# A SEDIMENTATION STUDY OF THE SLOCAN SERIES, SANDON AREA, BRITISH COLUMBIA

by

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## ABSTRACT

A study of the Slocan Series of South Eastern British Columbia along the three related paths of Lithology, Biology and Tectonics is made. The Lithotopes studied are mainly microscopic, though some megascopic characters are used to determine bottom conditions. The microscopic work was done on slides made from specimens taken at random on a cross-section of these sediments from near Zincton B.C. along the valleys of Seaton and Carpenter Creeks, to New Denver, B.C. The specimens indicated an increase of grain size and feldspar content from the bottom of the section towards the top. This is correlated with an increase in sediment supply and rate of subsidence. The fossils found by Cairnes show that these sediments were laid down in marine waters. A study of lithologic assemblages and types leads to some hypotheses. These, taken with a study of the Windermere geosynclinal assemblage, and theoretical considerations based on the orogenic cycle, allow a history of the area to be made. This history indicates that the Slocan Series, while the result of a separate downwarp of the crust, is probably part of the complex Purcell-Windermere geosynclinal sequence.

# ACKNOWLEDGMENTS

Grateful acknowledgment is expressed by the writer to Dr. Vladimir J. Okulitch, of the University of British Columbia, for his advice in the planning of this thesis. He examined the only fossil seen by the writer from the sediments of the Slocan series; this fossil was found by Mr. John Lamb, Geologist for the Kelowna Exploration Company.

Appreciation is expressed of the time given and the trouble taken by Dr. V. Dolar-Mantuani, of the University of British Columbia, who looked at all the thin-sections and offered much constructive criticism.

Thanks go also to Mr. William Sharp, Geologist for Kelowna Exploration Company, who kindly offered informal suggestions and advice in the field.

It is a pleasure to express my gratitude to Dr. Evans B. Mayo, Resident Geologist at the Nickel Plate Mine, for many encouraging letters and informative discussions on the subject of this thesis. Specifically, Dr. Mayo discussed with the writer and explained his conception of the structures affecting the Slocan series. He also discussed and rejected, in his opinion, an early idea of the writer's that the Slocan series as exposed in Sandon area is part of a single large deltaic deposit. Beyond these points the

writer must accept full responsibility for any and all observations of fact and inference from theory which are found in the following pages.

TABLE OF CONTENTS

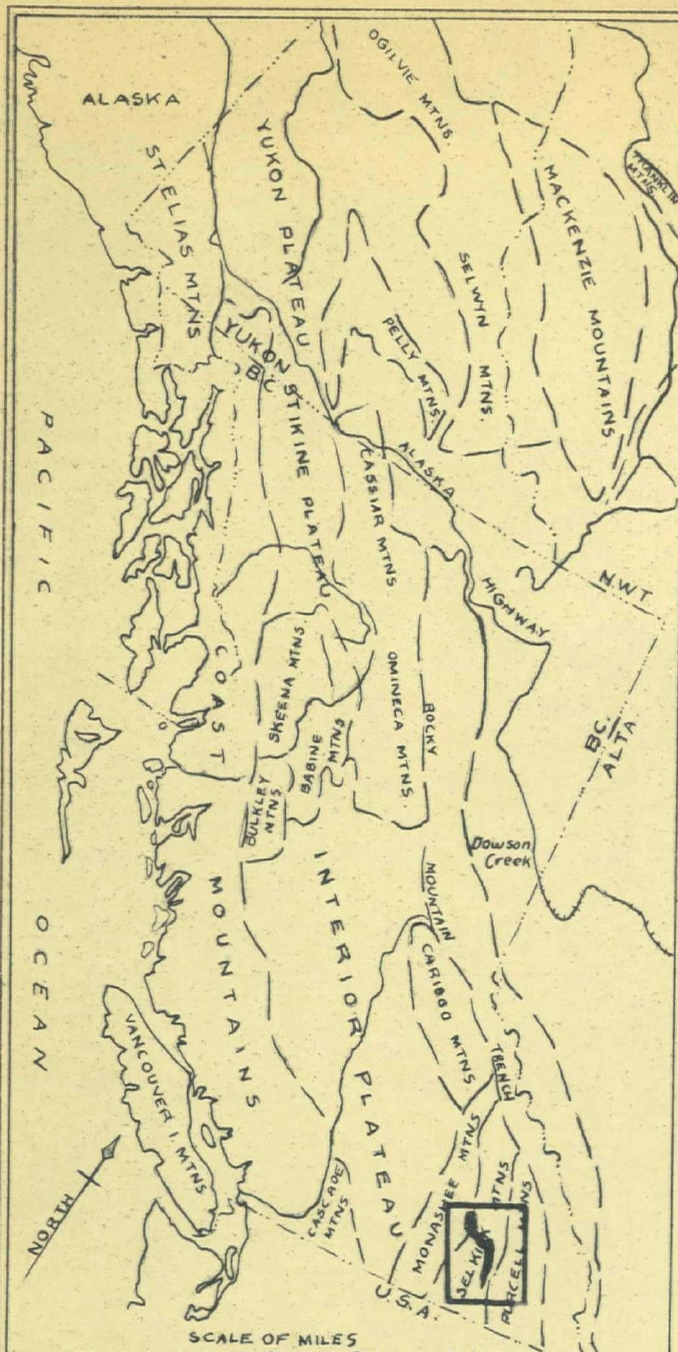


FIGURE - 1

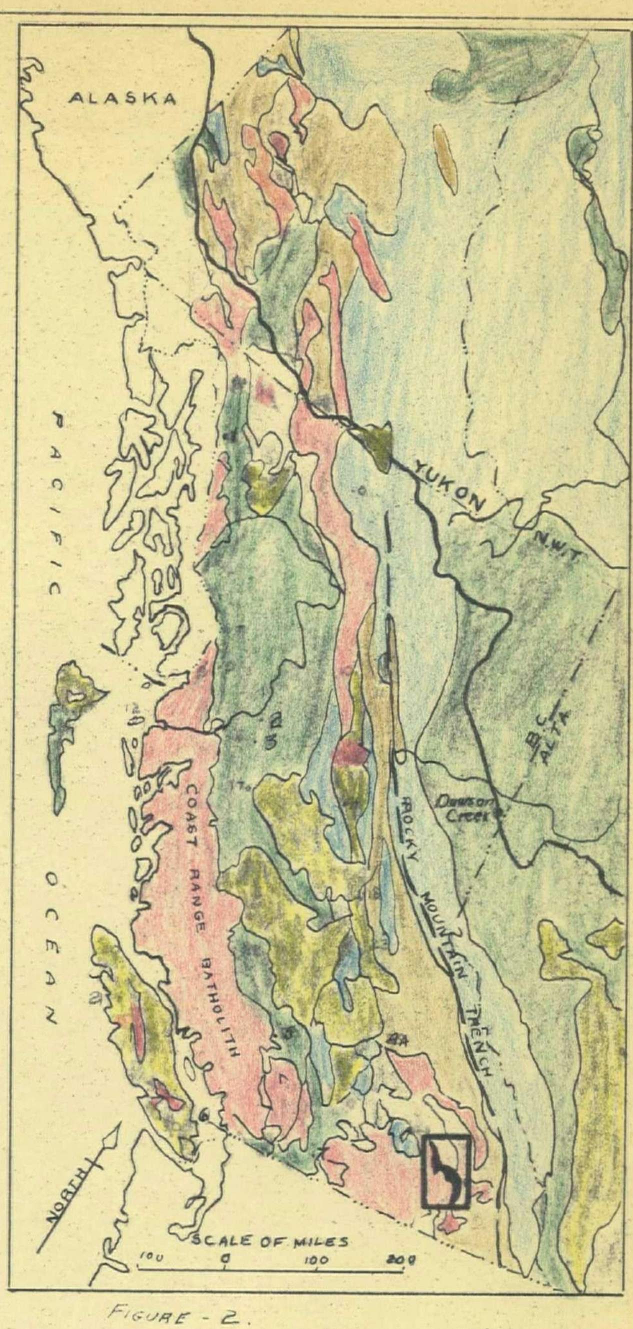


FIGURE - 2.

LEGEND

- Chiefly Tertiary strata.
- Chiefly Mesozoic strata.
- Chiefly Paleozoic strata.
- Chiefly Precambrian strata.
- Chiefly intrusive rocks.
- Approximate Shape & Location of the SLOCAN SERIES

1. Polaris Taku
2. Hazelton.
3. Surf Inlet.
4. Pinchi Lake.
4A. Wind Pass.
5. Bridge River.
6. Twin J
7. Hedley

Fig. 1 Diagram showing Main Physiographic Divisions of Canadian Cordilleran region, and approximate location of the SLOCAN SERIES.

Fig. 2 Diagram showing main geological features and some principal lode mines and camps in Canadian Cordillera. and gross geological setting of SLOCAN SERIES.

CORDILLERAN SETTING OF SLOCAN SERIES

Sketches after G.S.C. from C.I.M. Jubilee Volume.

PLATE I

to face p IV

# INTRODUCTION

## Location and General Geology

The location of the area studied is shown in Plates I, II, and X.

Plate I shows the general Cordilleran setting of the Series and Plate II gives the names and location of maps and reports which describe the Slocan and related series. Plate X is a composite map showing the regional geology.

The section of the Slocan series with which the writer is most familiar and with which this thesis is mostly concerned lies in the Selkirk Mountains in the vicinity of Sandon, B.C. This area is also the section in which the Slocan series has its greatest areal exposure.

The Slocan series is referred to the Triassic by Cairnes and "forms the largest single known area of Mesozoic sediments in the Selkirk Mountains" (3). The contact and age relationships of the series will be discussed in section VII. Briefly, the series is underlain by the Kaslo series which is in turn underlain by the Carboniferous Milford series.

The Slocan series is composed of a great thickness of argillites, limestones, quartzites, and some tuffaceous beds. The Kaslo series is made up of lenses of volcanogenic sediments associated with sheets, dikes, plugs, and lacco-

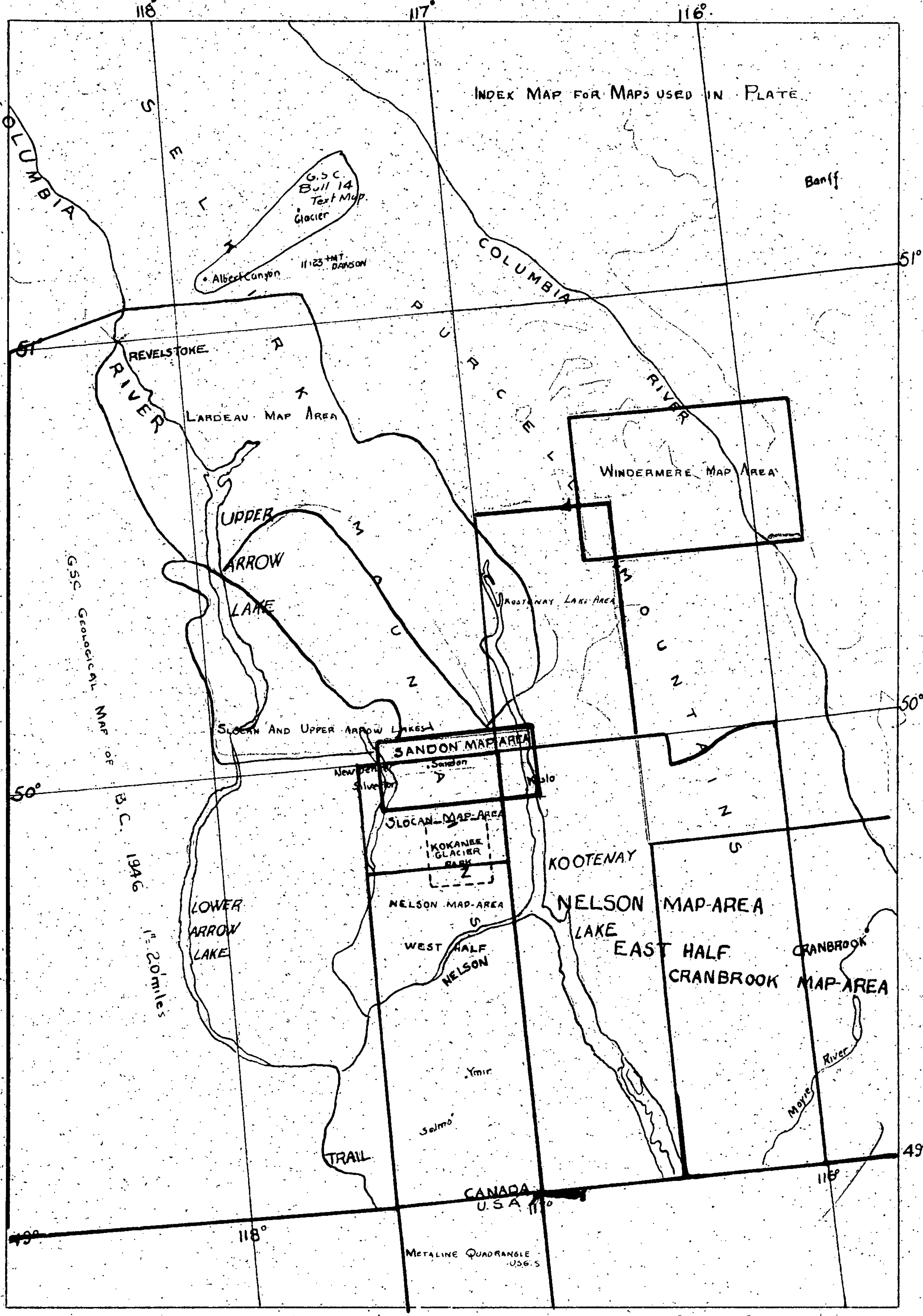


Plate II

to face p. 1

lithic masses of related intrusives. The Milford series underlying or cut by members of the Kaslo series is composed of an assemblage of limestones, slates, argillites, quartzites, and minor intrusive masses.

The formations to the east of the Slocan series range in age from Late-Pre-Cambrian to (?) Tertiary, but Pre-Cambrian measures occupy the major part of the Selkirk Mountains. The Nelson and Kuskanax batholiths and a host of attending minor stocks, dikes and sills intrude the sedimentary assemblage. A number of these larger stocks and a great number of minor dikes intrude the Slocan series in the Sandon area.

The rocks to the west of the Slocan series are crystalline schists, crystalline limestones, and paragneiss. These rocks have been referred to the Late Pre-Cambrian by Cairnes (3).

Topography

The following very brief description is adapted from Cairnes (3). The area in which the Slocan series is exposed is one of strong mountainous relief. There are no extensive uplands. The valley walls have comparatively uniform slopes of moderate angle. The areas of Nelson granite and Kaslo series are normally more rugged and sharper in outline than those underlain by sediments of the Slocan series and usually are higher in elevation.

Slocan and Kootenay Lakes occupy prominent linear valleys which in part cut across and in part coincide with

PLATE A

View taken from Silver Ridge looking northwest across Slocan Lake toward the Valhalla mountains . New Denver is in lower foreground.

to face p 2

the geological structures. These valleys are interpreted by Cairnes (3) to be the result of erosion by antecedent rivers.

Purpose of the Study and Materials Used

This thesis is an attempt to determine the depositional environments, source area and dominant tectonic activity affecting the formation of the Slocan series of South Eastern British Columbia.

It is also an attempt to use Holmes' conception of the orogenic cycle (7) in order to determine the time and space relationships of these rocks with some of the bordering assemblages of strata in this region of the Canadian Cordillera.

The materials used in this study are: published maps and reports of the Geological Survey of Canada and the United States Geological Survey, describing areas in which these and related rocks are exposed; a reconnaissance cross-section survey of these sediments by the writer from near their lower contact with the Kaslo series, east of Zincton B.C. to their disappearance beneath the waters of Slocan Lake near New Denver B.C.; and a microscopic study of representative lithologic types collected by the writer on this cross-section.

The field season of 1949 was spent by the writer in observing rock types, primary features and structural details of these sediments while assisting in a detailed geological mapping project for the Kelowna Exploration Company of Hedley, B.C. The general impressions of this experience are used in this study.

Four days were spend in the field mapping the cross-section mentioned above and three field days in an unsuccessful search for fossils. About four weeks were spent by the writer examining slides of hand specimens collected on the above cross-section. Many evenings of the summer of 1950 were spent in the preparation of maps and illustrations and the writing of this thesis in the geological office of the Nickel Plate Mine near Hedley,B.C.

It must be understood that this study is in no sense the final word on this aspect of the geology of the Slocan series. The conclusions are tentative and based upon incomplete data; still it is hoped that continued systematic observations along the lines sketched below could prove or disprove the following inferences and build up a more accurate picture of the stratigraphy of this section of the Canadian Cordilleran sediments.

Field Work

The generalized results of the field work done is shown on Plate V. The outcrops examined were those found in road cuts, railroad right-of-way cuts and stream banks. In addition to the reconnaissance traverses mentioned earlier, many reconnaissance trips were made by Mr. W. Sharp, geologist for the Kelowna Exploration Company, and the writer up to the prominent ridges of the district. These trips were made as part of the above company's

PLATE B

View taken from Silver Ridge looking northeast up the valley of Kane Creek. View shows the northwest side of seaton Creek valley. The Kaslo Volcanics and the Milford series form the high peaks in the background.

to face p 4.

'economic' mapping of the region. The generalized results of some of these trips are shown on Plate V.

For a distance of about 2000 feet vertically above Carpenter creek on the south slope of Carpenter Mountain a thick series of mostly vertical strata which had a northwest strike and 'tops' west were mapped. These observations taken with those shown on the west slope of Howson Creek, indicate that the axis of an overturned anticline lies at least two thousand feet above the valley bottoms. The exact location of the trace of the axis of the overturn and, indeed, none of the structural details of the region are of great import in a sedimentation study of this type. Once the major structural picture has been unravelled and the location of the strata with respect to the major structural pattern is determined then the primary and secondary characters of the rocks themselves are the important elements is a study of sedimentation and history.

On a reconnaissance trip on the east slope of Carpenter Creek above Cody and near the Reco-Texas Peak ridge an overturn was mapped by Mr. Sharp and the writer from observations of 'tops' (determined by cross-bedding) and by the attitudes of the beds. The approximate location of this overturn is shown on Plate V.

In addition to these trips four months of day-by-day mapping in the Howson Creek Queen Bess area has convinced the writer of the validity of the overturn concept since only when the broad structural pattern was kept in mind did the minor details of drag-folding, 'tops' and attitudes of strata become coherent.

The above mapping experience furnished the writer with ample opportunity for observing minor primary characters of the Slocan series such as cross-bedding, graded bedding and so forth. A familiarity with lithologic types was attained also during the course of this work. About fifteen observations of the orientation of cross-laminations were made during the course of the seasons work. These will be discussed later.

The observations noted on the cross-sectional traverses, mentioned earlier, were plotted directly on 8½ x 11" sheets onto which had been traced some geological features, roads, streams and other topographical details. These details were traced from an enlargement made by Mr. J. Lamb of part of Cairnes' map of the area (G.S.C. Map 273A). Position on the ground was determined by pacing and bearing to these topographic features.

The predominant rock type found on the Sandon-Three Forks traverse was a very black and soft carbonaceous shale. These rocks were found in formations which dipped steeply to the west. The strike was the regional one, i.e. northwest. There were a few outcrops where the dip was noted to be to the east. This rock was pyritiferous in part but in general consisted entirely of black fine grained material.

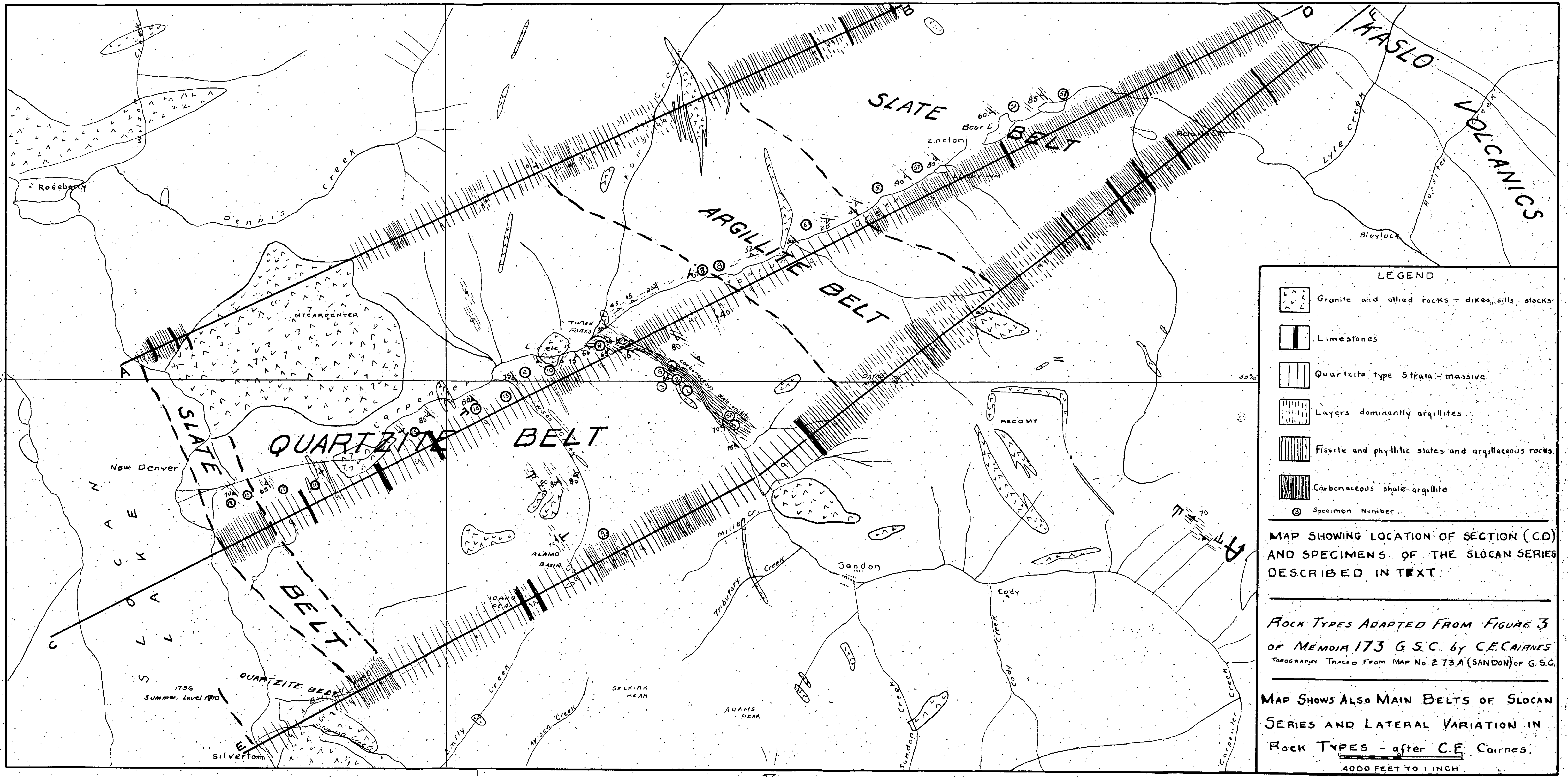
117°20'
117°05'
50°00'
50°00'
SLATE BELT
ARGILLITE BELT
QUARTZITE BELT
SLATE BELT
KASLO VOLCANICS
SLOCAN LAKE
Rosebery
Dennis Creek
Wilson Creek
MT. CARPENTER
THREE FORKS
Carpenter Cr.
New Denver
Zincton
Bear L.
Lyle Creek
Blaylock
Alamo Basin
Idaho Peak
Sandon
Cody
Miller Cr.
Tributary Creek
Selkirk Peak
Adams Peak
Emily Creek
Alyson Creek
Sandon Creek
Cody Creek
Carpenter Creek
Silverton
QUARTZITE BELT
1756 Summer Level 1910
RECO MT.
LEGEND
Granite and allied rocks - dikes, sills, stocks
Limestones
Quartzite type Strata - massive
Layers dominantly argillites
Fissile and phyllitic slates and argillaceous rocks
Carbonaceous shale-argillite
Specimen Number
MAP SHOWING LOCATION OF SECTION (CD) AND SPECIMENS OF THE SLOCAN SERIES DESCRIBED IN TEXT.
Rock Types Adapted From Figure 3 of Memoir 173 G.S.C. by C.E. Cairnes
Topography Traced From Map No. 273 A (SANDON) of G.S.C.
Map Shows Also Main Belts of Slocan Series and Lateral Variation in Rock Types - after C.E. Cairnes.
4000 FEET TO 1 INCH

PLATE V

In some areas the rock had weathered readily and broken into small red colored chips and gragments. Apparently the more advanced the weathering the redder in color the chips became.

Approaching Three Forks the rocks were harder. Argillites and argillaceous quartzites were encountered here. A large piece of conglomeratic float was found under one of the railway bridges near Three Forks. This was a rounded boulder about three feet in diameter. This boulder was composed of fine grained to coarse fragments of argillite. All the fragments were cemented together by argillaceous material. All the fragments were rounded to subangular. As this was a piece of float no interpretation can be placed upon this conglomerate from the point of view of sedimentation. Pettijohn has described a similar type of boulder and called it 'Mudball'. On the numerous trips the writer made up the Carpenter Creek there were no bedded rocks in place which corresponded even remotely with this 'conglomerate.' According to Pettijohn such boulders may be formed by the accretion of small rocks and pebbles to a nucleus of possibly a large mud-covered pebble,(as this nucleus is rolled in a stream bed.) The growth of the boulder is similar to the growth of a snowball as it rolls downhill.

Some fissile slates interbedded with thicker bedded argillites were found near Three Forks. These fissile slates consisted mainly of dark grey argillaceous layers with some sandy partings. Usually there was some evidence of dynamic metamorphism in the form of fine crenulations on the bedding planes.

From Sandon to about three miles from Three Forks no outcrops were encountered. In general throughout Sandon area the lower slopes of the valleys and many of the flat-topped ridges were commonly drift covered and outcrops scarce.

On the Three Forks-Zincton traverse the most striking feature was the change in strike of the beds. The predominant strike for at least a mile and a half from Three Forks was north east whereas the regional strike is northwest. The rock types encountered on this traverse were chiefly massive argillites and fissile slates. Some limestone members were seen also. In general dips here are less steep than to the west. They varied from twenty to fifty degrees.

Some large folds in the soft sediments were seen from the railroad but were not mapped. The general impression from this traverse is of an area of badly contorted incompetent strata. Detailed mapping, particularly on the London ridge side of Seaton Creek could possibly unravel the detailed structural picture. For about one mile and a half from west of Zincton to about one mile east of this village soft fissile slates were encountered.

The outcrops in road cuts along the Three Forks-

New Denver road were almost continuous. These rocks in general were more massive and harder. The types seen were mostly argillaceous quartzites and quartzites. The rocks appeared to be coarser grained than those east of Three Forks. No progressive increase in grain size could be deduced from megascopic examination. A dolomitic member was mapped near the projected location of a limestone band as shown in Cairnes' Section C-D (Plate III). Metamorphism near intrusive masses did not persist far from the contacts.

The strata in this traverse dipped steeply to the west for the most part. However some very steep east dips were encountered. The strike of these rocks was quite consistent and conformed to the regional attitude closely.

The primary and secondary features of the rocks seen on these traverses will be described in the following pages. The foregoing brief description of the geology of the area is intended to furnish a background for the succeeding discussion.

## APPROACH TO SEDIMENTATION ANALYSIS OF SLOCAN SERIES

An attempt will be made in this thesis to apply the principle that problems of sedimentation are 'most logically approached along three interrelated paths: lithology, biology, and tectonics'. (1)

The writer intends to use three terms suggested by Sloss et al (23). However the definition of these terms will be somewhat more extended than suggested in the above paper.

Lithotope This term refers to any single characteristic of a sedimentary deposit useful in reconstructing the sedimentary history of that deposit, which may properly be referred to lithology. For example, textures and structures which are environmentally significant are lithotopes. Thus cross-bedding could be a lithotope.

Biotope This term designates floral or faunal characteristics of a deposit which may aid in the interpretation of conditions of sedimentation of the deposit. For example, "a crinoid fragmental limestone and a coarse sandstone may represent identical dynamic but radically different ecological conditions." (2) Thus in a rock unit which contained fragmental crinoid columns this characteristic would be a biotope.

(1) (23) p. 91
(2) (23) p. 95

Tectotope A tectotope is a single characteristic of a deposit which indicates the dominant tectonic activity affecting the accumulation of that deposit. For example, a thick series of greywackes below a series of impure quartzites intercalated with volcanic intrusives would indicate eugeosynclinal deposition, and a lithologic assemblage of this sort would be a tectotope. Tectotopes are normally strata or successions of strata with gross and minor lithologic characteristics which are of tectonic significance.

The Slocan Series will be studied in terms of lithotopes, biotopes, and tectotopes. From the distribution and character of these sedimentation elements, interpretations of the paleogeography of the area can be made. Studies of large stratigraphic units are most useful in determining the tectonic aspects of the area in which sedimentary deposits were made. For this reason a consideration of the regional geology of the Slocan Series is essential. The geologic history of the whole area can shed light on the shorter term events and conditions involved in the formation of the Slocan series. An attempt at an elementary analysis of this type will be made in the following pages.

We will consider first the rocks and their primary features, then organisms contained in the rocks or affecting directly or indirectly the deposit formed, and, finally a limited regional tectonic appraisal and study of the regional history of the larger stratigraphic unit, of which the Slocan series is a part, will be made.

However, before considering the above elements, a brief discussion of the structural geology of the Slocan series as developed near Sandon is necessary.

STRUCTURAL GEOLOGY OF SLOCAN SERIES IN SANDON AREA

Cairnes (3) made the first generalization concerning the structure of these rocks. He recognized the complexity of the structure but subsequent investigations have shown these series to be more complex structurally than he had conceived. Cairnes' conception was that "the Slocan strata lie in numerous dome-shaped and basin-shaped folds."[1] Plate III shows Cairnes' conception and some of his structure sections. Mayo was first to recognize that overturning was an important element of the structural picture. In the summer of 1941, while mapping for the Kelowna Exploration Company on Payne Mountain, near Sandon, he found clear evidence of a major overturn in the tilted strata. Subsequent detailed mapping in succeeding summers clearly showed that there was many steep or gentle layers with 'tops' down. The evidence for this was chiefly cross-bedding. Moreover, drag-fold patterns corroborated these determinations in every instance. Furthermore, based on the concept of recumbent folds with overturned limbs, a coherent structural picture emerged which has formed the basis of much economic work by the Kelowna Exploration Company in Sandon area. Plate IV, which is adapted from a sketch kindly lent by Mayo to the writer, shows in idealized form

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[1] (3) p. 57.

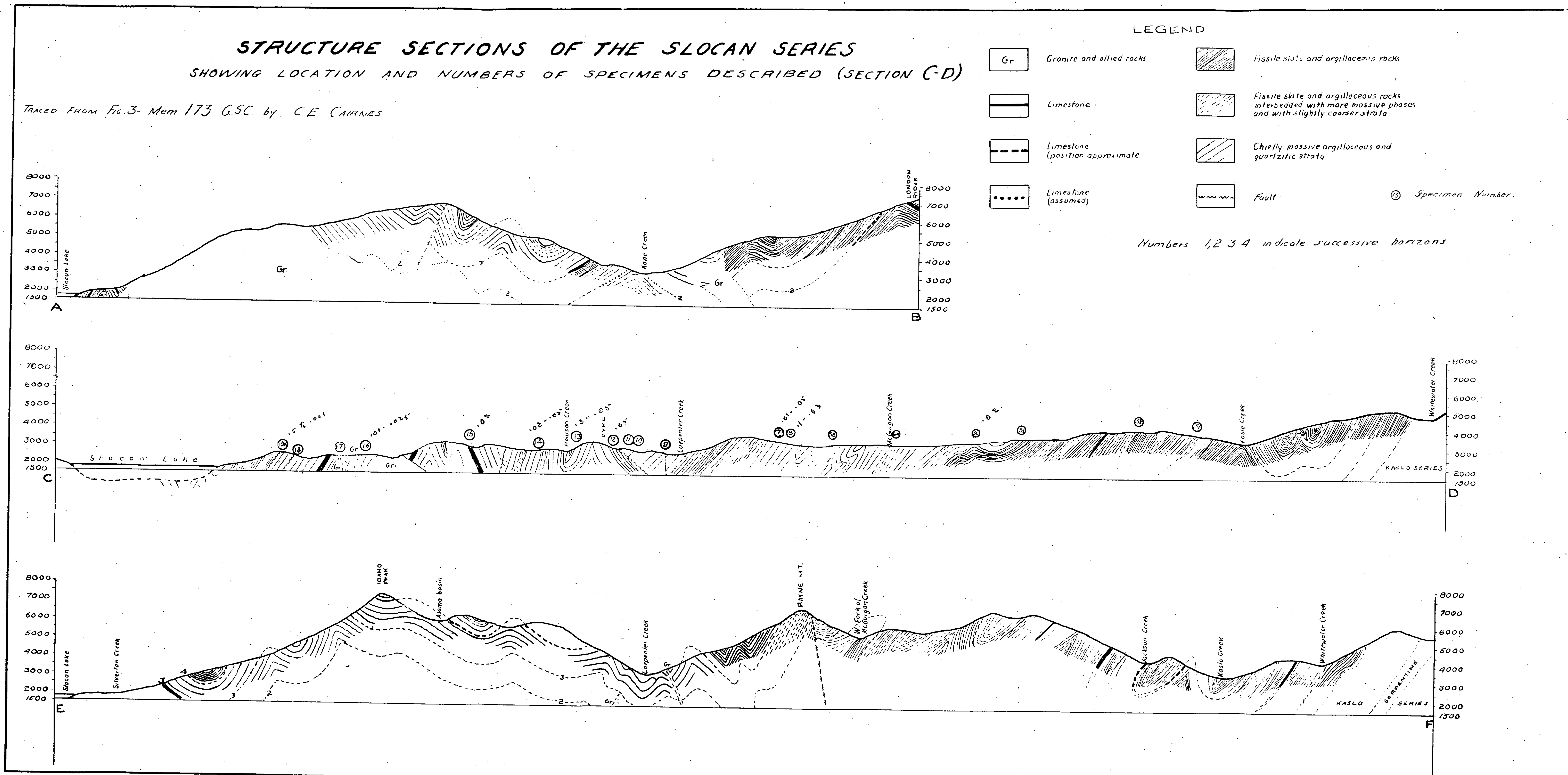
STRUCTURE SECTIONS OF THE SLOCAN SERIES
SHOWING LOCATION AND NUMBERS OF SPECIMENS DESCRIBED (SECTION C-D)
TRACED FROM FIG. 3 - Mem. 173 G.S.C. by C.E. CAIRNES
LEGEND
Gr. Granite and allied rocks
Limestone
Limestone (position approximate
Limestone (assumed)
Fissile slate and argillaceous rocks
Fissile slate and argillaceous rocks interbedded with more massive phases and with slightly coarser strata
Chiefly massive argillaceous and quartzitic strata
Fault
Specimen Number
Numbers 1, 2 3 4 indicate successive horizons
Slocan Lake
Kane Creek
London Ridge
Slocan Lake
Howson Creek
Dyke
Carpenter Creek
McGuigan Creek
Kaslo Creek
Whitewater Creek
Kaslo Series
Slocan Lake
Silverton Creek
Idaho Peak
Alamo basin
Carpenter Creek
Payne Mt.
W. Fork of McGuigan Creek
Jackson Creek
Kaslo Creek
Whitewater Creek
Kaslo
Serpentine
Series

PLATE III.

the concept of the structure of the Slocan series in the area near Sandon. The following quotation from a personal communication by Mayo describes in somewhat greater detail the origins and elaboration of the structural concept now accepted by those geologists who have worked in the area but who have as yet not published their findings.

"Development of Ideas on Structure in Slocan District

At the time of publication of C. E. Cairne's memoir on the Slocan District, the Triassic (?) sediments of that area were supposed to be deformed in to upright, more or less symmetrical anticlines and synclines. This concept of the structure appeared to be supported by the work done in 1939 by L. W. Cramer, for Kelowna Exploration Company.

In 1940, Mayo, assisted by Cramer, mapped part of the surface geology of Payne Mountain. The structure mapped appeared to be a syncline, but recognizable horizons on one flank of this fold were not repeated on the other flank. Somewhat later in 1940 Mayo mapped the accessible underground geology of the Payne Mine, which lay athwart the supposed syncline. The underground structure did not even remotely resemble a syncline. Among the surface structure mapped was a band of southwesterly dipping rocks almost vertically above rocks with northeasterly dip. Unfortunately, the significance of these observations was not realized, and at the close of the 1940 field season no coherent structural picture had been obtained.

In 1941, Mayo made a very detailed traverse across the axis of the supposed Payne syncline. In the course of this traverse, a small cliff, perhaps 20 feet high was descended at the top of the cliff, strata dipped southwestward, and at its base the beds dipped northeastward. From a trail at the base of the cliff, the actual <u>overturn</u> of the strata could be seen. Reconnaissance established the "Payne overturn" in the place of the Payne syncline, and its axis was traced for several thousand feet along the southwestern slope of the mountain. A structure section, using the then available data, showed the axial plane of the Payne overturn to dip northeasterly from its surface outcrop. Some 5 years later, Mr. Paul Billingsley using Mayo's field notes, made a number of structure sections of the southwestern slope of Payne mountain and the slopes south of Carpenter Creek. These sections showed the axial plane to dip southwesterly, and Billingsley then predicted that the Payne overturn would be found in the Ruth mine. This prediction was verified by A. E. Buller in the winter of 1946-47.

Meanwhile, in the Fall of 1941 Mayo mapped the geology of the 5 level, Queen Bess mine. Here Cramer, in 1939 had mapped a syncline on surface, which he termed the Queen Bess syncline. He had traced its axis for many thousands of feet, into Carnation basin to the southeast. The underground mapping again failed to reveal anything like a syncline, but the brief time available did not

# HYPOTHETICAL COMPOSITE STRUCTURAL SECTION OF THE SLOCAN AND OLDER SERIES

SEE PAGE 15

permit recognition of the true structure.

In 1946 Billingsley and Buller, examining Cramer's maps, noticed a place where the east dipping limb of the supposed Queen Bess syncline was almost vertically above its west dipping limb. They then recognized that here was another overturn, concave west, convex east. The Payne overturn was convex westward, concave eastward. The Queen Bess overturn lay above the Payne overturn, and was opposite in kind. Billingsley and Buller then arrived at the conclusion that the Slocan sediments had been deformed into a pile of recumbent anticlines and synclines, but there was at that time no means of telling which were anticlines and which were synclines.

In 1947, Mayo, then in charge of geological investigations for Kelowna Exploration Company in the Slocan district, started a systematic search for those primary depositional features that might reveal which beds were right side up, and which inverted. In this work he was ably assisted by W. M. Sharp and John Lamb. At about the same time a field party under the direction of Dr. M. S. Hedley of the B. C. Department of Mines, began a similar program. Of all the primary features found, cross-bedding proved to be the most useful. The many observations of this feature proved that the Payne overturn was a recumbent anticline; the Queen Bess a syncline. Roots of these folds should lie to the northeast.

In 1948, observations on the nature and distribution of minor drag folds proved that the recumbent anticlines and synclines were dominated by the flexural-slip mechanism. The directions of rotation about the minor fold axes agreed with the observations on cross bedding, and thus provided a double check on the structure. The sequence, as determined to date is:

Top 1. Silver Ridge recumbent anticline, tightly oppressed.

2. Queen Bess recumbent syncline.

Bottom 3. Payne recumbent anticline.

In 1949 some reconnaissance studies were made along the Kaslo River, and one structure section was made on a southwestern spur of the Slocan Alps. As a result, it was suggested:

1. That the roots of the "overturns" lie in the schist belt, just southwest of of the Kaslo volcanics.

2. That the Kaslo volcanics once arched, carapace-like over the pile of Slocan recumbent folds.

3. That, therefore this volcanic carapace must be the case of a huge overturned fold, with root beneath the present Kaslo outcrop, and upper limb northeast of the Kalso, and represented by that part of the Milford series nearest the Kaslo.

4. The "floor" underneath the recumbent folds must be the schists and gneisses such as outcrop in the Valhalla Mountains."

The composite structure section of Plate IV shows the axes of overturns higher than Mayo has described in the above quotation. This was done purposely by the writer because at the time this sketch was made, for policy reasons the Kelowna Exploration Compahy did not wish the exact location of the axes of overturns to be divulged. However, as the exact location of axes was of no import to this subject the writer decided to draw a generalized even somewhat incorrect structure section. The main idea that a traverse through these rocks was possible from bottom to top and would furnish an opportunity for the study of lithotopes and biotopes in sequence is illustrated in this section. This was one of the main purposes of this sketch and the writer feels this purpose was accomplished.

In addition to the above purpose the writer wished to show how the mechanism of sub-crustal convective currents and isostatic uplift of the 'root' might produce this type of structure.

The writer has no information concerning the structure of the series in areas of the Slocan strata not shown on Plate V. Interestingly enough one of Cairnes' structure sections (Section C-D, plate III near Three Forks) shows clearly a drag-fold occurring in competent beds of quartzite and argillite which from its pattern could occur only on the west-dipping limb of a recumbent fold, and could not possibly have occurred on the limb of an open broad fold. The writer is satisfied after one summer of mapping in the field, both of detailed and reconnaissance nature, that the broad structural picture as conceived by Mayo is valid. However in detail, as Cairnes realized, the structure of the Slocan series remains complex, especially so in the Slate Belt.

From the point of view of sedimentation study of the Slocan series, the recumbent folding concept is a very happy one. As Plate V and X show, the valley of Carpenter Creek furnishes a deep cut through the whole series at right angles to the regional strike. This means in effect that the steeply tilted strata here exposed in almost continuous section in stream and road cuts are a continuous record of the sedimentation history of the Slocan series. Beyond Three Forks towards White Water and Zincton the strike of the strata in many places almost parallels the valley of Seaton Creek and so the section here is not so useful for a sedimentation study. However there are many hundreds of feet of strata which do cross the valley and the road and railway cuts, and even here the vertical succession of strata can be seen clearly.

There will be no attempt here to give more than the above essentials of the structural picture, since such an exposition could only be and most probably will be described in papers by those geologists mainly responsible for unravelling the complexities of Slocan series structure.

There is, however, one point which should be mentioned here as pertinent to a discussion of this type.

Cairnes had measured and stated the thickness of the Slocan series to be only 6,800 feet. This figure was based on the structural concept of broad open folds. However since this concept is no longer valid, the figure for the total thickness of the series is also invalid. The writer will not attempt to give a figure for the thickness of the series. All that can be stated here is that the series is much thicker than 6,800 feet. A glance at and comparison of the structure sections of Cairnes and the sketch of Plate V will show this fact quite clearly. As total thickness of a stratigraphic unit is a tectotope, this fact then has sedimentation significance. Further discussion of the new structural concept of the Slocan series is reserved for the section on theoretical considerations.

## LITHOLOGY OF THE SLOCAN SERIES

The lithotopes most useful in sedimentation studies in rocks of Slocan series types are those determined mainly by microscopic methods. However, megascopic features are also useful. Testures, structures and composition are of course the most important lithotopes. Size range of the detrital particles on a single slide too can be used as a lithotope.

The location of the representative lithologic samples is shown on plates III and V. In addition to the section mentioned earlier a traverse from Sandon to Three Forks was made also. Samples were taken from this traverse as well as from the New Denver Zincton one, the location of samples taken from this traverse is also shown on these plates. This traverse is essentially parallel with the strike of rocks and gives some indication of the continuity of lithologic types along the strike of the formations.

An appendix gives brief petrographic reports on all of the speciments examined. A word here on the nature of the microscopic examination would be in order. The main object of the examination was to determine size and composition of the particles within rather wide limits. The percentages given are as accurate as two or three random traverses across the section with a stage micrometer would allow. No great accuracy for the determinations of size or percentage compositions is claimed, nor for the purposes of the thesis necessary. Also the method of sampling made a very accurate count of composition of little real significance.

In the following description of the lithology of the Slocan series as seen by the writer, rock types will be described in order of appearance from the basal part of the series as exposed in the Sandon area upwards to the youngest strata: that is, the rocks will be described in the order one would encounter them travelling from Zincton through Three Forks to New Denver along the main road and in the railway cuts.

Cairnes makes some generalizations on the petrology of the series which should be used to introduce this section: "The series comprises a variety of sediments which for convenience in description are classed as slates, argillites, limestones, quartzites, conglomerates, and tuffaceous beds. All gradations in textures and composition from one variety to the other may be found. In structure they range from massive blocky rocks to others notably fissile and slaty. The series has been subjected to varying degrees of local and regional, dynamic and thermal metamorphism" (3).

The writer did not see any true conglomerate but a variety of conglomerate which Pettijohn described as 'mudballs' (1) p. 146, composed of fragments of granite rocks, possibly from the Nelson Batholith and fragments of Slocan series argillite. Mayo (10) believes that what Cairnes has called basal conglomerate of the Slocan series in the Sandon area is not a true basal conflomerate. No tuffaceous beds were seen by the writer on the section examined.

Cairnes has excellent descriptions of rock types (pp.53-57 (3)) and it is not intended to repeat here these descriptions. Rather the types of rock actually seen and examined will be described as lithotopes. Included with the brief petrographic description will be one of megascopic lithotopes.

Subdivision of the Slocan Series

From cross sectional lithology, as shown in Figure 3 of Memoir 173, the Belts of Plate V were determined by simple projection to plan (See Plates III and V). Of course this is an oversimplified picture and is mainly a subdivision of convenience for descriptive purposes. In the Slate belt for example are limestone strata, quartzite strata, argillites and intermediate types. This division is thus one based on preponderance of lithologic type.

In view of the overfolded nature of the whole series it is not impossible that the second or 'youngest' slate belt is an overfolded segment of the oldest or western slate belt. A glance at Plate IV will indicate the plausibility of this hypothesis. In effect then we have only one slate belt, and the western belt can be considered from the point of view of sedimentation as part of the eastern one and does not record a change of conditions of the basin of deposition back to a state similar to those of Eastern Slate Belt time.

In overfolded strata such as the Slocan series a plan view of the lithology which does not take into account the structure can give a misleading picture concerning facies change. Apparently, in plan, limestone strata will grade out in strike into quartzite strata. This may however not be the case at all from the sedimentation point of view. Here the structural impress can be at least as important as the development of facies.

The only way of determing identity of strata on change of strata in strike or section is to "walk out" the beds. This is not possible in the Slocan series of Sandon area due to the scarcity of outcrop over large distances.

The writer has traced one band of carbonaceous shale for at least one mile from near Three Forks to several hundred yards east of Parapet. The Kelowna geologists have traced members further than that and with more certitude. Certainly then in view of structural factors, it is not impossible that conditions and types of sedimentation were consistent over large areas of the basin of deposition of the Slocan series. In other words, it is not necessary to state or assume that the strata were deposited as intertonguing mosaics of argillites, limestones and quartzites, though of course this may have happened.

Structure of the Slate Belt

The pronounced change in strike of the formations in the Slate Belt and the higher degree of metamorphosis apparently of dynamic type, indicates that this was a zone of adjustment of crustal forces. Hedley (6) believes that the apparent thickness of the series here is due to repetition of strata by small scale folding and faulting rather than due to large scale isoclinal folding as Cairnes indicated on his structure sections. In view of the new picture of the structure of the series, then it does seem that this area would be a center of complex deformation partly because of intensity of forces and partly because the strata involved were incompetent slates and yielded more readily than the more competent quartzitic strata to the west.

Lithotopes of the Slate Belt

The traverse ended in the Slate Belt. Lack of time made it impossible to reach the end of the Slate Belt and the contact with the Kaslo series. However, the writer feels he has seen all significant types of rock of this belt. In addition Hedley has excellent descriptions of this area (6). He states: "The sedimentary rocks are best referred to as slates. A number of distinct bands of limestone occur in them, as well as calcareous and quartzitic bands, but the bulk of the rocks are dark highly cleavable rocks of argillaceous character. Some are typical slates with poorly defined bedding; others are even more fissile and are properly speaking phyllites; some sections show an alternation of hard and soft beds. They range in color from various shades of grey to black and locally greenish."

Four specimens were collected from this area. All four were fine grained. One specimen showed cross lamination of the symmetrical type, that is the foreset layers are tangential to both the topset and the bottomset layers. The grain of the quartz particles was of silt size and dark argillaceous layers formed the dark line tangential to both bounding planes. This lithotope indicates very weak bottom currents. This specimen is illustrated in sketch C plate VII. The rapid alternation of <u>fine</u> argillaceous bands, with <u>fine</u> sandy bands in one of the specimens, could indicate during the time of deposition rather stable conditions of supply and basin floor. The general significance of slates and the limestone layers of this belt will be considered under the section on Tectonics. To summarize then, the lithotopes of these rocks would indicate, from the thinness of the beds, of the moderate to slow rate of sedimentation, moderate to shallow depths, since there is some evidence of bottom currents, and alternation of types of material deposited, i. e., clay and sandy silt material. The marl specimen would indicate a period of comparative crustal stability and fairly shallow water.[1]

Lithotopes of the 'Argillite Belt'

Three specimens were examined from this belt. They are massive argillites and quartzitic argillites. One showed rather vigorous alternation of argillaceous deposition with sandy deposition. The cross lamination seen in these strata i.e. truncated foreset layers would indicate more vigorous dynamic conditions on the basin bottom.

Actually this would be a good condition for the burial of benthonic organism. However, little or no evidence of life is found in these rocks. The angularity of the larger fragments would indicate both slight reworking and short transport of the fragments. There does seem, however, to be fairly good sorting in these fine grained rocks. One can conclude then that the supply of material was good and the rate of the subsidence of the basin was increasing, though basin conditions remained fairly shallow, certainly above abyssal depths. Nevertheless the depths may have approached bathyal limits for the lack of sunlight at these depths would inhibit the development of benthonic forms and any calcareous shell which might fall into these

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1 Pettijohn, p. 454.

depths would be dissolved. The assumption of bathyal depths could help to account for the absence of life.

Structure of the 'Argillite' and the 'Quartzite Belts'.

The structure of both these belts is apparently a homocline dipping very steeply to the west. However these layers are actually part, that is, the west dipping limb, of a major recumbent fold overturned to the east. There is possibly some repetition of strata due to faulting, though the writer found no obvious evidence that this has happened. Certainly such faulting could have happened and the apparent thickness be thereby much reduced.

Lithotopes of the 'Quartzite Belt'.

This area is one with which the writer is by far the most familiar. Eleven samples were taken from this section partly because it is the widest but also because, according to Pettijohn, the quartzitic or coarser grained members of a sedimentary deposit supply the most information concerning the sedimentation processes. No attempt will be made to describe in detail each specimen since this has been done in the appendix. The lithotopes of the section which are most significant will be described in the following order: texture, composition, and primary structures. The following tables show some results of measurement of grain sizes and estimation of composition in slides of specimens taken from the 'Quartzite Belt'. The location of the Specimens is shown on Plates V and III.

Table 1. Average Grain Size of Quarts and Feldspar Grains

| | |
|---|---|
| Specimen Number 19 | .15 mm |
| Specimen Number 18 | .10 mm |
| Specimen Number 17 | .07 mm |
| Specimen Number 16 | .05 mm |
| Specimen Number 15 | .02 mm |
| Specimen Number 14 | .05 mm |
| Specimen Number A 225 | .05 mm |
| Specimen Number 13 | .10 mm |
| Specimen Number 12 | .05 mm |
| Specimen Number 9 | .05 mm |

- - - - - - - - - - - - - - - - -

Table 2. Range of Grain Sizes of Quarts and Feldspar Grains

| | |
|---|---|
| Specimen Number 19 | .5 mm - .001 mm |
| Specimen Number 18 | .5 mm - .001 mm |
| Specimen Number 17 | Not measured |
| Specimen Number 16 | .01 mm - .025 mm |
| Specimen Number 15 | .03 mm - .01 mm |
| Specimen Number 14 | .05 mm - .02 mm |
| Specimen Number A 225 | .1 mm - .025 mm |
| Specimen Number 13 | .3 mm - .05 mm |
| Specimen Number 12 | .06 mm - .04 mm |
| Specimen Number 9 | .06 mm - .04 mm |

- - - - - - - - - - - - - - - - -

Table 3. Detrital Feldspar Grain Content

| | |
|---|---|
| Specimen Number 19 | -- 20% |
| Specimen Number 18 | -- 10% |
| Specimen Number 17 | -- Not estimated |
| Specimen Number 16 | -- 5 - 10% |
| Specimen Number 15 | -- 0% |
| Specimen Number A 225 | -- 2 - 3% |
| Specimen Number 14 | -- Not estimated |
| Specimen Number 13 | -- 2 - 3% |
| Specimen Number 12 | -- Not estimated |
| Specimen Number 9 | -- Not estimated |

- - - - - - - - - - - - - - - - -

Table 4. Matrix (illite, argillaceous material and pyrite) Content

| | |
|---|---|
| Specimen Number 19 | 10% |
| Specimen Number 18 | 20% |
| Specimen Number 17 | 0% |
| Specimen Number 16 | 1 - 2% |
| Specimen Number 15 | 1% |
| Specimen Number A 225 | 1% |
| Specimen Number 14 | 2% |
| Specimen Number 13 | 5% |
| Specimen Number 12 | Not estimated |
| Specimen Number 9 | Not estimated |

- - - - - - - - - - - - - - - - - -

The samples from which the above data was determined were selected at random from continuous road cuts on the traverse and at approximately equal intervals. They should be representative of the gross changes in composition and texture of these rocks from the bottom to the top of this 'Belt'. However for calculable statistical representativeness the samples are obviously too few. The statistical factor in favor of the validity of the suggested conclusion of increase in grain size, feldspar content and decrease in 'sorting', from bottom to top of the section examined, is the true randomness of the specimens.

The above data, in the writer's opinion suggests but does not prove that the sediments of the 'Quartzite Belt' were deposited in a basin where the overall rate of subsidence and supply increased as time went on. There are two specimens in the above tables which seem to contradict in some measure the above conclusion. However there are a number of explanations for this apparent contradiction. Firstly the inadequate sampling ; in order to determine adequately the grains sizes of the members of this section of the Slocan series, sampling obviously, should be on a larger scale than attempted in the above work. Secondly, if one considers the other lithotopes of these specimens the above apparent contradiction is not so obvious. The sorting in specimen 16 and 13 is much better than in specimens 18 and 19. The fèldspar content of specimens 16 and 13 is lower than 18 and 19 and the matrix content is also lower. Further almost all the specimens studied showed a progressive increase in angularity of the grains from specimen 9 to 19. There were some fluctuations. The above lithotopes all agree with Pettijohn's criteria for deposition in a basin where opportunity for reworking of the sediments decreases with time.

It should be noted that the increase in grain size from East to West was noticed by Cairne's. He states "...from east to west the beds tend to become more massive and coarser textured."[1]

The increase in the matrix content from top to bottom of this section is suggested in Table 4. This increase can be also correlated with a decreasing opportunity for reworking, i.e. the sediments are approaching the 'poured-type' of sediment of the eugeosyncline. Obviously an increase in argillaceous content of a sequence of sedi-

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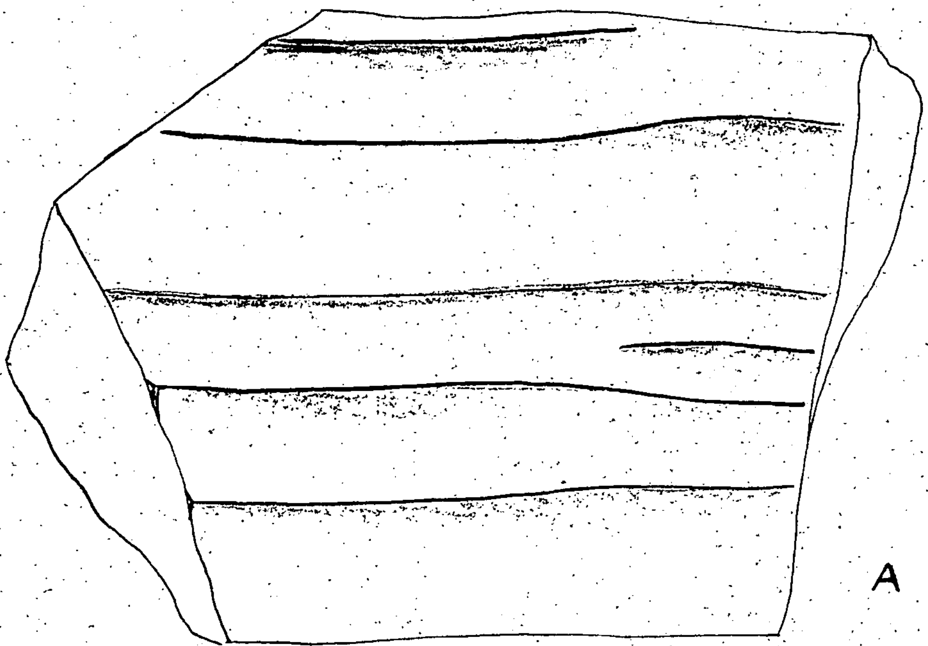
[1] (3). p. 59

ments will not of itself suggest increase in rate of subsidence and supply, for denudation of the bordering highland and decrease of rate of subsidence can also increase the matrix content. However when the increase of matrix is coupled with the other lithotopes associated with a rapidly sinking basin floor then it is a lithotope of genuine significance. In these sediments this matrix content increase is of genuine value in suggesting bottom conditions.

Specimen Number 19 was taken from a place which according to Cairnes' section would be in the western slate belt. No explanation for this can be given. Certainly as this specimen was near the junction of the New Denver road and the main lake road, position was easily and accurately fixed. It was this specimen which came closest to filling Pettijohn's definition of subgreywacke.

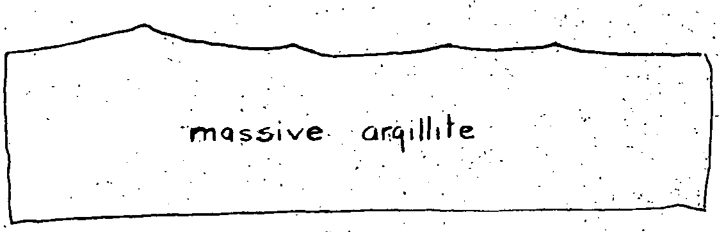
There is one rock type described by Cairnes which should be mentioned, though it was not seen by the writer. Cairnes called this type "tuffaceous sediment". "These are light to dark grey and yellowish brown massive rocks which in the outcrop or hand specimen could readily be classed as quartzite or calcareous argillites. Microscopically, they consist of large and small fragments of feldspar crystals; or feldspar crystals and rock fragments. Some of the rock fragments are fine grained, dense, and of indeterminate origin, but others are porphyritic and distinctly resemble volcanic rocks. Flakes and shreds of reddish brown biotite are generally abundant. Quartz is subordinate and thereby contrasts with the feldspathic sediments. The ground mass forms a large part of these tuffaceous rocks, and is of indeterminated composition and more or less opaque-like volcanic ash. The angular outlines and fresh appearance of feldspar fragments is plainly indicative of no normal process of erosion and deposition. North of the Sandon map area, exactly similar rocks have been found interbedded with volcanic breccia and one lave flow, all part of the Slocan series." The tectonic significance of this rock type will be developed later.

There is an interesting band of carbonaceous shale or slate which strikes parallel to the valley of Carpenter Creek above Three Forks. The carbonaceous nature of this very fine grained massive black rock is suggested by the following facts. The material is opaque and black in color under microscope. It burns to a white color in a Bunsen flame. A typical argillite did not change color in the flame. Cairnes mentions a carbonaceous shale which contained, on analysis, 2.22 percent of carbon. However no location for this specimen was given. The weathering effect is similar on the rocks called 'carbonaceous', by Cairnes, to the weathering effect on the rocks suspected by the writer to be carbonaceous shale. Some evidence points then to a stratigraphic layer of carbonaceous rocks near the base of the 'Quartzite Belt'.



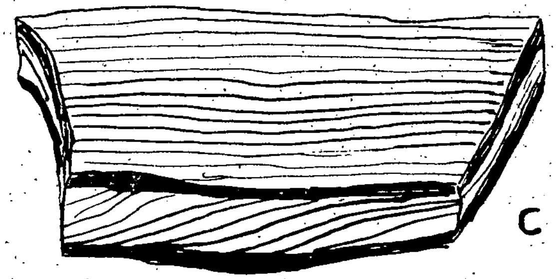
A

A- X1 Scetch showing scale and form of ripple mark found at 6000' elev- SLOCAN SERIES
B-X1. Cross section of A. showing ripple mark amplitude.

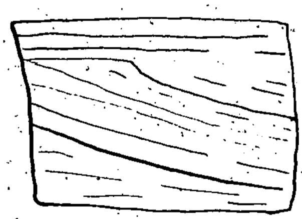



B

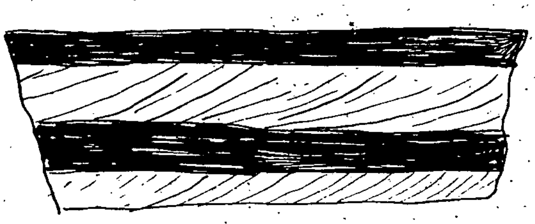
C. Phyllitic slate with current lamination tangential to topset and bottomset beds
D. Sandy argillite with truncated cross laminations (from polished and dyed spec.)
E. Scetch showing scale and frequency of truncated laminations in striped argillite
C D and E - X1



C



D



E

PLATE VI

to face p 33

The megascopic lithotopes observed by the writer consisted mainly of crossbedding, graded bedding and ripple mark. Two types of cross-lamination were observed by the writer. Above about 5500 feet elevation along Silver Ridge for the distance of about two miles, at widely separated points, the type of cross bedding is like that illustrated on plate VI figure 1. Below 5500' cross-lamination occurred in 'striped' argillite of the scale and frequency shown in plate VII figure E.

Clearly these contrasting types of cross-bedding indicated different bottom dynamic conditions. At first the writer considered the possibility of juxtaposition of unlike facies by thrust faulting. But he abandoned this idea not only because of the structural difficulties but also because of the fact that these contrasting types of cross bedding when seen under the microscope were of substantially the same scale and involved the same type of material and grain size. The difference is mainly one of frequency or repetition of cross-lamination and not one of scale. Two explanations are possible. There may have been a period of very strong storms which sent currents of greater strength than usual down to greater depths or there may have been a temporary decrease in the rate of subsidence of the basin resulting in shallower water for a time. This would allow currents to be more active and thus produce a greater frequency of cross-bedding in strata deposited at this time.

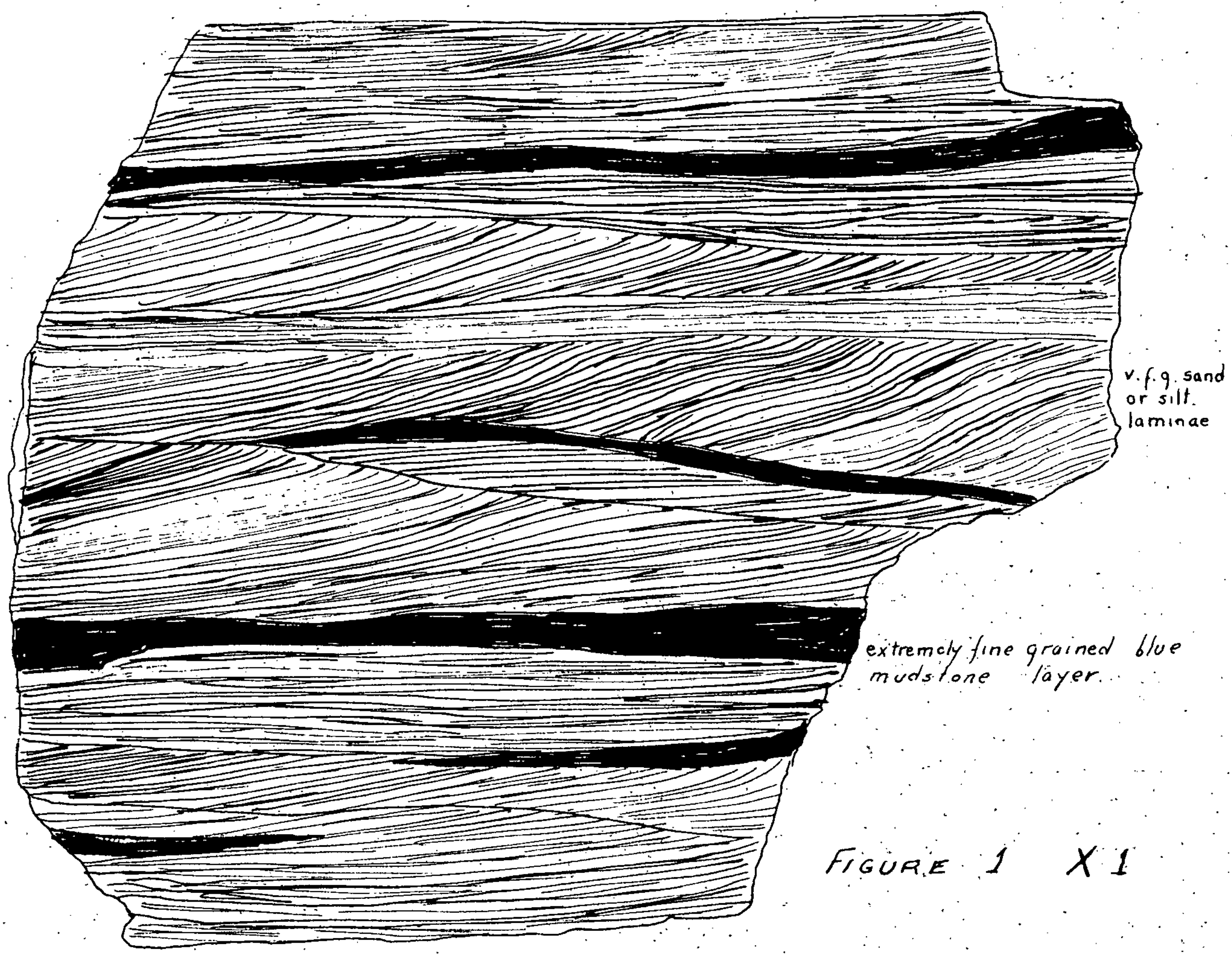



FIGURE 1 X 1

Sketch of Cross-lamination showing scale and vertical frequency as seen in the SLOCAN SERIES above 5500' elevation.

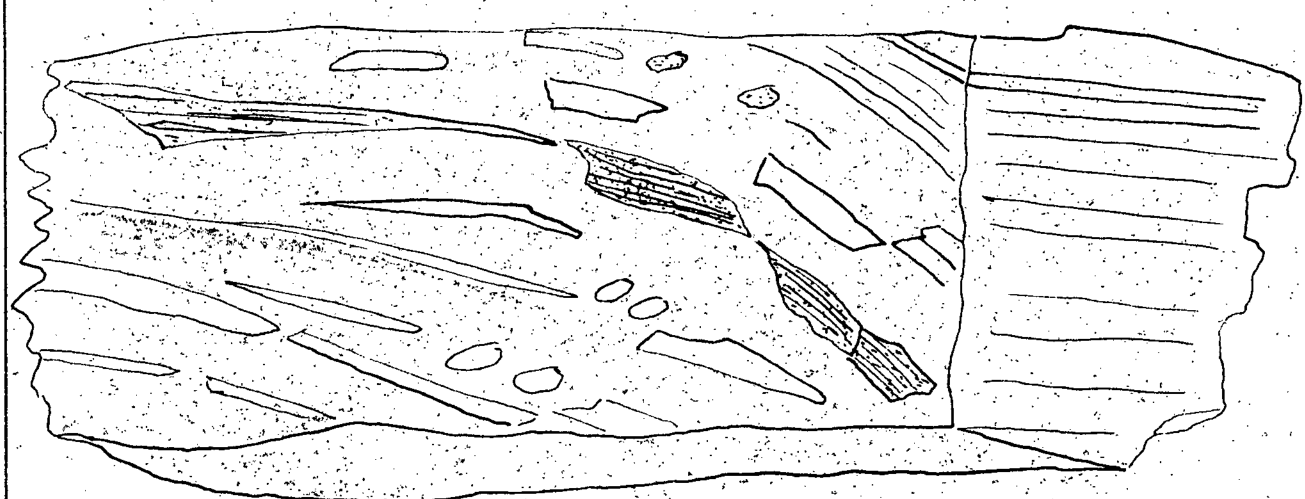


FIGURE 2 - X1

Example of Boudinage or 'pseudo conglomerate' on very small scale due to small scale folding of argillite with 'sandy' layers - SLOCAN SERIES.

PLATE VII

to face p 34

A type of cross-bedding which is seen less commonly is illustrated on plate VII figure D. This type occurs commonly in quartzites which are massive or thick bedded and behave as units of two or three feet structurally but are actually made of fine laminations of alternating argillaceous and quartzitic materials.

The 'striped' argillite mentioned above behaves when closely folded in drag folds as illustrated on plate VI figure 2. At times in the field this very small scale "boundinage" resembles an intraformational conglomerate.

The only ripple mark seen by the writer was seen in massive argillite on Reco mountain. The amplitude and wave length is as illustrated on plate VII figures A and B. This scale might indicate deep conditions but not necessarily so because there does not now seem to be any reliable correlation between scale of oscillation ripple mark and depth of bottom. "Any given set of oscillation ripple marks may be formed by small waves in shallow water or large waves in deep water."[1]

This completes the description of the lithotopes of the Slocan series observed by the writer. Many of these lithotopes will be considered again in the wider picture of sedimentation in these series to be discussed under the section dealing with Tectonic controls of sedimentation. The next section will deal with the effects of organisms on deposition in the Slocan series and the effect of the sedimentation conditions on life in the basin of deposition.

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[1] Pettijohn p. 131.

## BIOTOPES OF THE SLOCAN SERIES

No 'diagnostic' fossils were found by the writer, though three days were spent in search for them in an area where fossils had been seen. Also four months of detailed mapping in the Alamo basin area and numerous reconnaissance trips failed to reveal any trace of organic life in the Slocan series. This experience vindicates Cairnes' observation that fossils are extremely scarce in the western beds of the series.

The paucity of fossils in the western area or younger strata is in itself a biotope since in some way the basin conditions were such that life was limited or possibly non-existent on the bottom. The writer cannot satisfactorily explain the paucity of fossils in the younger strata of the series. Rapid subsidence, rapid deposition and great depths of water would be inimical to proliferation of life, though one would imagine that rapid deposition would readily preserve such forms as were present on the bottom. However great depths might dissolve carbonate shells before preservation. Pettijohn believes[1] that in sandstones the calcite of shells preserved or buried will be thinned and eventually completely dissolved. It is possible that this action has occurred in the quartzites of the 'Quartzite Belt'.

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[1]Pettijohn p.483 (14).

However there are many strata of this belt which are very argillaceous. It is difficult to conceive that this action has occurred in these rocks.

Taking into account the fact that there is no positive lithotopic evidence for shallow depth in this belt and the fact that where moulds of ammonite shells have been seen in these strata by the writer the cross-bedding has approached a shallower water type, it may be possible that fairly rapid subsidence, rapid deposition and moderate to fairly deep water conditions prevailed in the basin of deposition during much of the time of accumulation of these rocks.

Pettijohn states that "mingling of lime, sand, and quartz sand occurred in shallow waters"[1]. The thick strata of marls and limestones and interbedded shales of the 'Slate Belt' could indicate fairly stable shallow water conditions. These conditions would favor life on the bottom since sunlight could readily reach the lowest depths. Corals, crinoid columns and pelecypods which were found in the 'Slate Belt' limestones are indicative of shallow water conditions. The pelagic or nektonic ammonites and belemnites are not indicative of any particular bottom except possibly a fairly shallow one, since these pelagic shells could have been transported to and deposited in these bottoms either after or before death of the organism.

The above biota are all indicative of clear,

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[1]Pettijohn p. 454.

shallow water conditions in the eastern belts. The lithotopes in general agree with the idea of shallow water conditions in the eastern belts. This concept could explain the relative abundance of fossils in the eastern belts and the paucity of fossils in the western belt. It should be noted that this concept is in direct opposition to the explanation of Cairnes for the above biotopes.

That conditions were marine in the basin of deposition is not at all in doubt since as Cairnes states all fossils found were marine, except for some fossil plants remains on Reco mountain. It could be mentioned here that the writer did see on Reco mountain films of carbon very similar in shape to the films of carbon which were found on Silver Ridge by Lamb. These carbonaceous fossils were tentatively identified by Okulitch as algae. It is not impossible that these are the 'plant remains' of Cairnes.

Normally the biota and the ecology of organisms living in the basin of deposition are very fruitful sources of biotopic information. However in the Slocan series the biotopes furnish very little information on the environment of deposition of the rocks. It does seem that in the belt which suffered the most deformation and metamorphism of dynamic type the fossils were obliterated or deformed; and in the belt which suffered a minimum of metamorphism there are no fossils.

The writer feels that if the delicate laminations and cross-bedding of the 'Quartzite Belt' could be preserved, undistored by metamorphism, then certainly any fossil which might have been buried in this belt would also have been well preserved.

There does remain the possibility of fossil evidence someday being unearthed in the Slocan series which will throw more light on the uncertain conditions of the bottom during deposition of this thick assemblage of strata.

We will now consider the tectonic forces affecting the formation of the Slocan sediments.

## TECTONICS OF THE BASIN OF DEPOSITION OF THE SLOCAN SERIES

A useful term suggested by Sloss et al. (19) will be used in the following discussion. 'Tectofacies' is the total tectonic aspect of a stratigraphic unit. The tectofacies is determined by a study of the tectotopes of the unit studied and the tectotopes of related strata.

The tectotopes to be considered here are: assemblages of strata, structures, thicknesses, total lithologic aspect of the series under consideration or its lithofacies, and orientation of primary features. The attempt to discuss the Slocan series in terms of tectotopes is based principally on the recognition of the fact that "observed differences in lithology and associated phenomena, has been the rate of sedimentation which, in turn, is controlled by the related rates of elevation and depression of the source area and the basin of sedimentation respectively."[1]

Tectope study of the Slocan series involves application of recent generalizations concerning the families or suites of sediments which are developed in basins of varying tectonic aspect. Pettijohn has published the clearest and most sweeping of these generalizations. (14)

He has subdivided assemblages of sediments into

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[1]Pettijohn, p. 437.

geosynclinal and platform facies. The geosynclinal facies has been subdivided further into proximal, distal and medial facies. He has recognized various features of composition, textures, etc. to be diagnostic of different parts of the geosyncline. The discussion which follows will be based in part on these generalizations.

The 'Slate Belt' of the Slocan series is an assemblage of strata for which some tectonic explanation can be found. In a stable basin with a peneplaned bordering land mass, the materials to leave the land mass should be confined mainly to solutions and muds. Of course, because conditions of elevation and depresseion of basins and bordering areas fluctuate, there will be alternations of types of sediment carried to the basin of deposition. However, in a stable area, relatively speaking, deposition from a reduced land surface will be mainly of mudstone and chemical type. Hence the marls, argillaceous limestones and shales, now slates, of the 'Slate Belt'. The alternation of lithotopes of course could be due, as mentioned above, to the minor fluctuations of elevation of source area and basin. In considering then one unit, for example, a limestone stratum, little is gained in way of an interpretation of basin conditions unless one considers the tectotopes or lithologic associations. These associations can be on almost any scale, for example, it is intended to discuss later the association of the Slocan series as a whole with the deposits of the Windermere geosyncline.

In the argillite belt is found an assemblage of strata of predominantly argillaceous character. Two related events most likely produced the change in the gross statistical lithology at this time. Slight uplift leads to partial rejuvenation of the source area. The soil mantle, which was accumulated during the period of crustal stability, is destroyed and carried to the sea. This results in the formation of highly aluminous shales and some quartzites of the sedimentary type. Since on the whole the argillites predominate in the 'Argillite Belt' this was the dominant tectonic activity affecting the formation of these rocks and of course all the lithotopes developed. The biotopes also were dependent untimately for their form on this form on this tectonism.

As noted in the discussion of lithotopes, it must be obvious by now that there is some overlapping in the usage of the terms 'tectotope' and 'lithotope'. There is a suggestion of an increase in feldspar content, angularity of grains, grain size and range of particle size in specimens examined in the 'Quartzite Belt' from the eastern to western exposures. This fact which is now a tectotope must be related to some tectonic event. The explanation most applicable to the facts seems to be that the basin of deposition subsided at an increasing rate and the bordering uplands rose at an increasing rate also.

Cairnes has noted the intercalation of volcanogenic sediments with the Slocan series. This fact is a tectotope. Pettijohn has made the generalization that volcanic formations tend to occur in rapidly subsiding narrow throughs. The stratisgraphic position of the volcanic deposits is high in the Slocan series. Thus the production of subgreywackes and volcanic sediments were related events, and both indicate increasing 'acuity of diastrophism' in late Slocan time.

The thicknesses of the belts deserves consideration. The time relationships involved in the formation of the three belts cannot be deciphered, or at least the writer sees no way at present of determining the time involved in the formation of the different belts. It would seem that a one to one ratio of time and thickness for the three belts cannot be assumed. Certainly in the stable period, during which the Slate belt was formed, the rate of deposition must have been slow. It is not impossible that the thickest formation, the 'Quartzite Belt' was formed in the least time.

At one time the writer considered placing the Slocan series in some portion of the Windermere geosynclinal downwarp with which it is apparently so intimately related. However, as the writer now feels that there are indications that the center of subsidence moved westward forming the Slocan series as a separate or semi-separated assemblage, i. e. the geosyncline migrated, this endeavor has little relevance. Certainly though, it does seem that at the time of the deposition of the 'Slate Belt' at least and possibly for part of the time of deposition of the other belts, the Slocan sediments were formed on the proximal platform to the west of the land mass which produced the rocks of the Windermere geosyncline. The source of supply may have been the uplifted Purcell rocks to the east or another complex to the west. This cannot be settled one way or the other with present data. However, as happened in other geosynclines, this platform became a subsiding basin or marginal geosyncline in its turn. This fact will be discussed in its more theoretical implications later.

One general observation concerning graded bedding which has apparently been overlooked in the discussion on lithotopes could be inserted here. Pettijohn believes graded bedding to be characteristic of greywacke suite or poured-in type of sediment. This is of course valid as a broad statistical generalization. However in the Slocan series, in strata which were only a matter of feet removed in vertical section from true orthoquartzites and good cross-bedding, graded bedding was observed.

From a recent paper (9) which explained graded bedding as a result of turbidity currents, it seems clear now that graded layers will form wherever slopes of deposition are steep enough. Certainly it is admitted that on the whole, steep slopes will occur in the narrow rapidly subsiding troughs more commonly than in broader more stable basins. Still, locally at least, steep slopes can occur in almost any type of basin. It seems to the writer that the diagnostic properties of the lithotope of graded bedding has been overrated womewhat by Pettijohn.

In his discussion of Facies of Sedimentation, particularly in the table on page 455, (14) Pettijohn stated that in the orogenic facies, cross-bedding is infrequent and on a small scale. This is a very vague generalization. The writer is at a loss to know whether to class this lithotope of the Slocan series as an orogenic or a platform one. In transitional facies some method of numerical evaluation of frequency with which lithotopes of this type occur in the section studied would be useful and important in the classification of these deposits in terms of tectonics.

McKee (9) and a number of others (21) and (16) have suggested and used the orientation of primary features such as cross-bedding and ripple mark in paleogeographic studies. The writer made an attempt at a statistical study of the orientation of cross-bedding in the Slocan series. Unfortunately not enough determinations were made to have a statistically significant result. Fifteen determinations indicated, however, that the current direction in the basin of deposition of the Slocan series was from the west. Of course the fact that current direction was from the west does not prove that the source of sediment lay to the west.

Shepherd (20) states that current direction may or may not be related to the direction of the land mass supplying sediments. Insufficient work has been done on the determination of modern bottom currents in the oceans to test this idea. In the Slocan series the writer feels a statistically significant study of the orientation of the direction of cross-bedding laminae could be made. This direction could be correlated with other information which did accurately fix the direction of the supply of sediment.

Part of the difficulty the writer found in determinations of this sort was that the direction could be reversed if a 'tops' determination were not made on each and every specimen of cross-bedding. Later reflection has however shown that provided two bedding planes and a crossing lamina could be found the direction of 'tops' (up or down) is immaterial. The revolving of the exposed cross-bedding in steep beds may be in either direction and the resulting direction of the current forming the cross-lamination will be the same. A simple sketch can prove this to the satisfaction of the reader. This idea is, of course, very simple and yet strangely enough not obvious at first glance. This fact, if it had been understood in the field mapping, would have enabled the writer to make many more determinations. Certainly at least four hundred which is apparently the minimum for statistical significance.

The orientation of primary features is a useful tectotope which can be easily determined in many cases and can, if enough work is done on this feature of sediments, result in some important conclusions. Even though an insufficient number of determinations were made by the writer, as mentioned above, there was a striking consistency in even the few determinations made which inclines him to believe that any further determinations of this sort attempted in this area would verify the tentative conclusion that over a considerable range in vertical section the direction of current in the 'Quartzite Belt' time was from the west. It is not impossible to imagine that the study of primary features in the other belts might show other current directions.

The <u>succession</u> of lithotopes in a stratigraphic unit such as the Slocan series is a tectotope. The apparent succession in the Slocan Basin was (from top down):

5. Subgreywacke (and washed greywackes and shales)
4. Volcanogenics, flows, etc. (4 & 5 alternate)
3. Ortho quartzites and argillites
2. A carbonaceous member
1. Shales - metamorphosed to slates, and chemical sediments - limestones, etc.

The ideal or normal geosynclinal sequence as stated by Pettijohn page 447 is (from top down):

6. Subgreywackes (and washed greywackes) shales and coal
5. Massive greywackes (grits)
4. Interbedded greywackes and slates (flagstones)
3. Shales (with a few thin greywackes)
2. Chemical sediments (limestone, siderite, and/or chert
1. Basal breccia or conglomerate.

It is important to note that volcanic beds, both flow and tuff, may appear in the section and are most likely to occur late and intercalated with 4 and 5. There is, at first sight, little similarity in the above successions. It does seem, however, that the earlier speculation of an increasing rate of subsidence and supply in the basin of deposition of the Slocan series is valid, based on the lithotopes described above. The differences could be due to the fact that the succession described by Pettijohn is for the axial portion of a eugeosyncline. The Slocan series were probably deposited first on the platform and then on the proximal portion of a migrating geosyncline. The sequence then would not be the ideal one of Pettijohn, and would in part at least consist of platform facies.

This concludes the discussion of the facies of the Slocan series. The next section will deal with a very rapid and elementary survey of the place of the Slocan sediments in the geosynclinal succession of the Windermere geosyncline. Age and contact relations of the Slocan series will be considered here also.

## CONTACT AND AGE RELATIONSHIPS OF THE SLOCAN SERIES

The Slocan series lie to the west of a thick succession of sediments which, with the exception of the Milford and Kaslo groups, have been assigned to the Windermere series. This assemblage is measured in the tens of thousands of feet and has been involved in a single orogeny. To the east of these rocks lie the Lower and Upper Purcell series. As the Toby conglomerate is such a remarkably consistent conglomerate and is parallel to the strike of the Purcell rocks, which were involved in a separate folding earlier, the Toby conglomerate is a true tectonic marker. It records a widespread and important tectonic event, which is unrelated directly to the events of Purcell time.

The Toby conglomerate and the succeeding coarse sediments, such as the Horsethief Creek series, were formed as the result of the elevation of the Montana Island to the East and deposition of the materials derived from this rising land mass in a subsiding trough to the west (4). The history of the trough is complex and may, as suggested by Okulitch (10), have been both a migrating and 'cannabalistic' geosyncline, making 'time' relationships and divisions difficult of exact determination.

The Windermere geosyncline and its history is too large and important a subject to be settled as a part of this thesis. Nevertheless the writer feels that the Slocan series and its history are closely related to the rocks of this geosyncline. There is no widespread unconformity at the base of the Milford. Walker and Bancroft report in the Lardeau area a conglomerate of a few feet thickness at the base of the Milford. This cannot be a tectonic conglomerate similar in importance to the Toby conglomerate.

On theoretical grounds, which will be discussed in the following section, the writer suggests that the Slocan series and the Kaslo and Milford group are part of the Windermere geosynclinal complex. Since Schofield (15) had mapped the Slocan series as part of the Ainsworth, now Lardeau series, without any unconformity separating the two, surely there is some ground for suggesting this. If there is a gap in sedimentation of several hundred million years between deposition of the Lardeau series and the Carboniferous Milford, surely one should expect a major unconformity and widespread basal conglomerate of the dimensions of the Toby conglomerate at the base of the Milford. There is clear evidence that there is no such conglomerate. Moreover in the rocks to the south there is clear record in the Metalline quadrangle of continuous deposition from the Toby conglomerate, which is a pre-Cambrian formation through the Lower Paleozoic to the Devonian.

The Shedroof conglomerate underlies and is gradational into the Leola volcanics and both are considered to be late pre-Cambrian (13) (for names of equivalent strata in Canada the reader should see the legent to Plate X.) Parks states "An unconformity may intervene between these formations and the overlying Monk formation, of Cambrian (?) age." (13) However, Rice (17) states that the Horsethief creek series (the equivalent of the Monk formation) overlies the Toby formation conformably, in the area immediately to the north of the Metaline quadrangle.

The Gypsy Quartzite (Hamill series) grades downward into the Monk formation and upward into the Maitlen phyllite." (13). Rice does not separate the Hamill series into a phyllite member,however, he does note that in the Hamill series schist and phyllite are common rocks, especially in the upper members.

The Maitlen phyllite of Parks grades downward into the Gypsy quartzite, which is of Cambrian age and upward into the Metaline limestone, of Middle Cambrian age. He notes no fossils have been found in the phyllites.

The Metaline formation, which includes the Badshot, grades downward into the Maitlen phyllite below. The top of the Metaline limestone is sharply defined against overlying black slate. No gradational beds were seen by Parks. He states that the possibility of an unconformity between the limestone and the slate is unlikely though the possibility cannot be completely discarded.

In the younger Ledbetter slates Ordovician Fossils have been found. Devonian or possibly early Mississipian have been found in beds which were unsatisfactorily located by Parks in the stratigraphic sequence, as the outcrops were poor. In view of the fact that no certain unconformity has been found in the thick sequence of rocks of this region from the Shedroof conglomerate upward and that the identified Ordovician fossils occur low in the Ledbetter slate sequence and the identified Denvonian fossils many thousands of feet higher one can infer continuous deposition from the late pre-Cambrian to at least the Devonian. The fact that no Silurian fossils have been found does not prove that no deposition occurred in this area during Silurian time. It could well mean that bottom conditions were such as were inimical to life or the preservation of evidence of life. Moreover, as this is an orogenically deformed area fossils can be expected to be rare. The absence of a Silurian section in the stratigraphic sequence may well mean simply that no Silurian fossils have been found so far.

The Lardeau series, which is at least 15,000 feet thick is assigned to the Pre-Cambrian by Walker. Perhaps the Lardeau series, which is 'unfossiliferous', was deposited during the early and middle Paleozoic periods. This suggestion is advanced because it answers the grave theoretical difficulty of the absence of a basal conglomerate at the base of the

Milford. That there is no conglomerate at the base of the Slocan series in the Sandon area (Cairnes (2) and Mayo (8)) presents no theoretical difficulty, for the Milford, Kaslo and Slocan series could be formed in one continuous geosynclinal sequence, starting with active subsidence in Lowest Milford time in the 'Milford-Slocan' trough. Actually there also need be no conglomerate at the base of the Kaslo series, if one regards them as a volcanic phase of the tectonic activity resulting in the subsidence of the Milford-Slocan trough.

The problem of the age of the Windermere system is one which was not settled by Rice (17). As Parks (13) had assigned some formations which are continuous in strike with the Windermere series to the Cambrian and younger Paleozoic periods and as Walker had decided that <u>all</u> Windermere strata are Pre-lower-Cambrian, clearly "either Parks or Walker may be mistaken in their correlations".[1]

If one accepts Parks' stratigraphy, then it seems that the Milford and younger strata could be part of the Windermere geosynclinal assemblage. If one accepts Walker's stratigraphy, then there is a long period of erosion after the deposition of the Lardeau series, and the Milford, Kaslo and Slocan sediments are a separate sequence. Certainly the writer will not attempt to decide this issue. However his experience with and this study of the Slocan rocks tend to make him more receptive to Park's concept than to Walker's.

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[1](17) p. 24.

## THEORETICAL CONSIDERATIONS

### The Orogenic Cycle

Holmes (6) has excellently summarized the processes of geosynclinal formation and the orogenic cycle. It is not intended to repeat what Holmes has so well stated. What the writer will do is attempt to discuss the sediments described so briefly above in terms of orogenic belts and geosynclines and the convective mechanism for the formation of geosynclines.

"By the work of several generations of geologists it has been firmly established that the orogenic belts of each geological era originated in long downwarps of the crust in which extraordinarily thick deposits of sedimentary rocks accumulated during the era or eras that preceded the orogenic revolution."[1]

These downwarps were most often linear and the now familiar term geosyncline was assigned to them. The less familiar term orthogeosyncline referring to the linear geosynclines, and not all are linear,(indeed some are quite recurved) has recently been coined. The Windermere geosyncline is in the writer's opinion as orthogeosyncline. The concave-to-the-west-arching of the strikes of the formations (as seen in plate X) of the Windermere strata may be due to

[1] (7) p. 379.

to a compression with the most active force coming from the west or the curve may be a primary curve in the basin itself and this curve was maintained throughout the subsidence of the trough and during the subsequent orogeny. This curve is gentle enough so that the term orthogeosyncline is still applicable.

The structures found in the Slocan series and the related Windermere rocks are similar to the structures of other orogenic belts of the earth.

The overall structural pattern of the orogenic belts of Iraq and Iran and the Orogenic belt of the Himalayas and Tibet is that of folding and overthrusting of the geosynclinal deposits towards the foreland. The foreland is defined by Holmes as the crustal block towards which or over which the structures spray out.

Holmes makes no statement on the types of structure or folding which occurs in the median mass of the orogenic belt. It is possible that here the folding is of broad open fold type with the complex overfolds and recumbent folding confined mainly in the bordering ranges. This might account for the <u>apparently</u> simple folding which occurred during the folding of the Purcell series. The complexly folded bordering ranges which may have bounded the Purcell geosyncline area may have been removed by erosion and the isostatically elevated median mass which rose <u>later</u> has been less affected by erosion. This is a conjecture based solely on the theory of mountain structure proposed by Holmes.

Holmes conceives the crustal blocks of the fore-lands as acting like giant vices which cause the sediments to crumple up and splay out on both sides. This concept can be applied to the structures of the Slocan series (see Plate IV).

The type of folding in the Slocan series could be caused only by overthrusting from the east or under-thrusting from the west. As a result of 'tops' and attitude determinations by Kelowna geologists there can be no alternatives. The writer is of the opinion that under-thrusting from the west has occurred. Not only because this concept fits the idea of convective mechanism of crustal compression but because the structures and shape of the folds themselves suggest it. In addition, Mayo has found evidence, in the granitic rocks bordering the Slocan sediments, of lineations which suggest underthrusting (see Plate IV).

The writer has drawn the structure (Plate IV) to the east of Sandon area as broad open folds. This may or may not be the case. Actually there is some evidence that the overfolding has extended as far east as the Toby conglomerate. The only reason the writer suggested (plate IV) that the structures east of the Milford series were of a different type from that of the Slocan series is that a large scale drag fold on Milford Peak, drawn in one of

Cairne's sections (section B Plate IV), indicated that the strata in this section was involved in open folding and not recumbent folding.

The evidence for the above overfolding which in the writer's opinion is more likely than open folding lies in the apparent disappearance in strike of the western branch of the Badshot formation. This formation has been involved in a massive syncline overturned to the west.(12) It is possible this formation (see Plate X) has been involved in a huge recumbent fold to the east of Sandon area and that the western part of the Badshot, which should appear if the above structure is consistent to the south, has been eroded from the 'carapace' of Mayo. This idea suggests that the area near the north end of Kootenay Lake has been a centre of compressive force, which in turn suggests that the thickest part of the geosynclinal sequence is in this area also.

Hypothesis of Sub-crustal Convection Currents

In addition to the observed facts of mountain structure, which Holmes has summarized, he suggests a plausible mechanism for the geosyncline and the subsequent orogenic folding of the sediments deposited in it.

The effects of the suggested mechanism and the observed broad geological features of mountainous belts of the earth seem to be in agreement. It was in an attempt to reconcile the effects of a convective mechanism and the formation of the Slocan and Milford series that the writer offered the suggestion that the Slocan series was deposited in continuous sequence with the Milford and in a trough which lay to the west of the trough in which the Lardeau and younger Windermere rocks were deposited. To assume that the thick Windermere sequence was deposited and remained <u>unfolded</u> for practically a whole geologic era and that in the <u>same</u> trough deposition commenced <u>again</u> does not fit into the usual sequence of events in an orogenic belt. This sequence is outlined by Holmes[1] and is given below:

"(a) Development of a geosyncline with heavy sedimentation and occasional volcanic acticity.

(b) Compression of the belt by a first orogenic phase, involving root formation in depth, folding and overthrusting of the superstructures, and uplift of the compressed zone in response to the buoyant (isostatic) effect of the root.

(c) Lateral growth of the geosyncline by development of a new subsiding tract outside the rising mountains (Fig. 199). As the latter are carved into peaks and valleys by denudation, they provide much of the sediment which fills up the depression.

(d) Renewed orogenic compression of the whole belt. Stages (c) and (d) may occur twice or even three times (rarely more) in the more complex belts.

(e) During the more vigorous orogenic phases, and particularly during the climax of the revolution, the deeper rocks are intensely metamorphosed, and migmatites are formed by hot migrating fluids. Later, granite batholiths are emplaced, followed in some cases by the introduction of valuable ore deposits. These are gradually uncovered by denudation if the cumulative uplift of the completed belt is sufficiently long maintained." It is conceded by those who have worked in the Windermere and younger rocks of this area, that only one folding period occurred and that the Windermere and overlying strata are involved in the same structures. If Walker's stratigraphy is correct this means that a whole geologic era of erosion succeeded the deposition of the Windermere rocks and that no orogeny occurred until after the Slocan series had been deposited.

According to Holmes every geosyncline should be folded immediately after the down-bowing action of the currents have reached a climax, i. e. when there is a short period of relatively rapid currents. In other words, in a geosyncline a prolonged period of erosion cannot normally succeed a prolonged period of deposition <u>without folding</u>. However, and it seems to the writer that the Slocan-Milford trough is an example, it may happen that the centre of subsidence may migrate laterally <u>without folding in the original centre of subsidence</u>, in this case, the Windermere trough. This will happen when the tectogene or 'root' of light sediments rises slightly (isostatically) and overcomes the down-drag of the convective currents. When this happens, the currents, still exerting a downward drag on the crust in spite of the upward lift of the 'root', causes the crust to form a downwarp which borders the original geosyncline. It is possible that two downwarps will develop, each bordering the original area of subsidence. In this case we are concerned with the downwarp to the west of the Windermere trough.

What tectofacies might be expected as a result of such tectonism? One would not expect a widespread unconformity or basal conglomerate at the base of the series deposited in the new trough. One would expect rather argillaceous sediments to form since the foreland would have long since been denuded and only fine muds be available for deposition in the trough. The isostatic rise of the 'root' would be slow at first and in all probability would not rise above sea level in the early stages and could not contribute much sediment. Moreover the convection currents while they would accelerate rapidly to cause an increasing rate of subsidence would be counteracted somewhat by the effect of the rising 'root'. Thus we have sedimentation conditions corresponding to a slow rate of subsidence and supply. The lithotopes and the tectofacies of the Milford would seem to suggest this. We have in addition a very deep 'root' of Windermere sediments. Holmes suggests that volcanic activity accompanies the existence of a deep, albeit, in this case, rising 'root'. This explains the volcanic sediments of the Kaslo series. Finally we have the tectofacies of the Slocan series indicating an increasing rate of subsidence and supply - which is what one would expect in a trough sinking at an increasing rate. The source of the sediments may have been the Windermere strata, still unfolded which by now had risen to above sea level; and lay to the east of the Milford-Slocan trough.

The following sequence of events is suggested in order to harmonize the consequences of Holmes orogenic mechanism with the known facts:

Geological History of Area

1. Formation and folding of the Purcell sediments.

2. Uplift of the Purcell strata and lateral growth of this original geosyncline by the development of a new subsiding tract outside of the rising mountains. This subsidence resulted in the formation of the Windermere series. Deposition from late Pre-Cambrian to possibly Carboniferous.

3. Deposition of shales and chemical sediments suggesting both shallow water and denudation of the bordering highlands i.e. the Purcell mountains to the east and a highland to the west (?). These sediments were formed in the basin of the 'new' downwarp. This subsidence results in formation of possibly some of the upper Lardeau members and certainly the Milford series.

4. Volcanic activity at the period when there is a very deep 'root' --formation of Kaslo series.

5. Deposition of the shallow water shales and slates of the 'Slate Belt' of the Slocan series in the still slowly sinking 'new' Milford-Slocan trough.

6. Subsidence at increasing rate in the 'new' trough with eventually volcanogenic sediments and subgreywackes being formed near the climax of the cycle. These are the Slocan volcanics noted by Cairnes.

7. Folding of the whole Windermere-Milford-Slocan assemblage.

8. Batholithic intrusion and granitization of sediments.

9. A period of gradual uplift.

The above history based on theory which has not been completely accepted stands only until further study shows that another sequence of events has occurred. This interesting area could prove or disprove some of these generalized theories of the behaviour of the earth's crust. This thesis is not an attempt to prove this convective theory. It merely attempts to apply it in order to build up a history which could account for some known geologic facts of the Slocan and related series, of south eastern British Columbia.

Age of the Slocan Series

On the basis of poorly preserved fossils Cairnes has assigned the Slocan series to the Trissic. The fossil evidence found in the Slocan sediments is inconclusive though it indicated a late Carboniferous or possibly Mesozoic age.

The best evidence for the age of the Slocan sediments comes from the Carboniferous Milford. Since the Milford is placed in the Carboniferous on rather good evidence and the Slocan is younger, then it should be of Permian or possibly Triassic age. The Belemnites speciments are the best fossil evidence found in the Slocan series by Cairnes for assigning it to the Triassic.

With Okulitch (12) the writer sees no difficulty in assigning the rocks of a single sedimentary unit to two geologic eras or periods. With the experience of the Pre-Cambrian boundary of the Windermere series as a guide the rigid separation of sedimentary units into precise eras and periods seems to be no longer necessary. Or in Twenhofel's phrase, "The lithic unit may transect time diagonally."

In the writer's opinion the age of the Slocan series while settled within broad limits still is somewhat of an open question. It may be wholly Mesozoic in age or partly Mesozoic and partly upper Paleozoic.

Gross Statistical Lithology

This is a tectotope of major significance. Unfortunately since no completely reliable measurement of the thicknesses and types of the Slocan series is available the ratios which Sloss et al (23) use in integrated facies studies have not and cannot with present data be worked out for these sediments.

The ratios referred to above are those called the

the Clastic ratio and the Sand-Shale ratio. These are defined below:

$$\text{Clastic ratio} = \frac{\text{Conglomerate} + \text{Sandstone} + \text{Shale}}{\text{Limestone} + \text{Dolomite} + \text{Evaporite}}$$

$$\text{Sand-Shale ratio} = \frac{\text{Conglomerate} + \text{Sandstone}}{\text{Shale}}$$

"These ratios may be readily visualized by considering them as indices of the relative amounts of material in the numerator of the ratio deposited per unit thickness of material in the denominator. A clastic ratio of 2, for example means that on the average 2 feet of clastic material was deposited per foot of nonclastics; and a sand-shale ratio of $\frac{1}{4}$ means that only $\frac{1}{4}$ of foot of sandstone or conglomerate accumulated per foot of shale. These ratios apply as averages for the total section considered and are indices of the gross statistical lithology."[1]

No reliable estimate for the value of the Sand-Shale ratio for the three belts of the Slocan series can be given, but it is certain very approximate values for the Clastic ratio would show a marked increase in value for this ratio from the 'Slate Belt' to the 'Quartzite Belt.'

Cairnes measured some sections of the Lardeau series (3). The clastic ratio was estimated from this data, by the writer, to drop from 200 to 11. This would indicate that during the period of deposition of the

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[1](23) p. 343.

Lardeau 200 feet of clastics were deposited per 1 foot of nonclastics near the beginning of Lardeau time and that towards the end of Lardeau time only 11 feet of elastics were being deposited per one foot of nonclastics.

This would indicate a growing tendency toward crustal stability, which the writer doubts on theoretical grounds or a decrease in supply as a result of denudation of the source area coupled with shallow water conditions. This is more likely. The overall clastic ratio for 15000 feet of the Lardeau series is 6.approximately.

The above consideration of the Lardeau series is merely illustrative of the use of these ratios. A measurement of the lithology of the Slocan series could be made with these ratios in mind and would be very useful in determining the genetic conditions of these rocks.

# CONCLUSIONS

The Slocan series were probably formed in a lateral sequence with the rocks of the Windermere series. By this is meant that the rocks of the Slocan series were deposited in a trough which developed after the Windermere series had been deposited but not folded. This trough bordered the tract in which the Windermere sediments had collected and this trough (Milford-Slocan trough) may have been formed as a result of the isostatic rise of the Windermere 'root' and the down-drag of convective currents in the sub-crustal layers of the earth.

The sedimentary characteristics of the Slocan series as studied by the writer on one continuous cross-section through the series suggest deposition in a marine environment with a progressive change from conditions of very low rate of subsidence and supply to a more rapid rate of supply and subsidence.

The source of the sediment is unsettled though current directions in the Quartzite Belt of the Slocan series over a wide range of time possibly were from the west. However it is not impossible that the source area lay to the east and the sedimentary material came from uplifted Windermere formations.

The main fact which the admittedly inadequate sampling of the cross-section suggested is a progressive increase in grain size, feldspar content, grain size range and matrix content of these rocks from bottom to top of the section studied.

The age of the series is possibly late Paleozoic or Mesozoic. Available data and theoretical considerations on the formation of a geosyncline as presented by Holmes (6). enabled the writer to form an admittedly theoretical sequence of events for this area which was consistent with Holmes' hypothesis of sub-crustal convective currents and the orogenic cycle.

## APPENDIX

Petrographic Descriptions of Specimens Examined.

Brief petrographic descriptions are made below. Plates VIII and IX are camera lucida sketches of the thin sections which showed significant petrographic features. For location of speciments see Plates III and V.

Number 5E No slide made - This is a light grey green phyllite. The most important lithotope is the cross-lamination which indicates very weak bottom currents and also alternation of mud and fine sand material.

Number 5D No slide made. This is a fissile pyritic slate. It weathers rusty brown. Breaks on weathering to small flakes. There are no visible laminations.

Number 5C This is a calcareous argillite. Carbonate 30%, quartz and feldspar grains 40% and sericitic matrix 30%. The average grain size is .02 mm.

Number 5B No slide made - This is a dark grey to black carbonaceious argillite.

Number 6A No slide made. This is a grey soft massive argillite. Occurs interbedded with massive Quartzitic strata.

Number 8 This is an argillaceous quartzite. It is medium grey, unlaminated and fine grained. The average grain size is .05 mm. and the range from .1 - .03 mm. The grains are very angular but approximately evengrained. The composition is - quartz 70%, illite 29%, and feldspar less than 1%. Ther is some tourmaline probably clastic in origin.

Number 7 Medium hard, unlaminated, light grey argillite. This type of rock often has fine cross-laminations suitable for 'tops' determinations. Average grain size is .03 mm, the limits are .05 - .01 mm. The fragments of quartz and feldspar are angular. The composition is quartz and feldspar 70% and opaque material 30%. The felspar content is low. Possibly about 2%.

Speciments 2, 3, 4, 5A and 6 are of various stages of weathering of the carbonaceous shale (number 1 (see Plate IX)). These specimenswere not sectioned. They showed various degrees of weathering from hard massive grey argillaceous and carbonaceous shale to 'rotten' red and black colored rock.

Number 12 This specimen is similar to Number 9 (see Plate IX).

Number 15 Light brown and medium hard rock. Composition is quartz 50% Clear (secondary) feldspar 30%

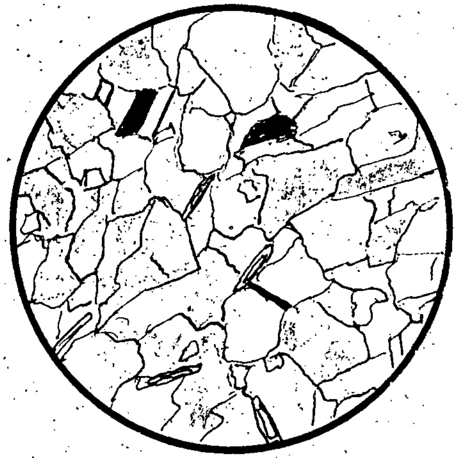
and carbonate 20%. The grains are of similar size and the average is about .02 mm. This is a calcareous orthoquartzite.

Number 18 Argillaceous quartzite. This is a medium hard unlaminated dark grey rock with fine pyrite crystals scattered through it. This rock approaches the texture and composition of Number 19. There are chert fragments of about .1 mm. Estimated from the number of twinned feldspar grains, the feldspar content is about 5%. Quartz is 75%. The matrix is opague with some sericite. The quartz and the feldspar grains are clouded. Pyrite, tourmaline and zircon are accessory minerals.

Number 22 This is a specimen taken from the Zuni claim near the Jackson basin (for location see Plate V). This rock consists of 50% carbonate and 50% clay material. It is a soft, dark grey to black argillaceous limestone.

.2 mm

No 19 X-Nicols

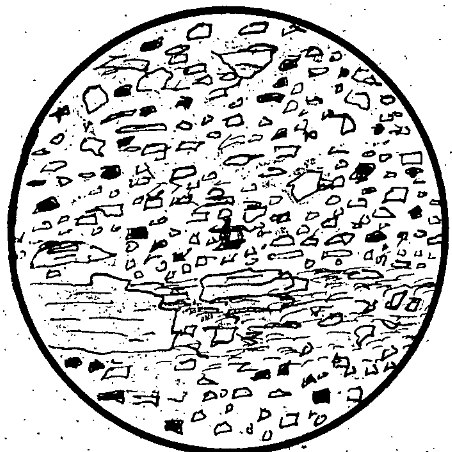


.2 mm.

No 13 X-Nicols

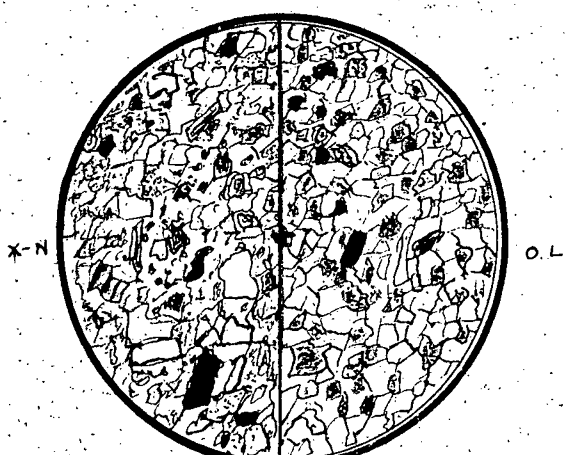

.05 mm

No 17 X-Nicols



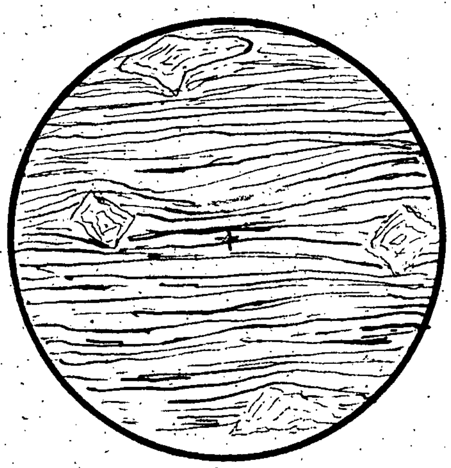
.2 mm

No 14 X-Nicols




2 mm

No 16 - X-Nicols & Ord. Light



.2 mm.

No 10 X-Nicols.

PLATE VIII

to face p 70

PLATE VIII

Number 19 Subgreywacke from upper strata of Slocan series near New Denver, B.C. Composed mainly of quartz and feldspar grains. Some large, rounded quartz grains have crystocrystalline appearance, possibly of volcanic origin or chert fragments. The fragments are very angular and show poor sorting. Size range: from .5 mm to .001 mm - average .15 mm. Most large twinned. Plagioclase grains are cloudy. There are some zircon grains. Carbonate content is minor. Quartz 70%, Feldspar 20%. Matrix is of sericite and opaque argillaceous material.

Number 13 'Washed' subgreywacke from near middle of 'Quartzite Belt' between Three Forks and New Denver, B.C. The composition of this rock is essentially the same as that of Number 19. However, the feldspar content is much lower - about 2 - 3%. The size range of the particles is less extreme - .3mm to .05mm average .10mm. There are fewer chert fragments. Possibly some of the feldspar is secondary. There are clear feldspar grains. Sphene grains are minor. No carbonates. Illite about 5% and quartz is about 90%.

Number 17 Calcareous sandstone possibly dolomitic sandstone near New Denver, B.C.

The drawing shows quartz fragments, feldspar grains and carbonate, (possibly dolomite, as the crystals of this carbonate are euhedral) The illite is shown as matted grains. There is apparently some replacement involving the carbonate and quartz. This carbonate does not seem to be clastic. There is opaque pyrite dust on the lines of suture of the grains. Quartz grains average size is .07 mm.

Number 14 Fine grained argillaceous orthoquartzite between Three Forks and New Denver, B.C.

This rock is composed mainly of quartz-feldspar grains. There is about 15% of pseudomorphous chlorite (?) in grains .15 mm - .20 mm. The Quartz and feldspar grains average .03 mm with range from .02 to .05 mm, a range which indicates rather good sorting action. Pyrite dust and a very small amount of carbonate (2%) with some argillaceous opaque material make up the rest of the rock. There is some biotite.

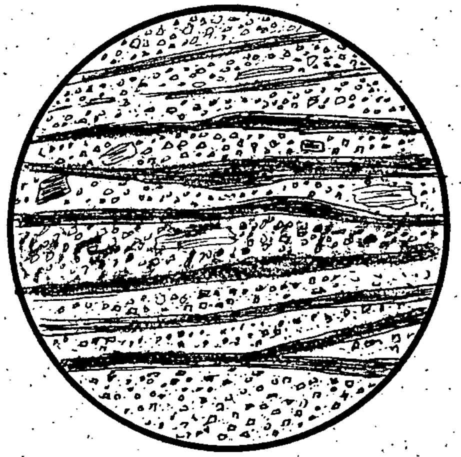
Number 16 Fine grained calcareous orthoquartzite or washed subgreywacke from near New Denver, B.C.

This rock approaches a finer grained equivalent of Number 19. The average grain size of the quartz and feldspar fragments is about .05 mm. The range is about .01 - .025 mm. There are minute embayments in the quartz indicating replacement of the quartz. The fragments are angular and sharp. There are some subangular grains. The quartz is about 60%, carbonate 30%, feldspar 5 - 10%. Illite, pyrite and clay material, 1 - 2%.

PLATE VIII

Number 10 Knottenschiefer from near a stock between New Denver and Three Forks, B.C.

This rock looks in hand specimen like a massive argillite. However, under the microscope, it shows a high degree of meta morphism. The matrix forms about 90% of the rock and consists of laminated layers of opaque material most likely argillaceous or carbonaceous material. The porphyroblasts are of pseudomorphous chlorite (?). There are also very small quartz fragments. There is fracture cleavate parallel to the bedding in hand specimen. The porphyro blasts are .4 mm. Before metamorphism this was probably a highly argillaceous rock.

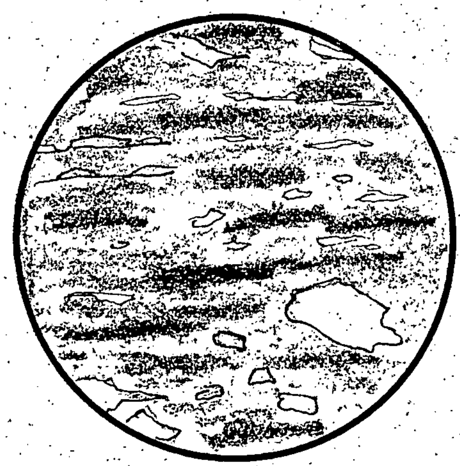


2 mm.

No 5F X-Nicols

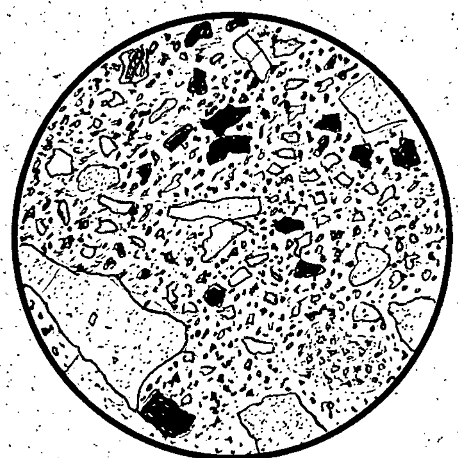
2 mm

No. 12 Ord. Light



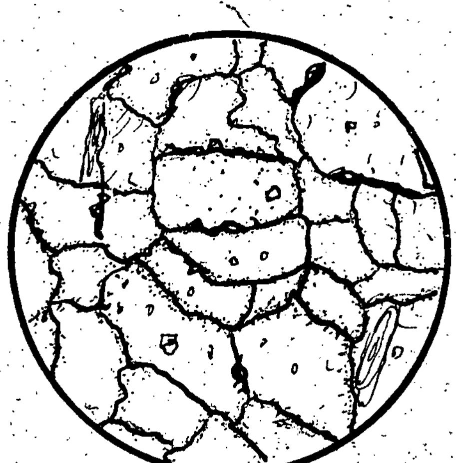
2 mm.

No 1 Ord. Light



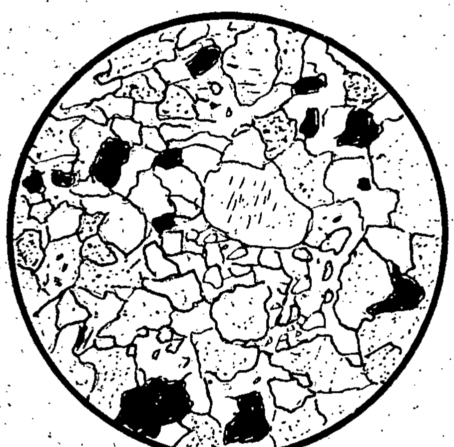
(app). 5 mm.

A X-Nicols



.05 mm.

A225



(App) .2 mm.

B X-Nicols

PLATE IX

to face p 74

PLATE IX

Number 5F This is a slate or phyllite from the 'Slate Belt' near Bear Lake.

The sketch shows very fine detrital grains of quartz and feldspar intercalated with layers of dark brownish opaque material. There are pseudomorphous prophyroblasts of chlorite (?) lying parallel with these layers. The opaque layers could be carbonaceous material. There are some fragments of twinned feldspar. The size of the grains seems to be about .002 mm average.

Number 9 This argillaceous quartzite is from between Three Forks and New Denver, B.C.

This specimen is similar to Number 13 (same range and grains size as A225) except that there is less feldspar and more argillaceous or carbonaceous material. The grains show much better sorting than in 13. The average size is about .05 mm and the range is very close to this figure. The opaque material is about 40%, quartz and feldspar grains 50% and sericite or illite and pyrite about 10%. There is no layering apparent. This is a porous black or argillite in hand specimen. There is little indication that quartz constitutes about 50% of the rock in the hand specimen.

Number 1 This is a carbonaceous shale-slate from between Sandon and Three Forks near Carpenter Creek.

PLATE IX

Number 1 This is a black rock in hand specimen which weathers readily and crumbles. The open clear spaces in the sketch are gaps in the slide left by the grinding out of pyrite crystals. The rest of the material is an indeterminate sooty black opaque material which is presumably a mixture of carbonaceous and argillaceous material with the argillaceous material constituting the greater part of the rock.

Number A225 This comes from the Howson Creek area near the Alamo Basin. This is a true orthoquartzite. The rock is almost 100% quartz grains. There is very good sorting and very little matrix. The average size of grain is .05 mm and the range is from .1mm - .025mm. Some quartz grains are fairly well rounded. The feldspar is 2 - 3% of the rock. There is some pyrite dust, and sericite. Tourmaline grains were seen in the slide but are not shown in the sketch.

Number A From Pettijohn (15) p. 245, Carboniferous Stanley shale near Mena Ark.

This sketch was traced from a photomicrograph in Pettijohn's "Sedimentary Rocks" to show comparison between subgreywacke types of Slocan rocks and true greywacke. This is a typical greywacke composed dominately of silver-like irregular quartz grains, together with a lesser amount of feldspar, and slaty or phyllitic rock fragments embedded in a chloritic or sericitic matrix. The latter forms a large and significant part of the rosk shown in A."

Number B From Pettijohn, p. 245, Atoka formation Carboniferous near Mena Ark.

"This rock is an orthoquartzite formed by elimination of fine interstitial detritus. Only quartz remains which shows a distinct rounding. Such a rock is not thoroughly cemented and constitutes a potential oil sand. The greywacke from which it is derived, such as A, is plugged tight with a paste and is impermeable."

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PLATE X

# GEOLOGICAL MAP OF SLOCAN SERIES AND RELATED SERIES OF SOUTH EASTERN BRITISH COLUMBIA

SCALE: 1 INCH = 8 MILES


## LEGEND

**MESOZOIC AND CENOZOIC**

- **VOLCANIC ROCKS** (MAINLY TERTIARY)
- **GRANITOID ROCKS** (GNEISS, ETC.)
- **GRANODIORITE (CHIEFLY)**
- **GRANITIC ROCKS (UNDIFFERENTIATED)**

**JURASSIC ROSSLAND GROUP**

- 18 — Argillite, sandstone and conglomerate, minor greenstone, mainly argillite. May be younger.
- 17 — Andesite, augite porphyry, latite, agglomerate, tuff, breccia minor argillite. May be in part younger.

**TRIASSIC SLOCAN SERIES**

- Slate, argillite, quartzite, limestone, schists. Impure argillite + quartzite.

**KASLO SERIES**

- 16 — Lavas, tuffs, breccias, allied intrusives schists.

**PALEOZOIC**

**CARBONIFEROUS MILFORD GROUP**

- 15 — Slate, argillite, quartzite, limestone, schists.

**LOWER CAMBRIAN EAGER FORMATION**

- 14 — Olive green, purple and grey shale.

**CRANBROOK FORMATION**

- 13 — White, rose, purple and grey quartzite and conglomerate.

**PROTEROZOIC**

**WINDERMERE**

- 12 — **LARDEAU SERIES** — Micaceous and Chloritic schists Quartzite and limestone, paragneiss.
- 11 — **LEDBETTER SLATE** — Black carbonaceous slate, black limestone near top.
- 10 — **BADSHOT-METALINE FORMATION** — Magnesian limestone.
- 9 — **HAMILL-GYPSY-MAITLEN SERIES** — Grey, green, and white silicious quartzite, phyllite.
- 8 — **HORSETHIEF CREEK-THREE SISTERS SERIES** — Green argillaceous quartzite, blue grey limestone arkose. pebble conglomerate.
- 7 — **MONK FORMATION** — Argillite, phyllite, limestone basal conglomerate.
- 6 — **IRENE-LEOLA FORMATION** — Sheared andesitic Volcanic rocks.
- **TOBY FORMATION** — Conglomerate.

**UPPER PURCELL-PRIEST RIVER GROUP**

- 5 — **MOUNT NELSON FORMATION** — Laminated argillite, magnesian limestone, quartzite.
- 4 — **DUTCH CREEK FORMATION** — Argillite, Magnesian limestone, Quartzite.

**LOWER PURCELL**

- 3 — **KITCHENER-SIYEH FORMATION** — Chiefly varicolored magnesian limestone and argillite, calcareous quartzite.
- 2 — **CRESTON FORMATION** — Purple and grey argillaceous quartzite, some argillite.
- 1 — **ALDRIDGE FORMATION** — Grey, rusty weathering argillaceous quartzite and argillite.

Note One: Ledbetter Slate And A Dolomite Member Are Assigned To The Ordovician And Devonian Respectively; Metaline, Maitlen, Gypsy And Monk Units To The Cambrian; And Leola, Shedroof And Priest River Units To The Pre-Cambrian By The U.S.G.S. Proterozoic Age Is Assigned By The G.S.C. To Equivalent Strata In The Canadian Portion Of The Windermere Geosyncline.

Note Two: Trend Lines For The Slocan Series Are Generalized From Available But Incomplete Data.

Geology And Topography From Maps Of The Geological Survey Of Canada And The United States Geological Survey.

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