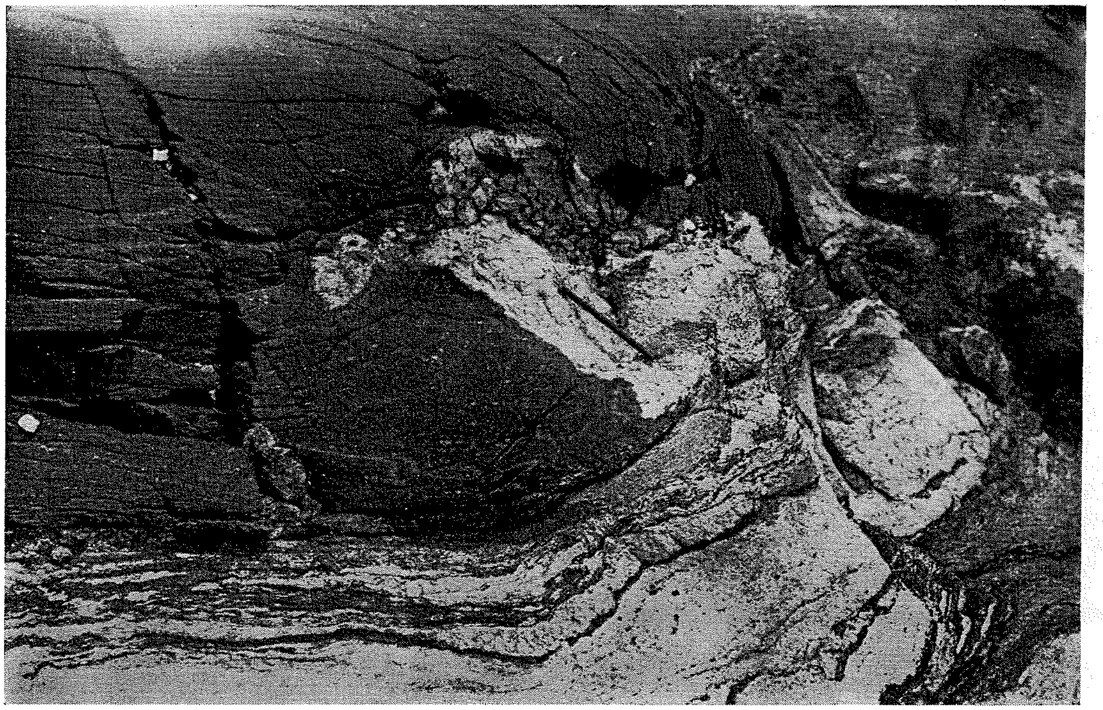


AGJ 4-11-49

Plate XII A. *Boudin of amphibolite sill tightly enclosed in quartzite host. Note pegmatite-filled re-entrants and marginal foliation. Cliff section trends perpendicular to lineation and fold axes; Mount Tilley. Boudin is about 2 feet high.*

Plate XII B. *Garnetiferous amphibolite boudin in feldspathic mica gneiss. Note pegmatite-filled re-entrant and marginal foliation; Blanket Mountain.*

AGJ 22-7-49



AGJ 4-12-49

Plate XIII A. Rhombic boudin of gneissic quartzite in mica gneiss. Note the rotation of the long diagonal into parallelism with foliation. The section is perpendicular to lineation; the shear-sense is given by nearby drag-folds. The boudin is about a foot long.

Plate XIII B. Common "beaded" structure in pegmatite (white). The dark host is biotite gneiss and schist; Cranberry Mountain.

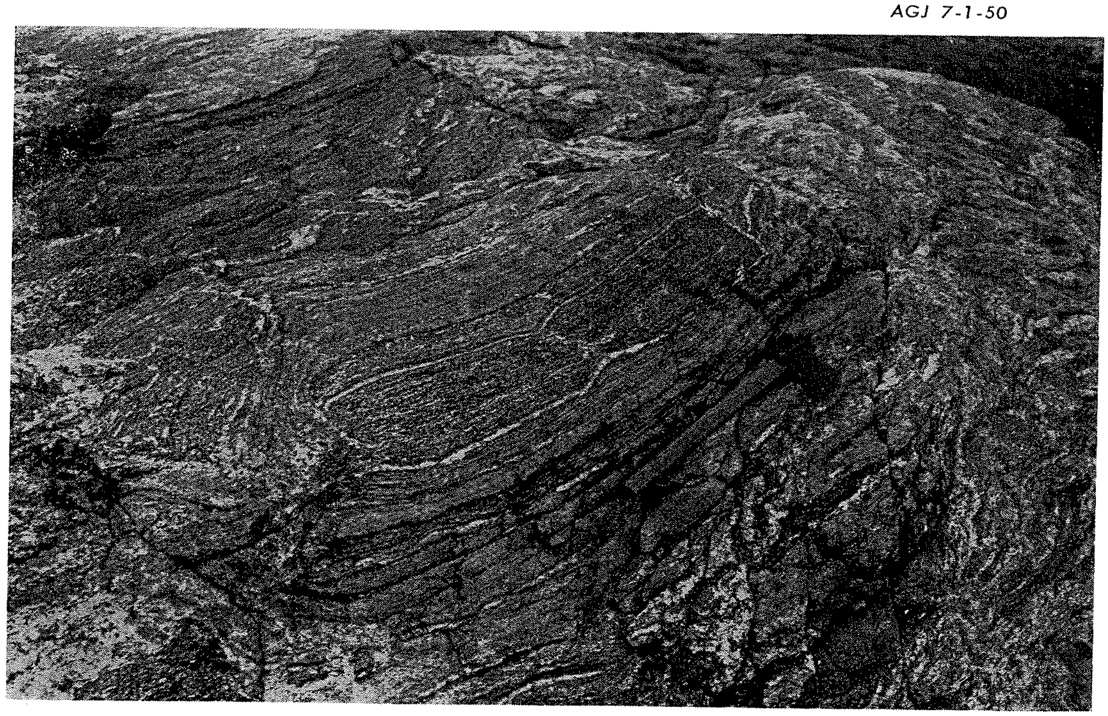
AGJ 23-4-49

AGJ 15-3-49

Plate XIV A. Aplitic granite lenses in amphibole-biotite schist. Drag-fold axes and lineation are parallel with cliff section; Upper Arrow Lake.

Plate XIV B. Boudin of hornblende-garnet gneiss surrounded by biotite gneiss. Note constriction without complete break; Blanket Mountain. Hatchet handle is 16 inches long.

AGJ 7-1-50



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