A BRIEF STUDY OF THE PETROGRAPHY OF THE SHUSWAP-BELTIAN ROCKS OF B. C.

by

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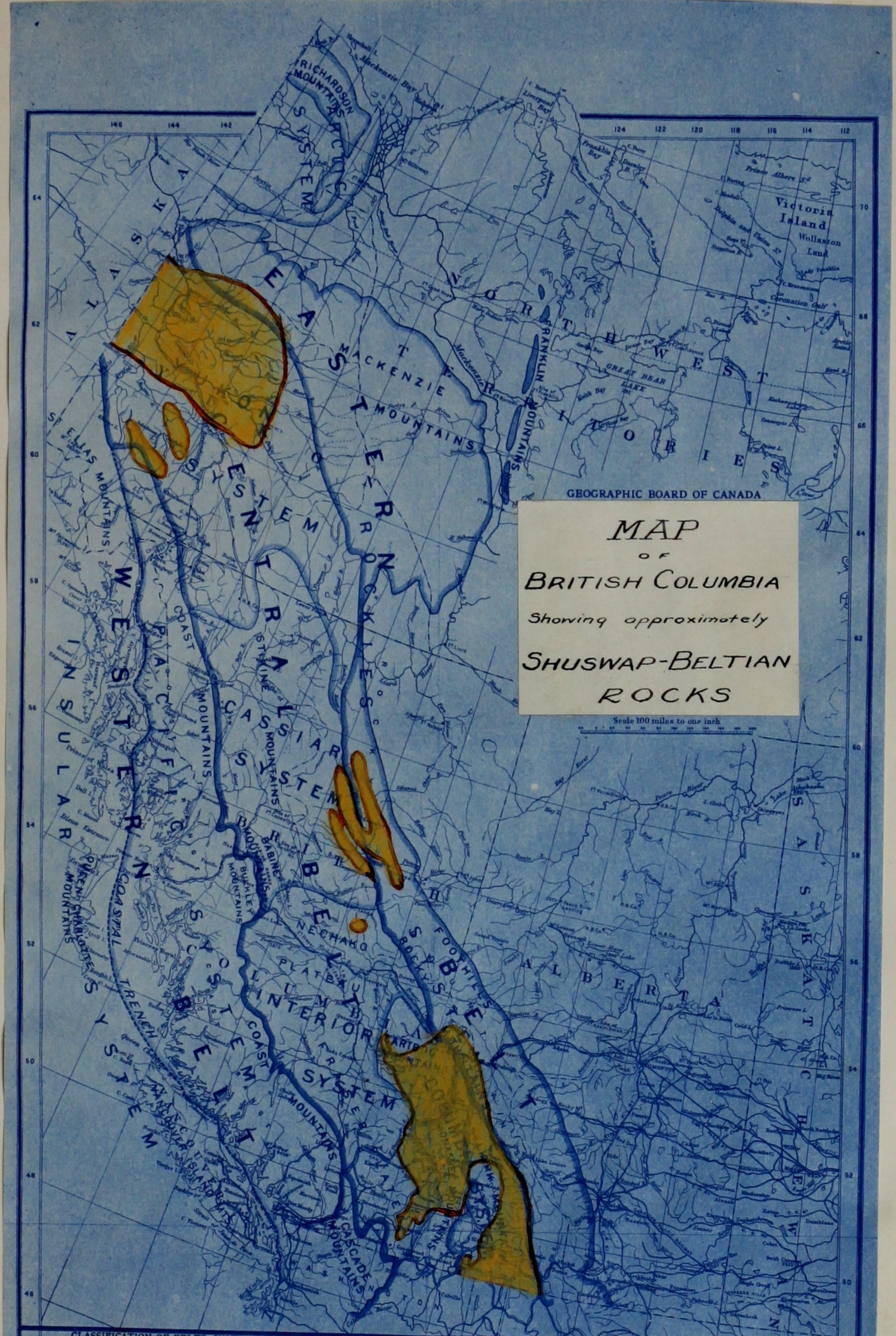

CLASSIFICATION OF BELTS, SYSTEMS, MOUNTAINS OR PLATEAUS, AND RANGES, GROUPS OR PLATEAUS, FORMING THE CORDILLERAS OF CANADA.

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CHAPTER ONE

INTRODUCTION

General Statement

In the interior of British Columbia there is exposed a great area of metamorphic rocks which constitute a large part of the Interior Plateaus, the Gold Range, and the Selkirks. These are the oldest rocks in the province, and form the basement complex for the younger formations.

Dawson, the pioneer geologist in this field, grouped these rocks under the term "Shuswap Series", and believed them to be of Archean age on account of their resemblance to the crystalline rocks of Eastern Canada. Since Dawson's time there has been a great deal of controversy regarding the age of his Shuswap Series, and a large part of it has been proved to be of Beltian age.

These are a very important group of rocks, and they afford a splendid field for the study of regional metamorphism. Although they have been partially studied, such work has been chiefly of the nature of the regional mapping of relatively small, isolated areas, and there has been very little attempt to treat the subject as a whole, or to consolidate the work of others.

Previous work

Although this is a petrographical study, and the writer does not profess to deal with the subject of age and correlation in this paper, a general statement of the problem is considered necessary. For this reason the second chapter is devoted to a brief summary of the previous work.

Field Work

As yet the writer has not had much opportunity for field work. During the field season of 1927 he was a member of a Geological Survey party in the country at the head of the North Thompson River, and travelled up the river from Kamloops to its headwaters. As this area lies within the zone of metamorphic rocks, valuable experience was gained. Besides this, he has had an opportunity of making a certain amount of private investigation in the Okanagan Valley.

Nature of the Present Thesis.

This thesis is essentially petrographical, and is based on the microscopical examination of some seventy-five thin sections, together with a careful study of the available literature.

Leaving the Shuswap Lake section, in the spring of 1927, the writer travelled north, encountering metamorphic rocks throughout the season. He conseived the idea, therefore, of making a microscopical study of these rocks, and collected specimens accordingly. It was found later that many of the specimens from the head of the Thompson River bore a striking resemblance to specimens from the Beltian System of south-eastern British Columbia. It was necessary , therefore, to include a study of the Beltian System, and from this the task has grown until the thesis is now an attempt to deal with the petrography of all the Shuswap and Beltian rocks in the province. This is far from satisfactory, since the writer is not personally familiar with all parts of the province, and it is difficult to obtain a representative suite of specimens, nor can such a subject be done justice to in the short time allotted to a Master's thesis.

The second chapter is devoted to a brief statement of the previous work, in order to give an idea of the problem of age and correlation. This is simply a statement, no attempt being made to work on the problem.

The third chapter contains brief descriptions of the lithology of the various formations.

The next three chapters are devoted to the petrography of the regionally metamorphosed argillaceous, calcareous, and arenaceous rocks respectively, the rocks being grouped according to their mineral constituents. At the end of each chapter will be found a summary of the course on metamorphism.

The next chapter is devoted to miscellaneous rocks.

The last two chapters deal respectively with regional and contact metamorphism in general.

Acknowledgments.

The writer wishes particularly to acknowledge the assistance received from Dr.T.C.Phemister, without which the work would have been impossible. He is also indebted to Dean Brock and Dr. Schofield of the University, and to Dr.Dolmage, Messrs.Guernsey, Goransen, and Blurton for information and the loan of specimens.

Many reports of the Geological Survey of Canada have been consulted, and information from them has been freely em-

bodied in the text. The more outstanding cases have been acknowledged in the text, and the other cases are hereby gratefully acknowledged.

CHAPTER TWO

GENERAL

A large part of the interior of British Columbia is underlain by crystalline rocks, which form the basement complex for the younger formations.

The largest area of these rocks is exposed in the south-eastern part of the province, between the International Boundary and the latitude of Mount Robson, and extending approximately from longitude 120 to the Columbia and Kootenay Rivers. A smaller area outcrops in the vicinity of the Finlay River. A third, and fairly large area is exposed in the Yukon, and is known as the Yukon Series.

The following description of the rocks in the vicinity Shuswap Lake, by G.M.Dawson[1], who made the first intensive study of these metamorphic rocks, will afford a good idea of their general character. Dawson states as follows:

"This series, where typically developed, consists of greyish gneisses, occasionally hornblendic or garnetiferous, glittering mica schists, with beds of crystalline limestone and quartzite. The gneisses, when in association with the last-mentioned beds, are often highly calcareous or siliceous, and generally rusty on weathering, and graphite is often present in these gneisses as well as in the quartzites and limestones. The rocks described undoubtedly represent parts of a bedded series, but are associated with a much greater mass of mica schists,

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1. Marginal notes, Shuswap Sheet, G.S.C. 1898.

gneisses, and granitoid gneisses, many parts of which are evidently foliated granites, from which it is impossible to separate them. The frequent occurrence of quartzites among these latter rocks, however, appears to show that they are at least in part the result of a further alteration of the same bedded series. On the other hand, these granites often pass gradually into unfoliated granites from which they are also inseparable on the map."

Dawson included all these rocks in his "Shuswap Series", and considered them to be of Archean age. The rocks in the eastern part of the southern area already referred to have since proved to be of Beltian age, and are referred to in this paper as the "Beltian Series".

For convenience, the remainder of the rocks under discussion ion are grouped as the "Shuswap Series". The relation of these rocks to the Beltian System has not as yet been demonstrated, but it is probable that at least part of them will eventually be correlated with the Beltian. The age and correlation of these rocks present many difficulties, and while the subject cannot be treated fully in a petrographical paper of this nature, an outline of the work done, in approximate chronological order, will now be given.

PREVIOUS WORK

This subject has been summarized by Schofield in a paper on "The Geological Record of the Cordillera in Canada"[1], from which much of the following information has been taken.

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1. Trans. of the Royal Society of Canada, 1923.

The rocks under discussion were first studied by Selwyn in 1871,[1] who described them as the "granite, gneiss, and mica schists of the North Thompson." He made no statement as to their age.

In 1881 Dawson designated the above rocks as "Archean."

In 1889 Dawson gave the name "Shuswap Series" to a large group of rocks in the West Kootenay district,[1] and on his Shuswap Sheet, 1898, he extends the Shuswap Series to a large group of schists, limestones, and gneisses occurring in the vicinity of Shuswap Lake. He defined the age of the Shuswap Series as Archean, due to its marked similarity to the Laurentian rocks of Eastern Canada.

In 1909 Malloch examined the "granite, gneiss, and mica schists of the North Thompson," in the vicinity of Tete Juane Cache, and expressed doubt as to their Archean age, suggesting alternatively that they might represent the metamorphosed equivalents of the Castle Mountain Series, of Cambrian age.

In 1912 Daly, while mapping the geology along the International Boundary, decided that a group of rocks previously mapped by Brock and McConnell as part of the Selkirk Series of Cambrian or Cambro-Silurian age, were Archean, and renamed them the Priest River Terrane, correlating them with Dawson's Shuswap Series. Daly stated that the Priest River Terrane was overlain unconformably by the Summit Series, part of which he placed in the Beltian.

In 1914 Schofield, working in the vicinity of Kootenay Lake, and having spent the seasons 1909-13 in the Cranbrook Map Area,[1] demonstrated that the Priest River Terrane, in part at least, is simply the more highly metamorphosed equivalent of the Aldridge formation of Beltian Age. This lead to the formulation of a new hypothesis, namely, that the whole of the Shuswap Series is of Beltian age, and that the original sediments laid down in the Cordilleran Trough were derived, not from an Archean land-mass rising out of the Trough, as Dawson advocated, but from a land-mass to the west, Cascadia. This hypothesis, together with that of Dawson, will be discussed later.

In 1914 Schofield also worked on the Beltian rocks in the Ainsworth Map Area.[2]

In 1915 Daly,[3] while studying the section along the Canadian Pacific Railway between Golden and Kamloops, remapped part of Dawson's Shuswap Sheet in the vicinity of Shuswap Lake, and, like Dawson, classed the metamorphic rocks as Archean. He also placed the Nisconlith and Adams Lake Series, which Dawson regarded as Cambrian, as the upper members of the Shuswap Series. This section has been worked out in greater detail than any other part of the Shuswap Series, and so is of great value.

In 1911-12 D.D.Cairnes[4] gave the term "Yukon Group" to a large area of metamorphic rocks in the Yukon. The age of these rocks was determined as pre-Middle Cambrian. More recent work was done on the Yukon Group, in the Whitehorse District, by Cockfield and Bell,[5] in 1922-24.

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1. S.J.Schofield, G.S.C. Memoir 76.
2. S.J.Schofield, G.S.C. Memoir 117.
3. R.A.Daly, G.S.C. Memoir 68.
4. D.D.Cairnes, G.S.C. Memoir 67.
5. W.E.Cockfield and A.H.Bell, G.S.C.Memoir 150.

In 1921 the late W.L.Uglow made a study of the southern part of the North Thompson Valley.[1] The oldest rocks in this district had been mapped previously by Dawson as belonging to the Nisconlith and Adams Lake Series. Uglow stated the age of these rocks as "Paleozoic or Precambrian".

During the seasons of 1921 to 1923 W.A.Johnston and W.L.Uglow were engaged in mapping the Barkerville Area.[2] Here a large area of metamorphic rocks was encountered and called the Cariboo Series. This series lies unconformably below Mississippian rocks, and its age is placed as lower Paleozoic to Precambrian.

In 1927 the writer was one of a party studying the country at the head of the Thompson and Clearwater Rivers. This area is mid-way between the two districts described by Uglow, and metamorphic rocks were encountered throughout. The rocks bear a striking resemblance to the description of the Cariboo Series, and also the specimens from the Beltian System.

The problem is, therefore, to extend the correlation of the Beltian System westward, for the purpose of determining how much of the Shuswap Series is, in reality, of Beltian age. Other parts may prove to be pre-Beltian or post-Beltian. This problem is closely connected with the geological history of the Cordillera, for which we have the two hypotheses already mentioned. That of Dwason requires the presence of the Shuswap Terrane as an Archean landmass separating the Cordilleran Trough into two seaways, into which the products of its erosion

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1. G.S.C.,Summ.Report, 1921.
2. G.S.C.,Memoir 149.

were deposited. Dawson believed that this landmass was submerged during the Carboniferous, since the Shuswap Series is overlain by the Cache Creek Series, of Carboniferous age. The relation of the contact has not as yet been definitely demonstrated.

The second hypothesis, by Schofield, postulates the presence of a landmass, Cascadia, off the present coast of British Columbia, with the Cordilleran Trough existing as an uninterrupted geosynclinal basin throughout the whole of Beltian and Paleozoic times.

A further treatment of this subject does not lie within the scope of this paper, so the fascinating problem of the age of the Shuswap Series must be left for the time being.

CHAPTER THREE

DESCRIPTION OF FORMATIONS

This chapter is devoted to a brief description of the various formations, taken largely from the reports of the Geological Survey of Canada. Such descriptions will be purely lithological, since the writer feels that it is unnecessary to deal with the distribution and stratigraphy in a paper of this kind.

As already stated, Dawson gave the name Shuswap Series to the great area of metamorphic rocks in the vicinity of Shuswap Lake, and the term was gradually applied to other areas. Dawson's general description of the rocks has already been quoted, and Daly's section of the same region described, since it affords a more detailed account.

Shuswap Lake Section.[1]

Daly has mapped in detail a narrow section of Shuswap and so-called Beltian rocks along the Canadian Pacific Raliway, extending approximately from Revelstoke to Kamloops. This section affords a splendid idea of the large area of metamorphic rocks occurring in this part of the province, but it will be many years before such detailed mapping can be extended. It should be noted that in such a complex area the boundaries are in some cases arbitrarily drawn, and Daly states himself that the sequence may not be exactly as given.

Daly's table of formations is as follows:

1. G.S.C. Memoir 68, page 12.

Adams Lake basic volcanics, thickness	10,000 ft.
Tshinakin limestone-metargillite	3,900
Bastion Schists, (phyllites,etc.)	5,000
Sicamous Limestone,(Dawson's Nisconlith)	3,200
Salmon Arm, mica schists	1,800
Chase Quartzite	3,000
Tonkawatla Paragneiss?	1,500
Base concealed	
Total Thickness	28,400

Tonkawatla Formation. This formation has been placed tentatively at the base of the Shuswap Series, as exposed in the Railway section. It consists of dark to grey micaceous schists,feldspathic as well as quartzitic. There are some thin beds or lenses of metamorphosed limestone.

Chase Formation. The Chase formation consists of a series of banded calcareous quartzites. The typical rock is a greyish quartzite containing calcite and such silicates as diopside, tremolite, microcline, titanite, and muscovite. These rocks are injected by granitic dikes and sills, so that the metamorphism is in part thermal, and Daly attributes the formation of the titanite, and the feldspathization of the sediments to this cause.

Salmon Arm Formation. This formation consists chiefly of coarse-grained garnetiferous schists, indicative of fairly high-grade metamorphism. This metamorphism was thermal, and has obliterated to a large degree the regional metamorphism common to the whole series. There are also some beds of micaceous quartzite. Near the top of the formation the intrusions are rarer, and the rocks pass into a true phyllite.

Sicamous Formation. The Sicamous Formation is simply a more calcic phase of the Salmon Arm rocks, the contact being transitional. The typical rock is a greyish, impure, carbonaceous, schistose limestone. There are interbeds of phyllites and sericitic quartz schists.

<u>Bastion Formation</u>. The contact of the Sicamous and Bastion formations is again transitional, due to an increasing number of phyllitic interbeds similar to those already mentioned. Besides beds of phyllite and limestone there are also beds of sericitic quartzite and dolomitic metargillite. Rarer rock types include talc and chlorite schists, and epidote or zoisite schist containing quartz and chlorite.

<u>Tshinakin Formation</u>. This formation consists of beds of limestone and phyllite which Dawson referred to the Carboniferous, but which Daly includes in the Shuswap Series. The limestone is very pure, and is recrystallized to marble. The phyllite is calcareous.

<u>Adams Lake Series</u>. This series, which overlies the Tshinakin, was considered by Dawson to be younger than the Shuswap Series, but Daly places it as the upper member. It consists primarily of greenstone and green schists, but contains some interbeds of limestone and quartz schist. Daly gives the section of these rocks as at least 10,000 feet thick.

<u>Sill Sediment Complex</u>. This complex group, partly igneous and partly sedimentary, forms an important part of the railway section. It is an example of lit-par-lit injection on a very large scale.

The igneous portion, consisting of sills and dikes, is similar to the intrusives occurring more sparingly in other parts of the series. The chief rocks are granitic aplite and pegmatite, and granite. These igneous rocks will not be dealt with in this paper.

The sedimentary rocks are highly metamorphosed, and consist of mica schists and paragneisses, with some beds of silicified and felspathized limestone and some quartzite. These rocks are good examples of the effect of thermal metamorphism.

North Thompson Area.

The North Thompson Map Area, reported on by W.L.Uglow,[1] is situated in the lower part of the North Thompson Valley, just north of Kamloops. It is thus in close proximity to Daly's section, and some of the Shuswap rocks occurring here are correlated with Daly's formations.

Metamorphic rocks occurring in this area have been mapped as the Badger Creek, Fennell, and Barriere Formations. These had been mapped previously by Dawson as Cambrian, but have now been placed high in the Shuswap Series

Badger Creek Formation. This formation, which is equivalent to Dawson's Nisconlith Series, consists chiefly of schistose sediments and volcanics, grey to green in color. The main rock types are as follows:

Schistose andesitic tuff.
Biotite schist.
Micaceous, thin-bedded, flaggy quartzite.
Dolomitic quartzite.
Quartz slate.
Silicified argillite.
Thin, fine-grained, dolomite and limestone beds.
Hornblende schist.

Fennell Formation. The principal rocks of this formation, which is equivalent to Dawson's Adams Lake Series, are altered basic

1. W.L.Uglow, G.S.C. Summ. Report, 1921.

volcanics. The chief types are chlorite schist, schistose greenstone, ans schistose tuff. The greenstone is derived from a basaltic rock showing pillow structure.

Barriere Formation. This formation was also included in Dawson's Adams Lake Series, and consists of metamorphosed sediments, with some altered volcanics. The rock types include sericitic quartzite, sericite schist, massive limestone, dolomitic quartzite, schistose quartz-pebble conglomerate, silicified argillite, talc schist, greyish green tuff, and schistose amygdaloidal metabasalt.

Barkerville Area.

This famous old gold district of the Cariboo was reported on by W.A.Johnston and W.L.Uglow.[1] About eighty-five per cent of the area is underlain by metamorphic rocks, somewhat similar in lithology both to the rocks of the North Thompson Area, and to those of the Beltian System. The Cariboo Series is unconformably below the Slide Mountain Series of Mississippian age, and its age is given as Precambrian to Beltian. A very large number of quartz veins cut the rocks of this area.

Richfield Formation. This is the lowest formation of the Cariboo Series. The majority of the rocks were originally quartzose sediments, now metamorphosed to massive quartzites, fine quartz-pebble conglomerates, micaceous quartzites, quartz slate, quartz-sericite schist, sericite schist, and carbonaceous and clay slate with minor intercalations of limestone, calcareous argillite, and silicified tuff.

Barkerville Formation. In this formation the chief rock is an

1. G.S.C. Memoir No. 149.

limestone, varying according to the intensity of deformation between a massive unmetamorphosed type, and crystalline and argillaceous types. There are also beds of sericitic quartzite, quartz slate, quartz-sericite schist, etc., similar to the Richfield Formation.

Pleasant Valley Formation. This is an argillaceous formation, the typical rock being a clay slate. Other rock types are:

Calcareous slate, with thin interbeds of limestone
Phyllite, grey, brown ,purplish
Sericite schist, slate, and phyllite, with knots of cordierite
Chlorite schist
Quartz slate
Schistose amygdaloidal metabasalt
Greenish schistose tuff
Schistose basic volcanic flow breccia
Black graphitic slate with cubes of pyrite
Greyish-green, schistose tuff-agglomerate
Black, knotted, glistening, pencil-like schist
Silver-white, knotted sericite schist
Fine-grained limestone
Sericitic quartzite

North Thompson-Clearwater District.

In 1927 the writer was a member of a party exploring the headwaters of the North Thompson and Clearwater Rivers. This district is situated between the two areas described by Dr. Uglow, and so forms an interesting connecting link. All the rocks encountered were of metamorphic type, and corresponded closely with the descriptions of the Cariboo Series. Many of these rocks were later found to bear a striking similarity to specimens from the Beltian System, forming a problem for future consideration

No younger sedimentary rocks, and no igneous rocks of any kind were encountered. There are, however, a number of quartz veins, evidently corresponding to those of the Cariboo Series, but no associated igneous rocks could be found.

All the rocks of the area appear to belong to one series, the different types occurring more as interbeds than as separate formations. The principal types are garnetiferous quartz mica schists, soft, green, fissile quartz mica schists, pure quartzites, micaceous quartzites, schistose grits, fine quartz-pebble conglomerates, and metargillites. One small bed of crystalline limestone was found.

Comparing this district with the others under discussion, the most striking difference is the absence of intrusives, together with the scarsity of calcareous rocks.

Finlay River Section.

Metamorphic rocks occurring in the vicinity of the Finlay and Omineca Rivers are described by R.G.McConnell.[1] The following types are exposed along the Omineca River for a distance of twelve miles: medium-grained biotite gneiss, muscovite and hornblende gneisses, felspathic augen gneiss, garnetiferous gneiss. Lustrous mica schists and hydro-mica schists alternate with the gneisses in bands and beds.

The oldest rocks in the vicinity of the Finlay River consist of a series of well foliated mica gneisses, probably derived to a large extent from sheared intrusives, limestone, mica, hornblende, and actinolite schists, and quartz schists.

McConnell correlates all these rocks with the Shuswap Series.

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1. R.G.McConnell, G.S.C. Annual Report, 1894.

Yukon District.

A large area of metamorphic rocks occurring in the Yukon has been termed the Yukon Series by D.D.Cairnes.[1] All that is known regarding the age of these rocks is that they are older than the Middle Cambrian, but the rocks are lithologically similar to these of the Shuswap Series, and so are here treated as part of it. Cairnes describes the rocks as follows:

"The members of this group are dominantly schistose in structure, and within this particular area (Yukon-Alaska Boundary) consist mainly of quartzite-schists, schistose amphibolites, and mica schists, but also include occasional beds of limestone. All these rocks are much folded, faulted, and distorted, and are so metamorphosed in places that it is difficult or impossible to determine their original characters or origin."

The rocks of the Mount Stephens Group, which is part of the Yukon Group, are described by Cockfield and Bell[1] as follows:

"The Mount Stephens Group includes a number of members widely different in appearance, composition, and possibly in age. They are, however, all old, and so extremely altered that their mode of origin and succession are obscured. They consist of sericite and chlorite schists, greenstone schists, sericitic quartzites, gneissoid quartzites, hornblende gneisses and crystalline limestone."

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1. D.D.Cairnes, G.S.C., Memoir 67, page 40.
2. W.E.Cockfield and A.H.Bell, G.S.C.Memoir 150, page 8.

BELTIAN SYSTEM

The Selkirk and Purcell Ranges are largely made up of great thicknesses of metamorphic rocks, including quartzites, argillites, schists, and crystalline limestones, in many respects similar to those of the Shuswap Series. These rocks are now known to be of Beltian age.

The age and correlation of the Beltian rocks was, and in some cases still is, a great problem, which cannot be dealt with in this paper. Schofield's memoir on the Cranbrook Map Area[1] affords a good description of the rocks and their correlation, so this district will be dealt with first.

Cranbrook Map Area.

This area is situated in the south-eastern part of the province, near the International and Alberta Boundaries. The rocks of the Beltian System are here grouped under the name "Purcell Series", comprising the following formations:

Gateway Formation,	thickness	2,000	feet.
Purcell sills and lava	"	300	"
Siyeh Formation	"	4,000	"
Kitchener Formation	"	4,500	"
Creston Formation	"	5,000	"
Aldridge Formation	"	8,000	"

Base unexposed

Aldridge Formation. The Aldridge formation is the oldest known member of the Purcell Series, the base of which is unknown, and constitutes a large part of the rocks of the Cranbrook district. This formation consists of a succession of dark grey

1. S.J.Schofield, G.S.C., Memoir 76.

argillaceous quartzites, characterized by their rusty weathering. There are also some purer quartzites and argillites.

<u>Creston Formation.</u> The Aldridge formation passes gradually into the Creston, which "embraces that succession of greyish argillaceous quartzites which is included between the dark, rusty-weathering argillaceius quartzites of the Aldridge, and the thin-bedded calcareous rocks of the Kitchener." This transitional formation consists of argillaceous quartzites, purer quartzites, and argillites, occurring as interbeds averaging about one foot in thickness.

<u>Kitchener Formation.</u> This formation rests conformably on the Creston, the contact being transitional. The chief rock types are calcareous and argillaceous quartzites, pure quartzite, and limestone.

<u>Siyeh Formation.</u> The lower part of the Siyeh formation consists of thin-bedded, green and purple, mud-cracked metargillites and sandstones, together with some black metargillites. Next comes about two hundred feet of massive conglomerate, consisting of pebbles of agrillaceous quartzite, sandstone, white quartzite, and altered basalt. Above this is one thousand feet of massive, siliceous, concretionary limestone. Schofield gives the following section, in descending order, for the upper part of the formation:

Purple and green metargillites and sandy quartzite	20	feet
Porphyritic amygdaloidal basalt	50	"
Purple and green metargillites and sandy quartzite	50	"
Non-amygdaloidal, non-porphyritic basalt	100	"
Purple and green metargillites	400	"
Amygdaloidal basalt	300	"
Purple and green metargillites and sandy quartzites	500	"
Remainder poorly exposed.		

Gateway Formation. The Gateway formation rests conformably on the Purcrll Lava, which is not described in this paper. The Gateway consists of fine-grained grit containing pebbles of the Purcell Lava, as well as quartzite, and is succeeded by alternating bands of conglomerate and siliceous limestone.

Windermere Map Area.[1]

This area is in the same district as the Cranbrook Map Area. Here the Purcell Series is represented by the Dutch Creek and Mount Nelson formations. Unconformably above these is the Windermere Series, which is divided into the Toby Conglomerate and the Horsethief formation.

Dutch Creek Formation. Tis formation is the northern extension of the Roosville, Phillips, and Gateway formations of Daly's boundary section, and is the oldest formation represented in the area. The rocks vary from slates and quartzites to magnesian limestone. The most common rock type is grey to black slate containing quartz grains and pyrite cubes.

Mount Nelson Formation. This formation, which is about 3,400 feet in thickness, consists of a succession of crystalline magnesian limestones and slates, with massive, white quartzites at the top and bottom. Resting conformably upon the Dutch Creek Formation, it is the youngest known member of the Purcell Series.

Toby Conglomerate. This conglomerate varys in thickness from fifty to twi thousand feet, and is also variable in composition. In places it consists of slate with occasional boulders of limestone and quartzite, in others the matrix is limestone,

1. J.F.Walker, G.S.C., Memoir No. 129.

with limestone boulders, while again the matrix may be siliceous, with boulders of quartzite.

<u>Horsethief Formation</u>. Walker states- "The formation is made up of grey, green, and purplish slate with several lenticular beds of coarse quartzite and pebble conglomerate and numerous thin interbeds of blue-grey, crystalline, and mostly non-magnesian limestone, which occur at different horizons but form a relatively small part of the whole formation.

<u>Ainsworth Map Area</u>.[1]

The Ainsworth mining camp, situated on Kootenay Lake, in south-eastern British Columbia, has been described by S.J. Schofield. The metamorphic rocks in this district were originally referred to the Shuswap Sèries by Dawson. Later McConnell called the upper members of these rocks the Slocan Series, of Carboniferous age. Schofield demonstrated that the lower members were stratigraphically above the Purcell Series, so described them as the Ainsworth Series, Beltian to Carboniferous in age.

Both the Ainsworth and Slocan Series have been metamorphosed by the West Kootenay Granite Batholith, and some of the Slocan rocks are quite as highly metamorphosed as the Shuswap Rocks, but since they are known to be of Carboniferous age, only the Ainsworth Series will be described here.

The contact between these two series is arbitrarily drawn, and the base of the Ainsworth Series is not known. Schofield divides the series into five formations, as follows:

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1. S.J.Schofield, G.S.C., Memoir No. 117.

Point Woodbury Formation. The rocks of this formation include micaceous quartzites and garnetiferous mica schists, intruded by granite and pegmatite dikes.

Early Bird Formation. This formation consists chiefly of massive thin-bedded, bluish-grey limestone, with thin interbeds if mica schist.

Princess Formation. Here the chief rock is a glittering mica schist, in many cases garnetiferous. There are some interbeds of micaceous quartzite.

Ainsworth Formation. The predominant rock of the Ainsworth Formation is limestone, massive and greyish-white in color. There are some beds of marble, and some argillaceous beds.

Josephine Formation. "The rocks of the Josephine Formation are heterogeneous in character, comprising from the base upwards a succession of mica schists, alternating thin-bedded quartzites, and green hornblende schists, with narroe lenses or bands of limestone, and at the top, staurolite schists.

Revelstoke Section.[1]

Daly has mapped, in his railway section, an area of Beltian rocks between Shuswap Lake and Revelstoke. Later workers have demonstrated that some of these formations are of Paleozoic age, so the writer includes this section with some reservations

Without treating the complex subject of stratigraphy, Dalys section is as follows:

1. R.A.Daly, G.S.C., Memoir No. 68.

	Top- erosion surface	
Glacier Div.	Ross Quartzite, in part	2,500 feet
Selkirk Series	Nakimu Limestone	350
of Dawson	Cougar Formation	10,800
Albert Canyon	Laurie Formation	15,000
Division	Illecillewaet Quartzite	1,500
Nisconlith	Moose Metargillite	2,150
Series of	Limestone (marble)	170
Dawson	Basal Quartzite	280
		32,750
	Base, unconformity with Shuswap Series.	

Upper Paleozoic fossils were found in the Laurie formation by Drysdale[1] in 1917, so this formation must be excluded from the above section, and will not be described here. The remaining formations will be described, but with the reservation that some of them may later prove to be of Paleozoic age.

Basal Quartzite. This bed of quartzite rests upon the sill-sediment complex, and is considered the base of the Beltian rocks in this section because the many aplitic dikes, so characteristic of the former, are thought by Daly not to cut the quartzite. There has been some controversy relative to the existance of an unconformity at this point.

The typical rock is a schistose arkosic quartzite, the felspar increasing toward the contact. Daly attributes this to the fact that that the rock has been derived from the granitic rocks of the sill-sediment complex. The combined results of several slides described by Daly show that the rock is made up of the following minerals, in order of importance: quartz, orthoclase, plagioclase, biotite, epidote, titanite, magnetite, apatite, zircon, sericite, and garnet.

1. G.W.Drysdale, G.S.C., Summ. Report 1916, page 61.

<u>Lowest Limestone</u>. The upper part of the above quartzite becomes interbedded with limestone until a bed 170 feet in thickness is reached. This rock is a fairly pure marble.

<u>Moose Metargillite.</u> Daly states: "...the formation is the recrystallized product of argillaceous material. The metamorphism has not generally gone to the length of developing a true mica schist, and the term metargillite is chosen as a truer designation. ...the rock is a massive, dark grey, carbonaceous rock, strongly charged with an obscure mineral which appears to be cordierite. Quartz in minute grains is a subbordinate essential, a little biotite and magnetite are accessory."

<u>Illecillewaet Quartzite</u>. This formation overlies the Moose Metargillite conformably. It is described as "comparatively homogeneous, hard, grey, rarely white, massive to fissile quartzite, with thin interbeds of dark-colored metargillite or phyllite."

<u>Cougar Formation</u>. This formation is made up as follows:

Grey quartzite with thin interbeds of phyllite & quartzite
White, homogeneous, massive, quartzite
Massive, light-grey quartzite, with bands of quartzitic grit and coarse sandstone, and siliceous argillite
Quartzite, phyllite, grey sandstone, fine conglomerate, and metargillite
Altered basaltic lava.
Grey quartzite

<u>Nakimu Formation</u>. The chief constituent of this formation is a bluish-grey, crystalline limestone, generally containing quartz, and sericite or talc. The limestone is magnesian.

<u>Ross Formation</u>. Daly believes that the Cambrian begins about midway in this formation, which is made up, as follows:

Grey, compact quartzite, with beds of sandstone and grit.
Pale, dolomitic phyllites and sericitic quartzites.
Grey, homogeneous quartzite, with interbeds of hard quartzitic grit and sandstone.

CHAPTER FOUR

REGIONALLY METAMORPHOSED ARGILLACEOUS ROCKS

Part one- Argillites

Under this heading are included the slates, phyllites, and Daly's "metargillites", rocks which, while not as plentiful as the schists and quartzites, are nevertheless important components of the Shuswap and Beltian Systems.

The writer was unable to examine many of these rocks, and, as they are not described in detail in the reports, the descriptions given here cannot be very complete.

1. Quartz-white mica-biotite.

The simpler argillites consist essentially of quartz and micas. Phyllites from the Salmon Arm formation are described by Daly as fine-grained rocks made up of sericite and quartz grains less than .1 mm. in diameter.

From the Barkerville Area Uglow describes bands of black, glistening, carbonaceous slates associated with the quartzites of the Richfield formation.

Quartz-slate and siliceous argillite occur in the Barriere and Badger Creek formations of the North Thompson Area.

A few rocks belonging here were found in the Clearwater district. Some of these show fissility transverse to the bedding, which is well marked, and are classed as slates, although they do not resemble typical slates. In the hand-specimen the rocks are dense, slightly laminated, and dark grey in color, some containing small holes from which pyrite has evidently been leached. Puckering or false-cleavage on a very fine scale is observed under the microscope. About three-quarters of the rock is seen to consist ofsmall, sub-angular quartz grains, slightly elongated in the direction of the puckering. The remainder of the rock consists of fine flakes of white and brown mica, which show signs of recrystallization and "flow" around the quartz grains in the direction of the puckering. There is also a little fine, opaque, argillaceous material. A few small grains of pyrite, usually oxidized, are accessory.

2. Quartz-biotite-cordierite?

A metargillite of this composition is described by Daly from the Moose formation, as "a comparatively massive, da dark grey, carbonaceous rock strongly charged with an obscure mineral which appears to be cordierite. Quartz in minute granules is a subordinate essential; a little biotite and magnetite are accessory". Daly gives no reason for supposing the mineral to be cordierite.

3. Quartz-white mica-chlorite-hornblende.

Rocks of this type were found in the Clearwater district. They are soft and massive, light green in color, and contain abundant pyrite cubes up to one inch in size. This rock passes into a soft, green, more schistose type. Under the microscope the rocks are seen to consist of extremely small, irregular grains of quartz, white mica, chlorite, and light-green, slightly pleochroic hornblende, showing some signs of allignment and puckering, and gradually passing into the schistose type. The quartz grains are irregular and slightly elongated, and show signs of recrystallization. The white mica has recrystallized between the quartz grains, and shows incipient parallel allignment. The chlorite and hornblende are in minor amounts. The hornblende is slightly pleochroic and does not exhibit its cleavage.In some cases pyrite has been so abundant that large quantities of cubes are found in the morraines. Daly describes very similar occurrences of pyrite from the Beltian of the 49th parallel[1], and from the character of the mineral, states that the cubes grew probably in the unconsolidated mud. If this were the case, it is difficult to understand how the pyrite, which is quite brittle, has withstood the crushing effects of metamorphism. Pyrite occurs in a similar manner in some of the micaceous quartzite, to be described later,and, although the quartz is strained and recrystallized,the pyrite appears in fresh crystals, so it would appear to be secondary.

4. Quartz-mica-calcite.

Calcareous argillites are mentioned from the Richfield formation, Barkerville, and from other localities. These are not described, and the writer could not obtain specimens of them. The above composition is assumed.

5. Quartz-mica-dolomite.

Dolomitic metargillite is mentioned by Daly as occurrin the Bastion formation, but is not described.

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1. G.S.C., Memoir 38, page 136.

Part two- Schists

The schists are grouped according to their mineral assemblages, and are dealt with in the approximate order of the generally accepted grades of regional metamorphism. In the absence of chemical analyses it is impossible to be certain of the original compositions, and therefore one cannot determine the exact mineral changes.

1. Quartz-white mica.

Quartz-sericite schists, glistening and very fissile, are mentioned from the Barriere and Richfield formations, but are not described. Most of the sericite schists contain other minerals besides quartz and sericite.

Glistening, light-grey, soft, fissile schists are described from the Mount Stephens group. These consist essentially of quartz and sericite, with accessory orthoclase, plagioclase, and secondary calcite. It is thought that these schists represent metamorphosed rhyolites, the sericite and calcite replacing the alkali felspars.

2. Quartz-white mica-chlorite.

Soft, green, fissile, schistose rocks occur in the Clearwater district. These are similar in composition to some of the green argillites, but with some development of schistose structure, and are intermediate between the argillites and the true garnetiferous mica-schists.

Under the microscope these rocks are seen to be very fine-grained, with marked puckering on a minute scale. About fifty per-cent of the rock consists of very small, irregular quartz grains, slightly elongated parallel to the schistosity, but without any sign of crushing or mylonitization. The other essential constituent is a fine aggregate of white mica and chlorite. The mica was probably an original constituent, but is recrystallized and oriented with its long dimensions parallel to the schistosity. Small prisms of tourmaline are fairly common and are thought to have been original accessories. Spots of goetite, pale yellow in color, are common and are probably derived from the alteration of pyrite grains.

3. Quartz-white mica-hornblende.

One of the specimens of green schist from the head of the Thompson River belongs in this class. Macroscopically it is a dense, slightly foliated rock, green in color, and showing some false-cleavage. Microscopically it is seen to consist chiefly of very small grains of quartz, white mica and hornblende, with allignment parallel to the schistosity very marked. The quartz is in small lenticular grains showing straining. The white mica occurs in small recrystallized laths oriented in parallel. The hornblende is in the form of minute, pale-green, slightly pleochroic needles, with parallel allignment. A few grains of apatite and oxidized pyrite are accessory.

4. Quartz-white mica-biotite.

Another specimen of green schist from the headwaters of the Thompson belongs here. Macroscopically it is similar to the rock just described, except that here the puckering is most spectacular, even in the hand-specimen.Under the microscope all the constituents are seen to be oriented parallel to the direction of the puckering. About sixty per-cent of the rock consists of small, irregular quartz grains, elongated but not broken. The other chief constituent is a fine aggregate of recrystallized laths of white mica, which "flows" in the direction of the puckering. Associated with the white mica are some fine flakes of biotite, which are probably derived from the chlorite found in other specimens. Numerous small grains of pyrite are altered to a pale yellow oxide, probably goetite.

5. Quartz-biotite-white mica.

Some writers mention biotite schists and quartz-biotite schists, but do not describe them. The writer has a specimen from the vicinity of Shuswap Lake which consists of quartz, biotite, and white mica, the biotite being greatly in excess of the white mica. Quartz is the predominant mineral, and it is questionable whether the rock should be called a quartz mica schist or a micaceous quartzite. The quartz has recrystallized in an irregular mosaic, the grains exhibiting strain-shadows, but there is no parallel allignment. The biotite is in fairly large irregular flakes scattered in parallel direction throughout the rock, but is greatly concentrated in fine bands parallel to the bedding. It has probably formed from white mica and chlorite, the chlorite being somewhat concentrated. The white mica occurs in the same way as the biotite, but in smaller quantities. Apatite and tourmaline are accessory.

6. Quartz-white mica-biotite-garnet.

One of the most common rock types in the Shuswap Series is garnetiferous quartz mica schist. Its frequent occurrence and widespread distribution might well make it representative of the average grade of regional metamorphism.

The essential constituents of these schists are quartz, white mica, biotite and garnet. The garnets, which occur in large numbers and range from one-eighth to one-half an inch across, are of the dark-red iron-rich variety, probably almandine. Such garnets are normally formed under high pressure from a reaction between biotite, chlorite, magnetite, and white mica. On account of their high crystal strength they are able to assume their crystal forms, usually dodecahedra, in spite of the high pressure of their environment, thus giving the idioblastic texture, with the weaker minerals "flowing"around the garnets.

These schists vary from relatively hard and massive forms to those soft and fissile, and are generally a mottled, silvery, glistening color. All the essential constituents can generally be recognized macroscopically.

A typical specimen from the headwaters of the North Thompson conforms to the above general description, and is somewhat rusty on weathering. The garnets, which are relatively small, are to a certain extent concentrated in bands, suggesting a corresponding concentration of the original constituents from which they were derived. Under the microscope the rock is seen to consist chiefly of quartz and micas, the white mica being in excess of the brown. The white mica occurs in aggregates of small recrystallized and alligned laths,together with some larger flakes. The biotite occurs in large flakes which are often broken, suggesting that they were formed before the metamorphism reached its maximum. The micas account for the schistosity, and their long directions are parallel to it and to the puckering, which is marked. The other essential constituent is quartz, in small grains elongated in the direction of schistosity, but more irregular than elliptical. Strain phenomena and recrystallization are very noticeable, but there is no sign of mylonitization. Both micas and quartz are very free from inclusions. Small, dark-red garnets, probably almandine, are common. Their crystal faces are not well preserved, but the dodecahedral form can be traced. They show some signs of crushing, indicating higher grade, or retrograde, metamorphism. There are a few inclusions of quartz and magnetite. The garnets have evidently been the last minerals to form, having thrust aside the micas and quartz, causing an idioblastic or ~~poikilitic~~ texture.

A schist from the West Kootenay district consists of fine grains of quartz, white mica, and biotite, exhibiting the same general characters as those just described, together with some pennine and magnetite. All the constituents show parallel allignment accounting for the schistosity. There are also a few large flakes of recrystallized white mica, drawn out in the direction of schistosity. A few prisms of tourmaline are accessory. There are some large idioblastic garnets and pseudomorphs after andalusite, causing ~~poikilitic~~ texture. The garnets show imperfect crystal outline, and are altered to chlorite around the edges and in streaks. The pseudomorphs, which are thought from their form to be after andalusite, now consist of white mica with some isotropic material, and a little biotite.

A specimen from the Finlay River contains a larger percentage of quartz than the average, and so is less schistose.

The quartz is in very fine to large irregular and strained grains, with a very few inclusions of magnetite. There are also a few accessory strained grains of andesine. The micas constitute only about ten per-cent of the rock, and occur in large flakes with only slightly parallel allignment. There are a few small garnets with inclusions of unstrained quartz, which in turn contains inclusions of magnetite.

7. Quartz-biotite-plagioclase.

A few specimens contain abundant plagioclase, although not in sufficient quantity to be seen macroscopically. One specimen from the Yukon is a greyish-black, fine-grained, quartz mica schist. It is about one-half quartz and andesine and one-half biotite. The andesine is in fairly large irregular grains showing straining, the twinning often being distorted. The quartz occurs as usual in irregular grains showing strain phenomena. These minerals are not elongated or arranged parallel to the schistosity, which is due to the mica. The biotite occurs in large irregular flakes with parallel orientation. A few grains of white mica, hornblende, and iron ores are accessory.

A similar rock from the Finlay River district corresponds so closely with the above that it needs no description.

Another specimen from the Yukon contains much less plagioclase, and in this case it is andesine. Quartz is predominant and occurs as usual. As well as albite, the rock contains a little epidote, zoisite, and pyroxene, so it is probable that it contained an original plagioclase which has thrown off lime to form epidote, and recrystallized to form albite.

8. <u>Quartz-biotite-hornblende</u>.

Quartz-mica-hornblende schists occur in a few instances, notably in the Josephine formation of the Ainsworth Area. A specimen examined microscopically was seen to be fine-grained, with parallel allignment very marked. Quartz and hornblende occur in about equal quantities, while the biotite is somewhat scarcer. The quartz is in sub-angular, strained grains, slightly elongated parallel to the schistosity. The hornblende is in irregular, elongated grains, is pale green and slightly pleochroic, and does not exhibit its cleavage. The biotite is in small flakes arranged in parallel. It is probably derived from white mica and chlorite, but the hornblende would appear to be original.

Course of Metamorphism.

The rocks dealt with in this chapter were evidently deposited as fine muds consisting of small grains of quartz, sericite, chlorite, and possibly some albite- typical shallow-water deposits. The consolidation of such sediments would result in the production of shales, but no such rocks exist now in the formations under discussion, regional metamorphism having produced higher-grade forms.

The rocks of lowest grade actually found are the met-argillites, slates, and phyllites. In these low-grade rocks there has not been much formation of new minerals, but increase in temperature and stress have caused the straining and elongation of the quartz grains, and the recrystallization of the white mica and chlorite. There is no sign of mylonitization.

Slaty and strain-slip cleavage are developed in most cases, put schistosity is not yet produced. There are of course variations in the original composition, some specimens consisting only of quartz and sericite, and others having the addition of chlorite, while one specimen is thought to contain cordierite. Some types contain a little calcite or dolomite. As a rule these rocks do not contain biotite.

With increasing metamorphism quartz-sericite schists are developed. The flakes of white mica become coarser and show marked parallel allignment, producing a schist of the same general composition as the average phyllite.

The majority of the schists, however, contain essentially quartz, white mica,and biotite: the biotite forming from chlorite and white mica under increased temperature and pressure. This increase of mica imparts a very schistose character to the rock. Some types belonging in this grade contain abundant recrystallized hornblende, but this is thought to have heen an original constituent.

The highest-grade products actually found are the garnetiferous quartz-mica schists. Their constituents are the same as those of the type just described, with the addition of garnets. However, the quartz is perhaps slightly more elongated and strained, and the micas have recrystallized into coarse flakes, producing a well foliated schist. The garnets form under high pressure from chlorite, biotite, white mica, and magnetite. Their idioblastic form has already been described.

No higher-grade schists, containing cyanite or sillimanite, and produced by regional metamorphism, are known to the writer, so the garnetiferous schists are considered to represent the height of metamorphism, at least in the rocks exposed and examined. Gneisses are common, but the writer does not feel certain that any of them are paragneisses, and therefore the high-grade metamorphic equivalents of argillaceous rocks.

CHAPTER FIVE

REGIONALLY METAMORPHOSED CALCAREOUS ROCKS

Part one- Pure Forms

Beds of limestone are found in practically all the formations under discussion, but in the majority of cases the rocks are inpure. Beds of pure limestone and marble do occur, however, and are probably indicative of increased depth of the seas in which they were deposited. In most cases regional metamorphism has produced marble, which is seen under the microscope to consist simply of a recrystallized mosaic of fairly large, subrounded grains of calcite, which show twinning but no development of crystal form.

Part two- Impure forms

1. Dolomitic limestone. Calcite-dolomite.

Dolomitic limestone is very common, occurring in massive beds, grey in color. These rocks consist of a recrystallized mosaic of calcite and dolomite grains.

2. Siliceous limestone. Calcite-quartz. (No silicates)

This is also a common type, occurring in massive beds often having associated with lenses of chert. The calcite forms a recrystallized mosaic as usual, and has associated with it various amounts of sub-rounded, recrystallized quartz grains.

3. Calc-silicate rocks. Calcite-white mica. (Non excess silica)

Various quantities of white mica are sometimes found as impurities in the limestones. The calcite occurs as usual. The regional metamorphism has caused the recrystallization of the white mica in parallel allignment, producing varying degrees of schistosity according to the proportion of mica to calcite.

4. Calc-silicate rocks. $CaO-CO_2-SiO_2-Al_2O_3-MgO$

This group includes a complex group of calc-silica rocks in which, besides quartz and calcite, there have been impurities containing alumina, magnesia, and iron. Due largely to the activity of carbon dioxide, metamorphism causes chemical reactions between these constituents, producing new and complex minerals.

a. Calcite-forsterite-serpentine.

A rock of this type, from the vicinity of Shuswap Lake, has a fine-grained base of recrystallized calcite. In this base are large, sub-rounded masses of serpentine, pseudomorphous after forsterite. There is also a very little unaltered forsterite. A few spinels are accessory. This rock is probably the result of "dedolomitization" (see Harker-Petrology for Students, page 278). Here impurities of magnesia and quartz combine to form forsterite, which alters readily to serpentine. Such serpentinous marble is called ophicalcite.

b. Calcite-quartz-plagiocalse-silicates.

One of the simpler types belonging here is a light grey, massive calc-silica rock from the Shuswap Lake district. Quartz and calcite can be distinguished in the hand-specimen, parts of which effervesce freely with acids. The rock consists essentially of small, sub-rounded quartz grains, showing strain effects, set in a massive, recrystallized base of calcite, showing twinning. There are afew large, irregular grains of diopside. There are also a few grains of indeterminate plagioclase.

Daly describes a "recrystallized calcareo-argillaceous rock" from the Tonkawatla formation, as follows:

"The essential constituents are quartz, biotite, plagioclase (averaging labradorite), and subordinate orthoclase or microcline. In one thin section a diopsidic mineral is abundant. Garnets, tremolite, and calcite are common accessories. The felspars are strikingly poikilitic and, like the other essentials, show strain phenomena. The mineralogy and structure of the rock are appropriate to a recrystallized calcareo-argillaceous rock, e.g., "Kalkthonschiefer",(see Rosenbusch,Elemente der Gesteinslehre,p.599)."

One of the most interesting, and yet most difficult, specimens studied during this work is a calc-silicate rock from the canyon of Shuswap River. This rock has such a complex mineral assemblage that, without an analysis and a more detailed study of its field relations, it is impossible to do it justice in this paper.

Macroscopically it is a fine-grained, grey rock with fine, white, calcareous bands, so that at a distance it resembles a gneiss. Quartz, calcite, and innumerable small grains of pyrite can be distinguished with the naked eye. It occurs in greatly contorted beds, and is evidently the result of high-grade metamorphism.

The bese of the rock consists of irregular, recrystallized, and interlocking grains of quartz, calcite, and orthoclase. None of these minerals have developed their crystal form, and so form a mosaic. All show the effects of straining to a marked degree, without any sign of displacement.There are a few grains of andesine. Occurring in minor quantities, either as inclusions in the above-mentioned minerals, or in the interstices, are grains of zoisite, white mica, sphene, diopside, pyrite, and apatite. The sphene, which is highly pleochroic, is the only mineral to develop its crystal form, and is probably secondary after titaniferous magnetite, ilmenite, or rutile. Small irregular grains of pyrite are very numerous.

A calc-silicate rock was studied from the West Kootenay district. Here the chief constituents are hornblende and quartz, while calcite occurs in minor amount. The quartz is in fairly small, irregular, recrystallized grains, showing strain-shadows. The hornblende is in irregular masses, with some parallel allignment, giving a semi-banded effect. It is extremely pleochroic, ranging from deep green to greenish yellow. The orientation c:C is from ten to seventeen degrees. Cleavage, both basal and prismatic, is very marked.

Calcite occurs in large, sub-rounded grains, showing twinning. There are a few small, irregular grains of felspar, (microcline and a plagioclase so strained that it could not be identified). There are also a few flakes of biotite, showing alteration to pennine. Other accessories are zoisite, epidote, pyroxene, sphene, and apatite.

c. Calc-silicate schist.

A rock from the Clearwater district shows an abundant development of white mica, imparting a schistose character to it. The quartz grains are irregular, recrystallized, and slightly elongated parallel to the schistosity. Calcite occurs in minor amount, in sub-rounded, recrystallized grains. Large of white mica are very conspicuous, even in the hand specimen. They show marked parallel allignment, and are sometimes broken, suggesting the effects of retrograde metamorphism. Large masses of yellow iron oxide are very common.

Course of Metamorphism.

In the pure calcareous rocks, since no new minerals can form, the only effect of increase in temperature and pressure is one of recrystallization, resulting in the production of pure marble. In general, increased metamorphism causes a coarsening of grain. There was no development of crystal form in any of the specimens examined.

With impurities of quartz and white mica, low-grade metamorphism caused only recrystallization. This held also in the case of dolomitic limestones, but with increasing metamorphism dedolomitization was effected, resulting in the production of forsterite marble.

In the calc-silica rocks with alumina and magnesia, epidote was the characteristic mineral formed, together with pyroxenes. Sphene ~~Spinel~~ was generally present, the titanium probably being derived from rutile or titaniferous magnetite present as an impurity in the original rock. These transformations were probably effected under fairly high-grade metamorphism.

Where micas formed, metamorphism caused increasing parallel allignment, with a corresponding increase in schistosity, resulting finally in calcareous and calc-silicate schists.

CHAPTER SIX

REGIONALLY METAMORPHOSED ARENACEOUS ROCKS.

Part one- Pure forms

Absolutely pure quartzites are not common in the formations under discussion, and few of the specimens examined could be classed here. Quartzite is known to occur at Shuswap Lake which is so pure that it is of commercial value as a flux, but no description is available. The effect of metamorphism on such pure forms could be only one of recrystallization

A good specimen of pure quartzite was studied from the West Kootenay. The rock is white, massive, and even-textured. Under the mivroscope it is seen to consist of a fine-grained granoblastic aggregate of sub-rounded to interlocking quartz grains which impinge on one another without any interstitial filling. There is no development of crystal form. The grains show strain shadows and minute cracks, so the rock has evidently been subjected to high pressure. A few flakes of biotite and grains of iron ore are accessory.

Part two- Impure forms.

1. Quartz-dolomite.

Just as we find siliceous dolomites and limestones, so we find dolomitic quartzites, depending on which mineral is in greater proportion. Such rocks consist of a recrystallized mosaic of quartz and dolomite, generally showing strain effects.

2. Quartz-orthoclase-plagioclase-biotite.

Daly's basal quartzite of the Beltian is an arkosic quartzite. It consists of the following minerals in order of abundance-quartz, orthoclase, plagioclases, biotite, with accessory epidote,titanite,magnetite, apatite,sericite, and garnet. Daly attributes the arkosic nature of this bed to the fact that it rests on the sill-sediment complex, having probably been derived from it by weathering. This would account for the felspars.

3. Quartz-plagioclase-biotite-white mica.

Several slides from the Ainsworth area are classed here. Quartz is the predominant mineral and occurs as usual. The few grains of undetermined plagioclase are almost accessory. Flakes of biotite and white mica occur sparingly and need no description. Iron ores and apatite are accessory.

4. Quartz-plagioclase-biotite-sericite-calcite.

A rock of this composition is mentioned fromthe Mount Stephens group, but is not described in detail. Here the quartz grains are intergrown with a felspar which is much altered to sericite and calcite. There are also numerous shreds of biotite.

5. Quartz-biotite.

A quartzite from the Clearwater area consists essentially of quartz, with a little biotite and argillaceous material. It is fine-grained and massive, with no directed character. It is white on weathering, but greyish on a fresh fracture. The quartz is in extremely small, irregular, interlocking, recrystallized grains showing strain effects. The mica is in fine whisps between the quartz grains.

Several quartzites from the West Kootenay contain a little biotite. The quartz occurs as usual, but with less srtain effects. A few flakes of biotite are scattered between the grains, without any parallel allignment, and are likely formed from argillaceous impurities. There are also afew grains of magnetite.

6. Quartz-biotite-white mica.

A schistose grit from the ClearwatermDisrtict contains both white and brown micas.The quartz grains are coarse, up to one quarter inch in diameter, and show straining, shattering, and elongation parallel to the schistosity. About ten per cent of the rock consists of fine flakes of white and brown micas arranged in parallel between the quartz grains.

This has evidently been a coarse grit with some argillaceous impurities which have produced the micas under stress.

7. Quartz-biotite-white mica-garnet.

A specimen from the same locality as the above is similar, with the addition of a few badly shattered garnets and a few accessory grains of calcite. There is not sufficient calcite to warrant placing the rock in the calc-silicate class. The garnets might have been present in the original sediment, but it is likely that they formed under high stress.

8. Quartz-white mica.

In most of the reports sericitic quartzites are mentioned, but as they are not described, we cannot be certain that these are the only minera;s found in them. However, they may be provisionally classified here.

One specimen from the Clearwater belongs here. It is buff colored and massive, with no directed character. Most of the rock is made up of rounded quartz grains. These are set in a base of small grains of white mica, with but slight parallel allignment.Numerous spots of goetite are likely derived from the oxidation of pyrite grains.

Course of Metamorphism.

It is more difficult to work out the sequence of metamorphism in the case of the arenaceous rocks. The original rocks were obviously sands, consisting primarily of quartz grains, with varying amounts of argillaceous material, mostly sericite and chlorite.

The quartz does not react chemically under metamorphism, but simply recrystallizes. In the pure forms this is all that can happen, and pure quartzites result. Strain effects and shattering are the results of still higher stresses.

In the impure forms the quartz reacts in the same manner as above, and so does any felspar present. The argillaceous impurities react as in argillaceous rocks, producing biotite and recrystallized white mica, the parallel allignment of which imparts to the quartzite a schistosity proportional to the amount of mica. One specimen, containing garnets, is evidently the result of still higher metamorphism.

CHAPTER SEVEN

MISCELLANEOUS ROCKS

Altered Basic Volcanics

Altered volcanics occur in great numbers in rocks which are tentatively referred to the upper part of the Shuswap Series, such as the Adams Lake Series, and its equivalent-the Fennell formation.

In the Fennell the basaltic rocks are altered to chlorite schist and slightly schistose, fine-grained greenstone, associated with bands of schistose tuffs.

Daly describes basic schists from the Adams Lake Series as follows:"They are generally chloritic. Uralite, epidote, zoisite, and secondary quartz...are regular associates of the chlorite. Comparatively abundant crystals of dolomite or calcite, titanite, leucoxene, and pyrite are the normal accessories.Not a certain trace of felspar was found in any of the thin sections....... According to mineralogical constitution the metamorphic types actually found are: chlorite-schist, uralite-chlorite-quartz schist, uralite-chlorite, epidote-quartz schist, dolomitic quartz schist, and true amphibolite."

A specimen from the vicinity of Shuswap Lake resembles basalt, but is brownish-green in color. It consists of a fine aggregate of hornblende largely altered to serpentine, and some small angular quartz grains showing straining. There is also also a little biotite and epidote, and a few grainf of pyrite. It does not appear to b e as highly altered as the specimens described by Daly.

Metamorphosed Conglomerates.

A good example of sheared conglomerate occurs in the vicinity of Shuswap Lake. Here the pure quartzite pebbles are drawn out to one-half an inch in thickness and about two inches in length. The matrix is now a fine-grained quartz schist, made up of small, angular, interlocking, recrystallized, and strained quartz grains, and small flakes of biotite. The rock has evidently been subjected to great stress. A somewhat similar occurrence is described by Kolderup from the vicinity of Bergen, in Norway, but here the quartz pebbles are still further drawn out and form small lenses in the matrix.

Sill-sediment Complex.

This consists of a multitude of injections of granitic, aplitic, and pegmatitic sills and dykes, together with their gneissic equivalents. These intrusice rocks will not be described here.

The sedimentary parts of the complex are all highly metamorphosed, since contact metamorphism has been superimposed on the rocks already regionally metamorphosed. The rocks are now mica schists and paragneisses, with white crystalline limestone (usually silicated and often feldspathized) and a few quartzite beds.

Gneisses.

Gneisses are common in the Shuswap Series, but the majority are orthogneisses, passing into unmetamorphosed granitic rocks. These gneisses are therefore younger than the

Shuswap Series, although forming an integral part of it. Since the intrusives have been excluded from this study, and although a large number of specimens have been examined, only the main types need be described here.

Daly mentions paragneisses from a number of formations, and no doubt such rocks occur, but none of the slides examined could be classed as such with certainty.

1. Orthoclase-plagioclase-quartz-biotite.

A rock from the Shuswap Lake district is light colored with a few thin dark bands. About half of the rock consists of large interlocking grains of andesine and orthoclase showing straining, the twinning often being distorted. Quartz occurs in slightly minor amount in small grains showing recrystallization and straining. Small flakes of biotite are chiefly concentrated in the dark bands. A few zircons are accessory.

A large number of specimens from the West Kootenay conform in a general way to the above. Orthoclase and plagioclase occur in varying amounts, the plagioclase ranging from labradorite to bytonite. Quartz occurs as above. The rocks contain up to ten per cent of biotite, chiefly concentrated in bands showing parallel allignment. Pyrite, magnetite, apatite, and zircons are accessory.

2. Plagioclase-quartz-biotite.

Specimens from the West Kootenay and Finlay River districts belong here. As they are similar to the preceeding type, with the absence of orthoclase, they will not be described.

3. Plagioclase-quartz-hornblende.

Hornblende gneisses occur in the Whitehorse District, Yukon. They are described as fine to coarse textured rocks with decided gneissoid structure. As well as hornblende they contain a little augite. The rock is thought to be derived from granodiorite or gabbro.

CHAPTER EIGHT

REGIONAL METAMORPHISM IN GENERAL

The mere cataloging of metamorphic rock-types is of slight importance compared to the study of metamorphism as a process. The approach of the subject from a genetic point of view introduces the study of the factors which have united to produce a given rock-type, which in turn must be regarded only as representing a stage in a continuous process.

Metamorphism is the attempt of rocks to attain a state of equilibrium for changed conditions of chemical environment, pressure, and temperature. The writer means to exclude from this definition the effects of weathering and metasomatism, where the bulk composition of the rock is altered. The chief factors affecting metamorphism are, therefore, as follows:

1. The original composition of the rock.

2. Temperature. Changed conditions of temperature are produced chiefly by the general increase of temperature downwards, or the rise of isogeotherms, or by the intrusion of igneous rocks.

3. Uniform or hydrostatic pressure.

4. Non-uniform, directed pressure, or shearing-stress.

5. The effect of chemically active fluids and gases which facilitate solution, and therefore recrystallization. This is meant to exclude metasomatism.

In general, all these factors are active to a greater or a less degree, and in most cases the effects of one factor cannot be treated independently. We do, however, get special cases where only one factor is of importance. For instance, there is a type of metamorphism in which directed pressure is the only factor of importance, as in overthrusting. This is termed mechanical or cataclastic metamorphism. On the other hand, in the contact aureoles of stocks and batholiths, heat is the predominant factor, although pressure is also present. The metamorphism so produced is called thermal, contact, or local metamorphism. It should be noted that in the study of ore-bodies, the term contact metamorphism is generally taken to imply metasomatic action.

By far the most widespread type of metamorphism is, however, that which is produced by the action of the two independent variables heat and directed pressure. This is often called dynamic or dynamo-thermal metamorphism, but due to differences of interpretation the term regional metamorphism seems preferable. The pressure is largely tangential to the earth's surface and due to orogenic movements. Daly and others have introduced the term static metamorphism, or load metamorphism to describe the effects of the weight of superimposed strata. This seems scarcely necessary, since it involves only a change of direction. The pressure is here radial instead of tangential, but it is nevertheless directed pressure, and the metamorphisms so produced are essentially similar. In any event the term regional metamorphism covers all cases.

If in the field we find flat-lying metamorphic rocks with schistosity parallel to the bedding, we would be justified in attributing the pressure to load, but to state that all the metamorphism in the rocks under discussion is static, and that the orogenic movements were post-metamorphic and therefore superficial, would be ratheraa sweeping statement for the present amount of field data.

The course of regional metamorphism is best exhibited in the argillaceous rocks, since here we get a definite mineral assemblage for each grade. In the quartzites and limestones the quartz and calcite simply recrystallize, and when impure the impurity is generally argillaceous, and reacts under metamorphism in the same manner as in the argillaceous rocks. The calc-silicate rocks are an exception, since here the quartz and calcite react with impurities to form a complex mineral aggregate. The course of metamorphism in these types has already been summarized, and repetition is unnecessary.

It will be remembered that in the argillaceous rocks neither of the extremes- the shales nor the sillimanite-cyanite gneisses, were found. The rocks fell into three main classes- the slates, phyllite, and metargillites, the quartz mica schists without garnets, and the garnetiferous quartz mica schists. There are not sufficient field data at present for the mapping of these three metamorphic zones, but no doubt this will be possible in the future. On the whole the grade of metamorphism of the calcareous and arenaceous rocks is more difficult to determine, and can best be ascertained from the field relations when such rocks occur as interbeds with argillaceous rocks.

The Beltian rocks appear to be of lower grade than the Shuswaps, as evidenced by their preponderance of metargillites over schists, their lack of gneisses, and the fact that the conglomerates are not squeezed like those of the Shuswap Lake district. This statement is very superficial, since the specimens examined for this work were not nearly comprehensive enough for an accurate comparison.

Retrograde Metamorphism.

The effect of retrograde metamorphism is seen in some cases. The straining and crushing of quartz grains after recrystallization suggests this type of metamorphism, although it might be simply due to still higher grade. In some of the schists flakes of mica are bent and broken, and this is attributed to the effects of retrograde metamorphism. This is an important branch of the subject which requires more study than the writer was able to devote to it.

CHAPTER NINE

CONTACT METAMORPHISM

In contact metamorphism increased temperature is the predominant factor, and pressure is of minor importance. Normally, therefore, we get such rocks as hornfels formed under this type of metamorphism. Such types are characterized by their lack of directed character, since there has not been sufficient pressure to cause the formation of predominantly flat or acicular crystals, or the parallel orientation of the minerals. This type of metamorphism is found in the contact zones of intrusive bodies.

In the rocks under discussion, however, contact metamorphism plays a secondary part, being superimposed on rocks already subjected to regional metamorphism. Therefore we do not get the normal contact types, but simply a coarsening of the texture of previously metamorphosed rocks, and the conversion of minerals to high-temperature forms.

Daly states: "The large masses (batholiths?) of granite and orthogneiss have developed broad aureoles of normal contact metamorphism. In these the schists have become more or less massive, tough, and hornfelsy; the limestones are silicated, sometimes to a remarkable degree; and felspathization is common. The phyllites become garnetiferous, often coarse, mica schists. The greenstones, chlorite schists, and uralite schists become amphibolites and hornblende gneisses."

In the Aldridge formation an argillaceous quartzite has been converted into a garnetiferous mica schist containing sillimanite. The inversion point of sillimanite from cyanite is about 1350°C. Close to the intrusive the quartzite becomes knotted due to concentrations of carbonaceous material.

In the Salmon Arm formation phyllites become schists in the vicinity of the granitic intrusives, which here take the form of sills and dikes.

In the Ainsworth formation limestone has been converted to hornblendite, containing greenish-black secondary hornblende, probably originally augite, at the contact of a granitic body.

A good example of altered impure limestone occurs near Shuswap Lake near a granitic intrusion. The rock now contains calcite, orthoclase, andesine-labradorite, biotite, quartz, and abundant pyrite. The biotite is in very large flakes, probably recrystallized. The rock appears to have been feldspathized, silicated, and pyritized by the intrusive, as well as recrystallized.

A quartz biotite schist from the same region shows large flakes of biotite transverse to the schistosity at the contact of a small dike.

The last two examples are the only ones personally studied by the writer, since no igneous rocks were found in the North-Thompson-Clearwater district, so the subject of contact metamorphism must be left with this very sketchy statement.

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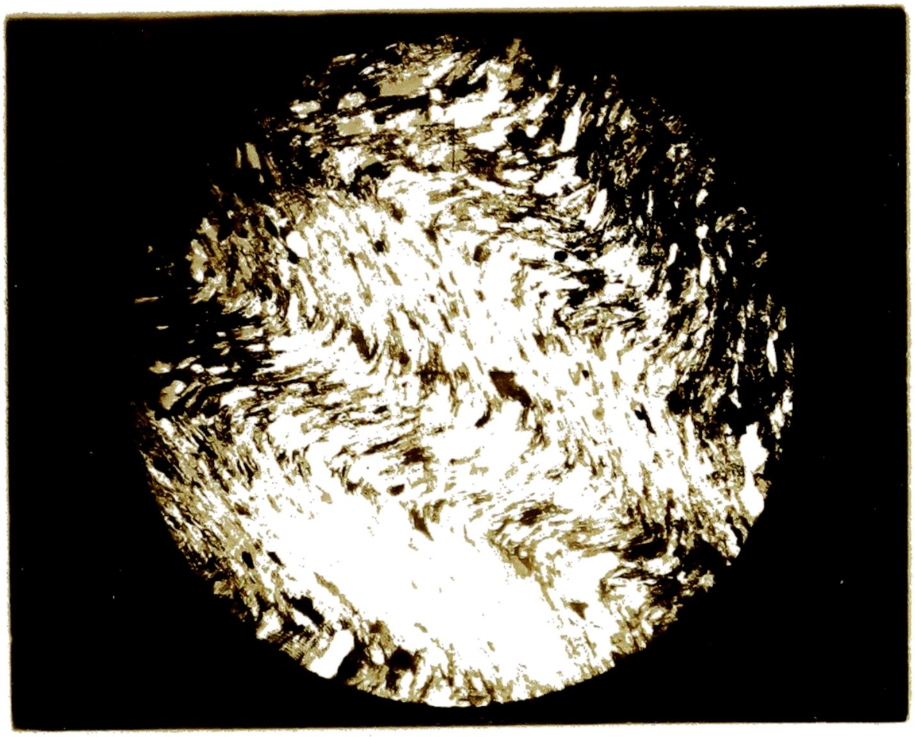
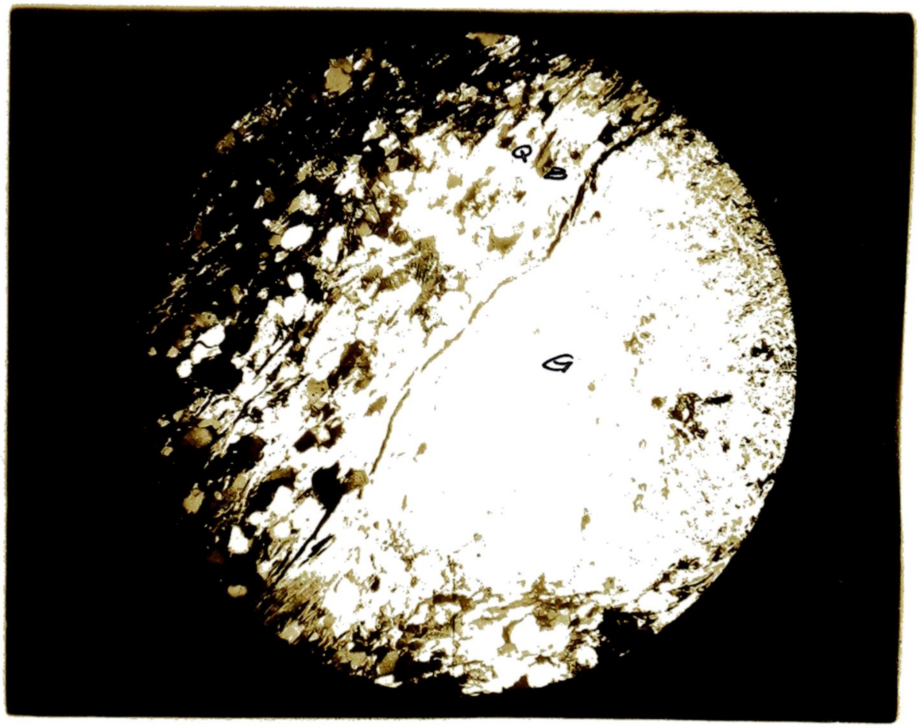
Abbreviations-
G.S.C.- Geological Survey of Canada

T.R.S.C.- Transactions of the Royal Society of Canada.



X82
Crossed Nichols

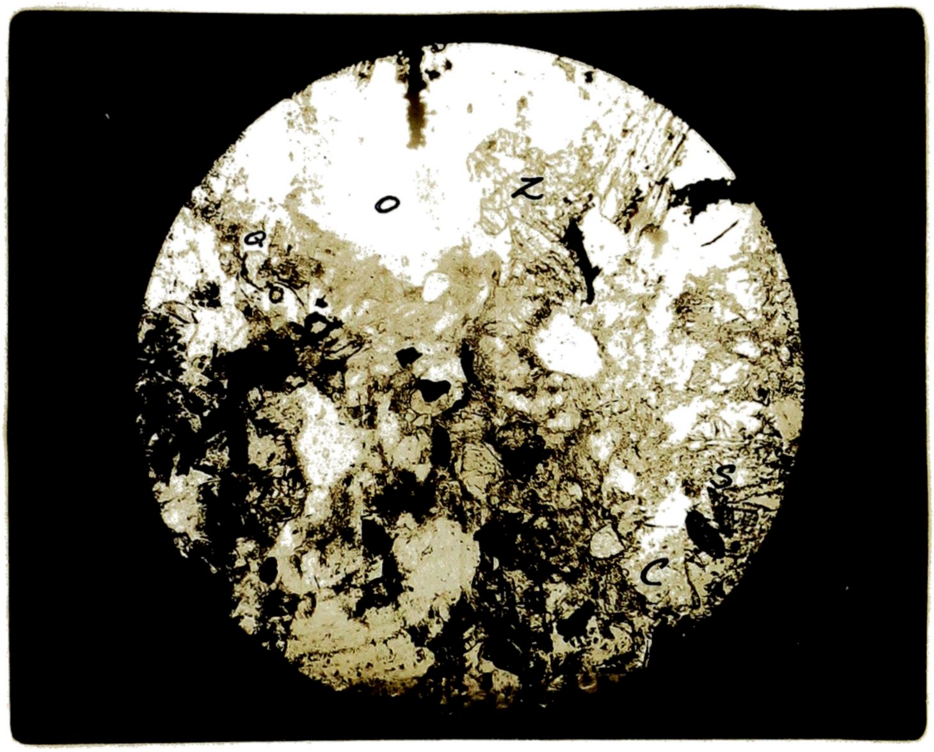
PUCKERING in ARGILLITE
Locality - Head of North Thompson River



Q - Quartz
B - Biotite
G - Garnet

X 82
plain polorized light

GARNET - QUARTZ - MICA SCHIST
Locality - West Kootenay

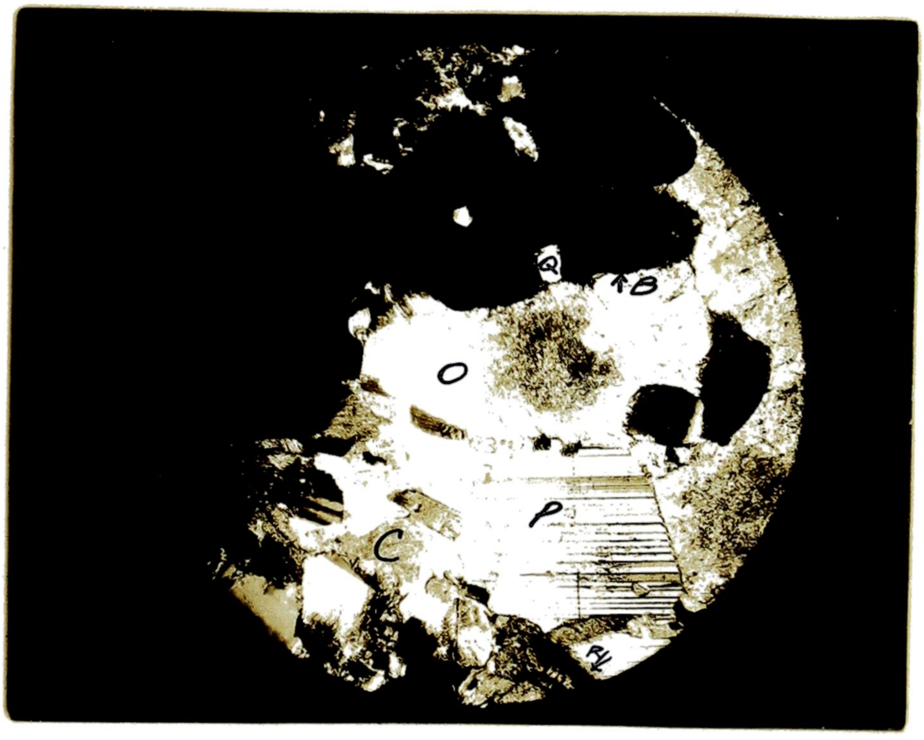


O - Orthoclase
Q - Quartz
Z - Zoisite
C - Calcite
S - Sphene

X82
plain polarized light

Calc-silicate Rock

Locality - Near Vernon (Shuswap Falls)



Q - Quartz
O - Orthoclase
P - Andesine - Labradorite
B - Biotite
C - Calcite
Py - Pyrite

X82

Crossed Nichols

Contact Met. Impure Limestone

Locality - Cotton Belt Mine - Shuswap Lake