

GEOLOGICAL STUDIES IN THE
GOLDSFIELDS AREA, SASKATCHEWAN
AND
THE GENESIS OF PITCHBLENDE

By

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ABSTRACT

The Goldfields area of Northern Saskatchewan is of particular interest as a metallogenic province for the mineral pitchblende. Rocks of the area are predominantly granites, schists, and gneisses of Precambrian age. Pitchblende occurs in calcite veins in or near fault zones. Mineral deposition was preceded by a period of brecciation, mylonitization, and hydrothermal alteration.

The present work consisted mainly of detailed geological mapping during three field seasons, examination of 250 thin sections and analysis of 60 rocks. Except for SiO_2 and FeO , major elements were analyzed by the author using quantitative spectrochemical techniques.

The work showed that chlorite, hematite, albite, calcite, and carbonaceous material were introduced during alteration. Introduced hematite and red albite are responsible for the red-alteration so conspicuous near most pitchblende deposits. In general, alteration is characterized by increases in Fe_2O_3 , K_2O , CaO , MgO , FeO and CO_2 ; Na_2O and SiO_2 commonly decrease.

The copper, nickel, and cobalt content of 20 diabases from Great Bear Lake, N.W.T.; Goldfields, Saskatchewan; Theano Point, Ontario; Cobalt, Ontario; and Cornwall, Pennsylvania was determined spectrochemically. The diabases analyzed contain roughly the same amounts of these metals as average diabase or gabbro.

Abstract - Continued

An extensive review of available literature leads to the conclusion that there is little geological evidence to support the commonly held belief that pitchblende deposits are genetically related to granite.

CONTENTS

	<u>Page</u>
Abstract	
Introduction.	1
General statement	1
Acknowledgements	3
Purpose of thesis	5
Research undertaken	5
Analytical methods	6
Accuracy of spectrochemical data	8

PART I

GEOLOGICAL STUDIES IN THE GOLDFIELDS AREA

SASKATCHEWAN

Introduction	11
Goldfields Area	11
Previous Work	13
Present Work	14
General geology	16
Table of formations	16
Geological history	17
Petrology	19
General statement	19
Eagle-Ato-Mic claims	20
Quartzite	20
Slate	22
Plagioclase-amphibolite	22
Chlorite-sericite schist	28
Garnet-mica schist	28
Chlorite-schist inclusions in alaskite	29
Alaskite	30
Athabaska conglomerate	33
Structural breccia	36
Ace property	42
Mafic inclusions in alaskite	42
Plagioclase-amphibolite	42
Alaskite	44
Chlorite-sericite schist	45
Donaldson Lake property	46
Alaskite	46
Granodiorite	47

	<u>Page</u>
South Shore Beaverlodge Lake	49
Plagioclase-amphibolite	49
Quartz-muscovite schist	49
Structural breccia	49
Correlation of intrusive diabase with flows . . .	50
Hydrothermal alteration	57
General statement	57
Presentation of data	60
Plagioclase-amphibolite	66
Blue alteration	66
Epidotization	68
Propylitization	68
Alaskite	71
Red alteration	71
Structural breccia	73
Chloritization	73
Sericitization	78
Red alteration	83
Introduction of carbon	88
Alteration of diabase at Great Bear Lake . .	91
Summary and conclusions	95

PART II

THE GENESIS OF PITCHBLENDE

Introduction	102
General Statement	102
Analyses of diabase	103
General statement	103
Major elements	103
Minor elements	106
Radioactivity	110
Conclusions	110
Review of literature	113a
General statement	113a
Northwest Territories of Canada	113b
Goldfields, Saskatchewan	113g
Theano Point, Ontario	117
Cobalt, Ontario	120
Silver Islet, Ontario	123
Wilberforce, Ontario	125
British Columbia	128
Gilpin County, Colorado	131
Coeur d'Alene, Idaho	133
Marysvale, Utah	136
Erzgebirge of Central Europe	138
Cornwall, England	146
Katanga, Belgian Congo	150
Summary and conclusions	155

ILLUSTRATIONS

		<u>Page</u>
Figure	1. Map showing location and access	11a
	2. General geology, Goldfields area	16a
	3. Map showing location of specimens	19a
	4. QLM diagram of Niggli	62
Plate	I. General view of Beaverlodge Lake Eagle mine head-frame	15a
	II. Photomicrograph of plagioclase-amphibolite Photomicrograph of diabase	27a
	III. Photomicrographs of black mylonite	41a
	IV. Detailed map of structural breccia	41b
	V. Detailed map of psuedo-conglomerate Drawing of diamond drill core-specimen	41c
	VI. Photomicrographs of greywacke-looking rock	41d
	VII. Variation diagrams showing blue-alteration of plagioclase-amphibolite	67a
	VIII. Variation diagrams showing epidotization of plagioclase-amphibolite	69a
	IX. Variation diagrams showing propylitization of plagioclase-amphibolite	70a
	X. Variation diagrams showing red-alteration of plagioclase-amphibolite	75a
	XI. Variation diagrams showing chloritization of albite-alaskite mylonite	81a
	XII. Variation diagrams showing chloritization and sericitization of albite- alaskite-mylonite	86a
	XIII. Variation diagrams showing chemical changes accompanying introduction of carbonaceous material	90a

Illustrations - Continued

		<u>Page</u>
Plate	XIV. Variation diagrams showing red alteration of diabase at Great Bear Lake N.W.T.	93a
	XV. Typical working curve	169
Table	I. Spectrochemical methods	8
	II. Analyses of quartzite	21
	III. Analyses of slates	23
	IV. Analyses of plagioclase-amphibolite . .	26
	V. Analyses of inclusions in alaskite . .	31
	VI. Analyses of alaskites	34
	VII. X-ray data on black mylonite	40
	VIII. Analyses of granodiorite	48
	IX. Analyses of basalt flows	52
	X. Analyses of diabase dykes	54
	XI. Example calculation of Niggli values .	64
	XII. Equations for determining Q,L,and M. .	65
	XIII. Analyses of blue-rock	67
	XIV. Analyses of epidotized rock	69
	XV. Analyses of propylites	70
	XVI. Analyses of red-altered alaskites . .	74
	XVII. Analyses of structural breccia	79
	XVIII. Analyses of chloritized and sericitized alaskite	84
	XIX. Analyses of muscovite schist and structural breccia	89
	XX. Analyses of diabase, Great Bear Lake, N.W.T.	92

Illustrations - continued

		<u>Page</u>
Table	XXI. Analyses of diabase, Theano Point, Ontario	104
	XXII. Analyses of diabase, norite, and gabbro drawn from literature	107
	XXIII. Minor element analyses of diabase and norite	108
	XXIV. Radioactivity measurement of diabase and basalts	111
	XXV. Radioactivity measurements of miscellaneous rocks	112
	XXVI. Analyses of uraninite and pitchblende-ore	127

Maps inside back cover

Sheet	1. North part of Eagle-Ato-Mic claims
	2. South part of Eagle-Ato-Mic claims
	3. Eagle mine-area

	<u>Page</u>
Bibliography	164a
Appendices	165
Spectrographic technique	166
Standards	168
Typical working curve	169
Spectrochemical and chemical analyses	170
Radioactivity measurements	204
Location of specimens	206
Biographical note	210

GEOLOGICAL STUDIES IN THE
GOLDFIELDS AREA, SASKATCHEWAN

and

THE GENESIS OF PITCHBLENDE

INTRODUCTION

General Statement

The Goldfields area in Northern Saskatchewan has become important in recent years because of numerous discoveries of pitchblende. The area is underlain by rocks of Precambrian age and, because of metamorphism and hydrothermal alteration, the geology in the vicinity of pitchblende deposits is exceedingly complex and presents a challenge to all geologists working in the district. The work carried out by the author is a contribution to the geological literature pertaining to pitchblende deposits in the area and to such other related problems as time would allow.

Field work in connection with this thesis was carried out during the summers of 1948, 1949 and 1950 while the author was employed as assistant geologist for the Crown Corporation, Eldorado Mining and Refining (1944) Ltd., Goldfields area, Saskatchewan. Laboratory work was undertaken at the Massachusetts Institute of Technology during the winter months of 1949-50 and 1950-51 and extended through the summer of 1951.

The thesis represents the first large scale application of spectrochemistry to major element analyses in the study of igneous and metamorphic rocks. The author analyzed 60 rocks for CaO, Al₂O₃, MgO, MnO, Na₂O, K₂O, and total Fe using spectrochemical methods. SiO₂ and FeO were determined by other analysts at the University of Minnesota using chemical methods. TiO₂, H₂O and CO₂ were not determined so that the tables of analyses given cannot be considered as entirely complete.

The complex geology in the Goldfields area presented a number of unique problems in correlation of rock types and hydrothermal alteration. It became obvious that linear analyses were entirely inadequate to determine the rock composition, as many were too fine grained to be resolved under the microscope. Chemical analyses were necessary, but normal chemical analyses are prohibitive both as regards time and expense for work of this kind. On the other hand, spectrochemical techniques for major elements have opened up a new era in geochemistry as multiple analyses can now be turned out with satisfactory accuracy at a fraction of the time and expense of chemical work. It was fortunate for the author that spectrochemical methods for analyzing major elements had just previously been developed by Dr. W. H. Dennen and Dr. L. H. Ahrens in the Cabot Spectrographic Laboratory at M.I.T. This is the first thesis at M.I.T. to demonstrate the practicability for a field problem of the spectrochemical methods developed for major elements.

Sixty linear measurements of thin sections were made of rocks in which major elements were determined. The linear measurements were particularly useful in correlating chemical changes during alteration with corresponding mineralogical changes.

The chief contribution of the thesis in the field of geology is the geochemical study of rock-alteration in a metallogenic province for the mineral pitchblende. This is an entirely new contribution and no such similar study is known in any other pitchblende province in the world.

Acknowledgements

The research and preparation of this thesis has been made possible by the assistance and cooperation of a number of individuals and organizations. In the first place, the financial assistance given by Eldorado Mining and Refining (1944) Limited during the whole period at M.I.T. is gratefully acknowledged. The author is also grateful for an M.I.T. scholarship covering tuition fees for the summer of 1951.

The cooperation in the field of the officers and staff of the Eldorado Mining and Refining Co. is sincerely appreciated. Thanks are especially due to Dr. E. B. Gillanders, Manager of Mining and Exploration, Dr. B. S. W. Buffam, Consulting Geologist, Mr. R. B. Allen, Chief Geologist and Mr. S. N. Kesten, formerly geologist for the company.

Dr. E. W. Nuffield of the University of Toronto kindly supplied a number of diabase specimens from the Theano Point area of Ontario and diabase specimens were also obtained from the Eldorado mine at Great Bear Lake N.W.T. through courtesy of Mr. D. D. Campbell, mine geologist.

The author wishes to express his appreciation to the staff of the Geology Department at M.I.T. for assistance and guidance of research undertaken. Dr. H. W. Fairbairn,

thesis supervisor, kindly gave freely of his time with many valuable suggestions and advice on petrological problems. Special mention should also be made of Dr. L. H. Ahrens whose assistance in the spectrographic work was invaluable and Dr. P. M. Hurley who kindly assisted the author with the radioactivity measurements.

Thanks are also due to Dr. W. H. Dennen, Mr. F. C. Canney and Miss Margaret Kearns for technical guidance in the Cabot Spectrographic Laboratory. Miss Geraldine Sullivan helped with chemical determinations of carbon, Mr. Leonid Azaroff with x-ray work and Mr. William Leavitt with photomicrography.

Dr. H. Eugster kindly assisted the author with translation of several articles in German.

To my wife, I am deeply grateful for much needed encouragement and for assistance with the calculations.

Purpose of Thesis

The overall purpose of this thesis was the study of two main problems as follows:

(1) Petrology in the vicinity of pitchblende deposits in the Goldfields area, Saskatchewan. The work undertaken consisted of a study of the various rock types present and an investigation of mineralogical and chemical changes during hydrothermal alteration.

(2) Possible genetic relationship between the nickel-cobalt-native silver-pitchblende type of mineralization and diabase. The approach to this problem consisted of an investigation of major and minor elements in diabase from Great Bear Lake, N.W.T., Goldfields Saskatchewan, Cobalt and Theano Point districts of Ontario and Cornwall Pennsylvania and a review of pertinent literature.

Research Undertaken

The laboratory work carried out by the author consisted chiefly of 560 spectrochemical analyses in duplicate supplemented by an examination of 250 thin sections. Other work consisted of 27 radioactivity measurements, an x-ray investigation of several mylonites and a determination of carbon in a breccia by chemical means.

Sixty silica and ferrous iron determinations were also made for the author in the rock analysis laboratory at the University of Minnesota. In addition, while studying the geochemistry of gallium and fluorine at M.I.T., Mr. C. K. Bell analyzed 6 of the author's specimens for gallium and Dr. Robert Seraphim analyzed 26 specimens for fluorine.

Analytical Methods

As this thesis did not involve the development of new analytical methods, only a brief outline of procedure followed will be presented; more detailed information may be obtained from references given.

In the preparation of a sample powder for analytical work, a steel mortar and pestle, operated manually, was used for preliminary crushing. This step reduced the material to about -20 mesh. After coning and quartering, a few grams of the powder were placed in a mechanically operated agate mortar for final grinding to approximately -100 mesh.

The size of rock specimens used for sampling varied somewhat with the amount of material available, but in most instances was about 2 to 3 cubic inches. The general rule followed was that used by Dennen (1949), which was based on the assumption that a sufficiently representative sample may be obtained from a specimen containing a minimum of 1000 mineral grains. Most rock specimens analyzed contained many

times this minimum and even the smallest specimens used probably did not contain less than 2000 to 3000 grains.

All reasonable precautions were taken against contamination and in this regard no screens were used in sizing material. To avoid the use of screens, material successively crushed in the steel mortar was placed on a sheet of paper ($8\frac{1}{2}$ x 11") and by repeated shaking coarse material was readily separated from the fines.

The analytical method used for the determination of Al, Ca, Mn, Fe and Mg is essentially the one used by Dennen (1949) which was modified after Kvalheim (1947). For the spectrochemical analyses of remaining elements, all methods have been developed by students and research assistants in the Cabot Spectrographic Laboratory at M.I.T. under the supervision of Dr. L. H. Ahrens.

In the spectrographic work, the D.C. arc was employed and a general outline of the analytical scheme used is shown in Table I.

In the determination of Al, Ca, Mn, Fe and Mg, the spectrographic plate was calibrated by means of a multiplet of iron lines of known intensity (see Ahrens (1950), page 31). For all the remaining elements analyzed spectrographically, the intensities were obtained by means of the self calibration method (see Ahrens (1950) pp. 136-137). Working curves used were all similar to that shown by Ahrens (1950 p. 134) with the exception of working curves for Cu, Co and Ni in which a single point working curve was employed (see Ahrens (1950),

p. 135). An example of a working curve used is included in the appendix (p. 169) along with spectrograph operating data.

Carbon was analyzed chemically. A description of the method used is given by Burton and Sullivan (1951)

Table I

Element and Line	Internal Standard and Line	Spectrograph
Al (2652) Ca (3158 and 3006)		Grating (Wadsworth mounting)
Mn (2801)	Sr (2931)	
Fe (2929)	as Sr CO ₃	
Mg (2779)		
Na (5682 and 5688)	Li: (4972) as Spodumene	Hilger (Quartz and glass prism)
K (6939)	Na (variable), (5682 and 5688)	
Rb (7947)		
Li (8126 and 6707)		
Cu (3247)		No internal standard
Co (3453)		
Ni (3492)		

Standards: In the case of the major elements Al, Ca, Mn, Fe, Mg, Na and K, the standards relied upon most were G-1 (standard granite) and W-1 (standard diabase). Both of these standards had been previously analyzed by 33 analysts in 24 rock laboratories in various parts of the world. To supplement these standards, for the purpose of increasing the overall range of composition, several chemically analyzed mineral powders were also used (see page 168). For analyses of G-1 and W-1 see Fairbairn and others 1951.

The analyses of the remaining elements Rb, Li, Cu, Co and Ni are also based on chemical data but only from a relatively few independent laboratories.

Accuracy of Spectrochemical Data

The accuracy and reproducibility of spectrochemical data in this report depends in the first place upon whether the method used was quantitative or semi-quantitative. Except for Cu, Ni and Co, which were analyzed semi-quantitatively, quantitative methods using suitable internal standards were employed for the analysis of all elements. The accuracy of quantitative methods used probably corresponds fairly closely to reproducibility, as actual analyzed rocks and minerals, and not artificial mixtures of the oxides, were used as standards (see page 168).

Reproducibility of a number of quantitative spectrographic techniques have been determined by students and research assistants in the Cabot Spectrographic Laboratory at M.I.T. and as shown by Ahrens (1951), the standard deviation of all techniques presently in use invariably fall within the range of 2.5-8 per cent, with the exception of the method for fluorine which is 11 per cent.

In the analyses of Cu, Co and Ni, the standard used was the standard diabase (W-1) which corresponds closely in composition with most of the specimens analyzed. As no internal standard was employed, however, the method used can be considered as semi-quantitative only. The reproducibility of this method is not known as an insufficient number of analyses were carried out on any one specimen. However, a

comparison of the analyses of Cu, Co and Ni on pages 201-203, with those of quantitative analyses on the preceding page and show that with the method used, reproducibility suffered little if any because of the lack of an internal standard.

When a complete chemical analysis of a rock is made, it is the common practice of analysts to check their overall work by adding up the constituents to 100 percent. However, as H₂O, TiO₂ and CO₂ were not analyzed in the present work, this check could not be applied except in a rough manner.

PART I

GEOLOGICAL STUDIES IN THE

GOLDFIELDS AREA SASKATCHEWAN

INTRODUCTION

The Goldfields Area

The Goldfields area is located in the northeast corner of the province of Saskatchewan, near the western margin of the Canadian Shield (see Fig. 1). The area is accessible by air from Prince Albert, Saskatchewan, or from Edmonton, Alberta; both routes are approximately 450 miles. Heavy freight is brought in from the end of the steel at Waterways Alberta by river and lake barges to the north shore of Lake Athabaska.

In general, the area is fairly rugged with hills rising to over 700 feet above the nearest lakes. This contrasts with the nearly flat topography normally found on the Canadian Shield.

Interest first centered in the Goldfields area in 1934 when gold was discovered on what is now the Box property of the Consolidated Mining and Smelting Company of Canada. This was rapidly followed by several other gold discoveries on the Athona and Nicholson properties and in 1935 a few minor occurrences of pitchblende were found. At that time, the chief interest was in gold and little attention was paid to the pitchblende.

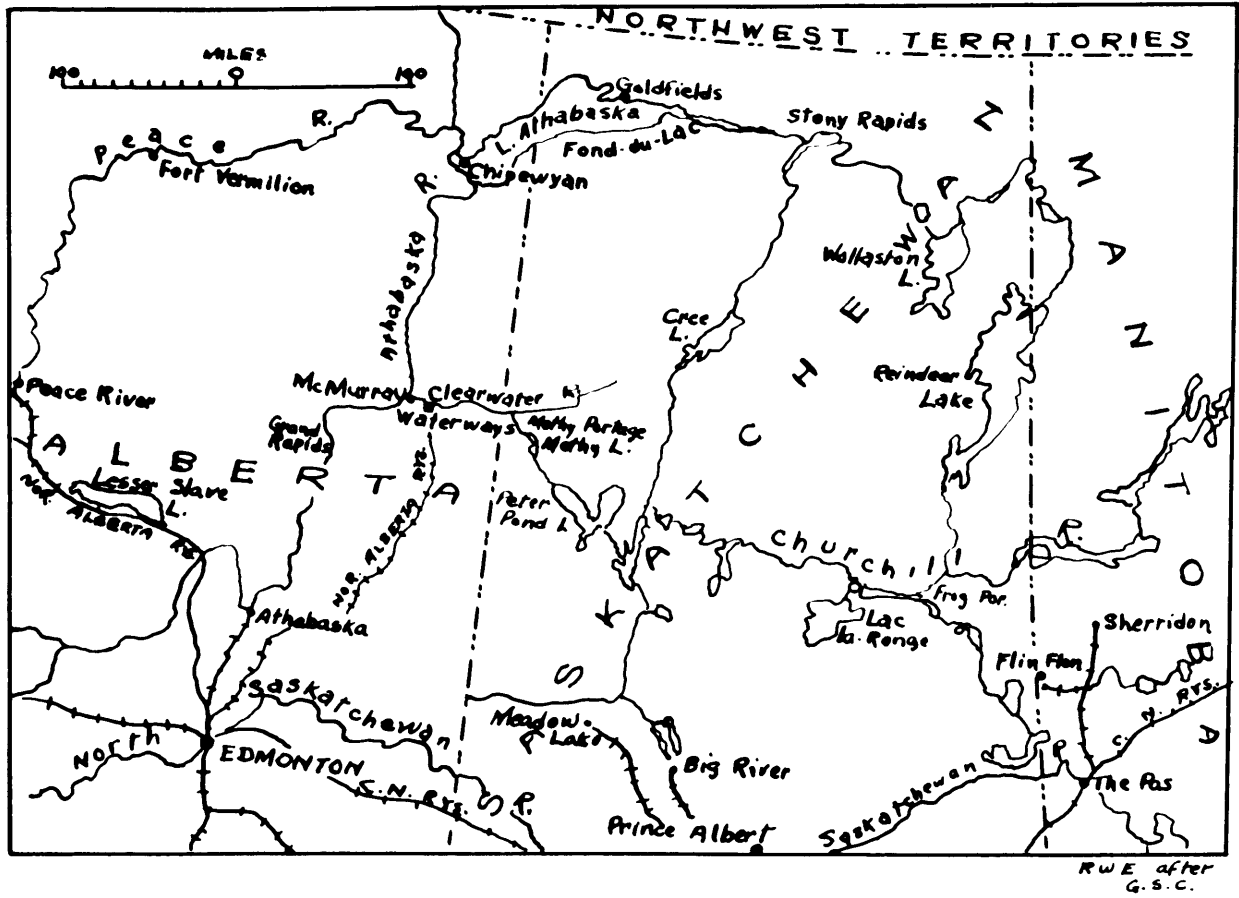


Figure I. Showing location and access.

After extensive underground operations and mill tests, the largest and most promising operation in the area, the Box Gold mine, did not prove to be economic and closed down in 1942. Interest then waned in the area until near the close of World War II when the Eldorado Mining and Refining Company, a crown corporation, initiated an extensive exploration program in the quest for new sources of uranium.

The exploration undertaken by the Eldorado Mining and Refining Company is still continuing and about forty mining companies have now entered the field. Interest has not revived in gold and all companies are engaged in the search for uranium. In the last few years, hundreds of uranium discoveries were made and underground operations have begun at a number of properties including the Martin Lake, Ace and Eagle mines of Eldorado Mining and Refining, the Nesbitt-Labine uranium mine; the Nicholson Consolidated mine and the Rix Athabaska mine. To date, no uranium has been produced but Eldorado recently announced in the press that a mill with a capacity of 500 tons of ore daily would be constructed in 1952 with initial production schedule for early 1953.

Besides the mining and exploration activity, a number of construction projects are underway at present. A new townsite, a few miles west of Beaverlodge Lake is being surveyed and will be known as Uranium City. The new town will replace the present settlement at Goldfields as the center of activity in the area. Roads are being constructed

to link up the principal uranium properties and a large air-field will soon be in operation.

Hydroelectric power is available in the area from a plant originally constructed by the Consolidated Mining and Smelting Company in 1939.

Previous Work

The first extensive geological work in the Goldfield area was undertaken by F. J. Alcock (1936) for the Geological Survey of Canada in 1935. Mapping was done on a scale of one inch to four miles covering a large area both north and south of Lake Athabaska (Tazin Lake, Fond-du-Lac and Stoney Rapids sheets). In the vicinity of the settlement of Goldfields, mapping was carried out on a scale of one inch to one mile (Goldfields sheet).

Geological work in the area was continued by the Survey in cooperation with the Eldorado Mining and Refining Company during 1947 and 1948. This resulted in Geological Survey paper 49-17 by A. M. Christie and S. N. Kesten (1949). Preliminary maps which accompany the paper are on a scale of one inch to 1/2 mile.

A. M. Christie completed a Ph.D. thesis at McGill University in 1948 based on his work with the Survey in the Goldfields area in 1947. This is an excellent work and along

with the report by Christie and Kesten, has formed the basis for further detailed geological work in the area.

An unpublished M.Sc. thesis on the geology of the Eagle property of the Eldorado Mining and Refining Company was completed by E. E. N. Smith at Northwestern University in 1949. This is primarily a petrological study and was a great help in studying petrological problems in the area.

Gonybeare and Campbell (1951) recently published a paper on red alteration in the Goldfields area of Saskatchewan. This is a good paper, but deals with mineralogical changes only and is not supported by chemical data.

A general survey of Canadian uranium deposits by James, Lang, Murphy and Kesten (1950) and another paper by Lang (1951) include discussions of uranium deposits in the Goldfields area. A paper by R. B. Allen (1950) discusses structural features favourable to ore deposition and another paper by S. C. Robinson (1950) covers the mineralogy and paragenesis of a number of uranium deposits in the Goldfields area.

Present Work

The original field work on the Eagle-Ato-Mic claims of the Eldorado Mining and Refining Company was done by E. E. N. Smith, I. Bain and others in 1948 on a scale of one inch to 200 feet. The mapping was carried out by pace and compass using a system of surveyed picket lines two hundred

feet apart for control. During the summer of 1948, the author also mapped part of the Eagle property in the vicinity of some of the more important uranium veins, on a scale of one inch to 40 feet.

After examining a number of thin sections at the University of Alberta during the winter of 1948-1949 and again at the Massachusetts Institute of Technology during the winter of 1949-50, the author revised the geology of the Eagle-Ato-Mic claims in the summer of 1950. This work consisted mainly of subdividing the so-called mafic rocks into plagioclase-amphibolite, slate, chlorite-sericite schists, garnetiferous-muscovite schist and structural breccia and checking contacts in the field. The revised maps are shown in three sheets and are included in this report.

Plate I.



General view of Beaverlodge Lake, Saskatchewan,
summer 1950.



Eagle mine head-frame, December, 1950.

GENERAL GEOLOGY

The following table indicates the probable succession in the Goldfields area.

Table of Formations

Quaternary	Gravel, sand, boulder clay	
Erosion		
Proterozoic	Athabaska* series	Basalt flows, sills (?) and diabase dykes Arkose Conglomerate
Unconformity		
Granite and granite-gneiss		
Intrusive contact		
Proterozoic or Archaen	Tazin* group	Plagioclase-amphibolite Garnet-mica schist Chlorite-sericite schist Slate Quartzite Conglomerate Dolomite and dolomitic quartzite

*The relative position of the various rock types in the Tazin group and Athabaska series is arbitrary

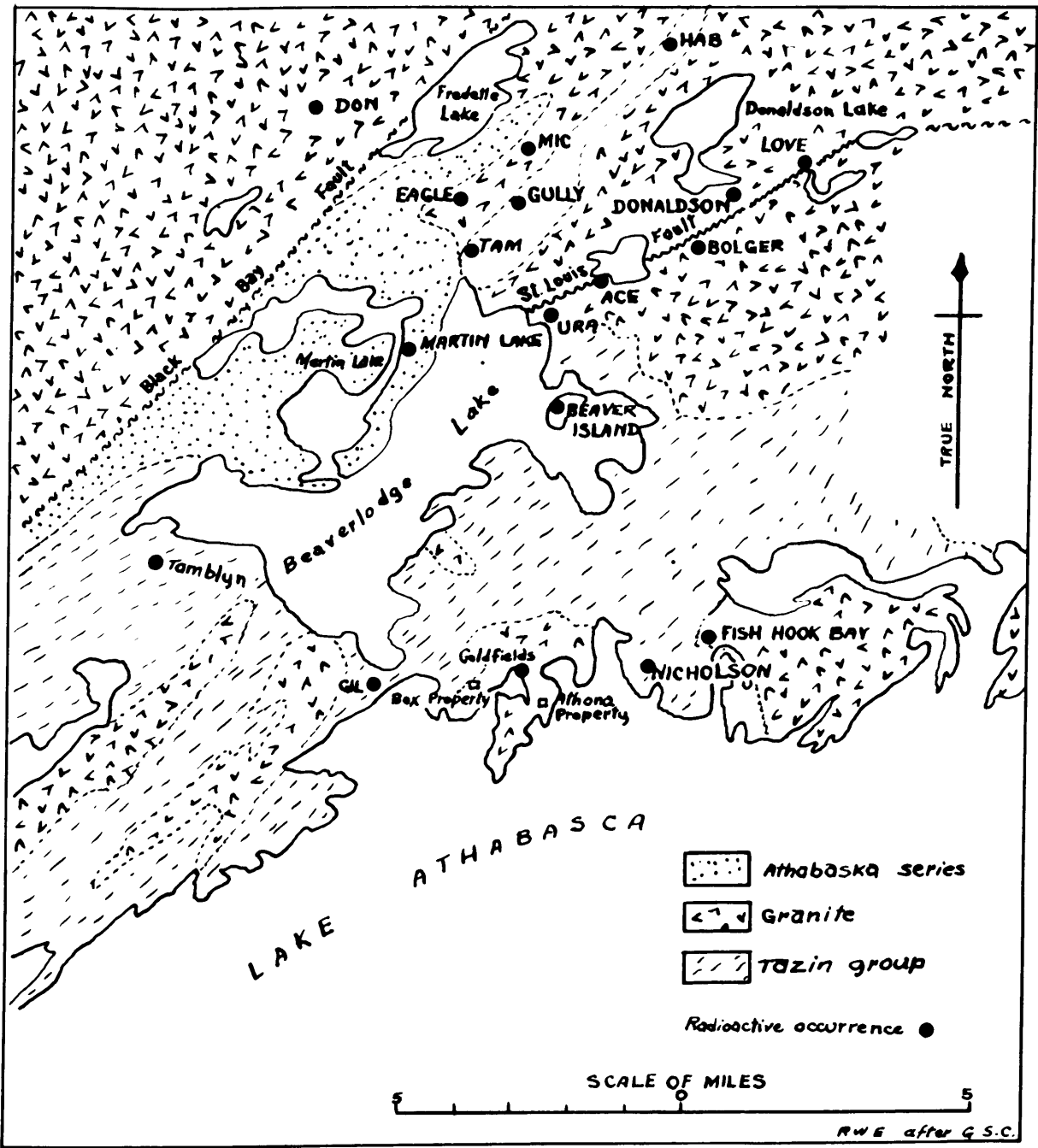


Figure 2. General geology, Goldfields area
Saskatchewan

Historical Geology

In his report on the geology of the Lake Athabaska region, Alcock (1936) divided the pre-Athabaska rocks into two groups, an older Tazin series and a younger Beaverlodge series. However, Christie and Kesten (1949) in a more recent work include all pre-Athabaska rocks (other than granite and lamprophyre) in the Tazin group and this system will be followed in the present report.

The Tazin group comprises an assemblage of sediments, lava flows and basic intrusive rocks that have been regionally metamorphosed and intruded by granitic rocks of batholithic extent. Several types of granitic rocks are recognized, including granodiorite, granite and alaskite but the relationship between these rocks is not known.

After erosion laid bare large areas of granitic rock, the Athabaska series was laid down on the unconformity. Athabaska rocks consist of interbedded conglomerate, arkose and basalt flows with a few intercalated basic sills.

Numerous diabase dykes in the Goldfields area are believed to represent feeder dykes to flows and sills. It is possible that some dykes are younger than any flows now exposed.

Athabaska time closed with a period of folding which folded the rocks into rather broad open folds whose axes trend north-northeast. This was followed by faulting along northeast trending lines. The faulting was accompanied by extensive

shearing, mylonitization and brecciation and is believed to have provided the channelways for hydrothermal alteration and uranium mineralization.

In the area north of Lake Athabaska, most of the Athabaska rocks have been eroded away since late Pre-Cambrian time except where local post-Athabaska folding has preserved synclines: the best example of which is the syncline at Martin Lake (see Fig. 2). Linear remnants of Athabaska rocks have also been preserved at several places in the area along the southeast side of northeast trending faults.

PETROLOGY

General Statement

Except for the relatively young Athabaska series, the petrology in the Goldfields area is complex. The Tazin rocks in particular have been highly metamorphosed during two successive stages. The first stage was largely thermal (regional metamorphism) and was accompanied by intrusion of granite. The second stage at a much later date was largely cataclastic in which both Tazin and intrusive granites were locally mylonitized, brecciated and finally hydrothermally altered. Unfortunately for the mining geologist the areas requiring detailed study in the exploration and development of uranium deposits have been subjected to the most severe metamorphic changes. This has created a difficult problem in recognition and correlation of the various rock types. For this reason the writer has included in this report all information available about the rocks, including detailed descriptions and criteria for recognition and petrographic, chemical and spectrochemical data.

In studying the petrology of the Goldfields area, most attention was paid to the Eagle-Ato-Mic claims because here the geology seemed to be the most complex. However, specimens were also selected for study from other areas mentioned herein that posed unique problems.

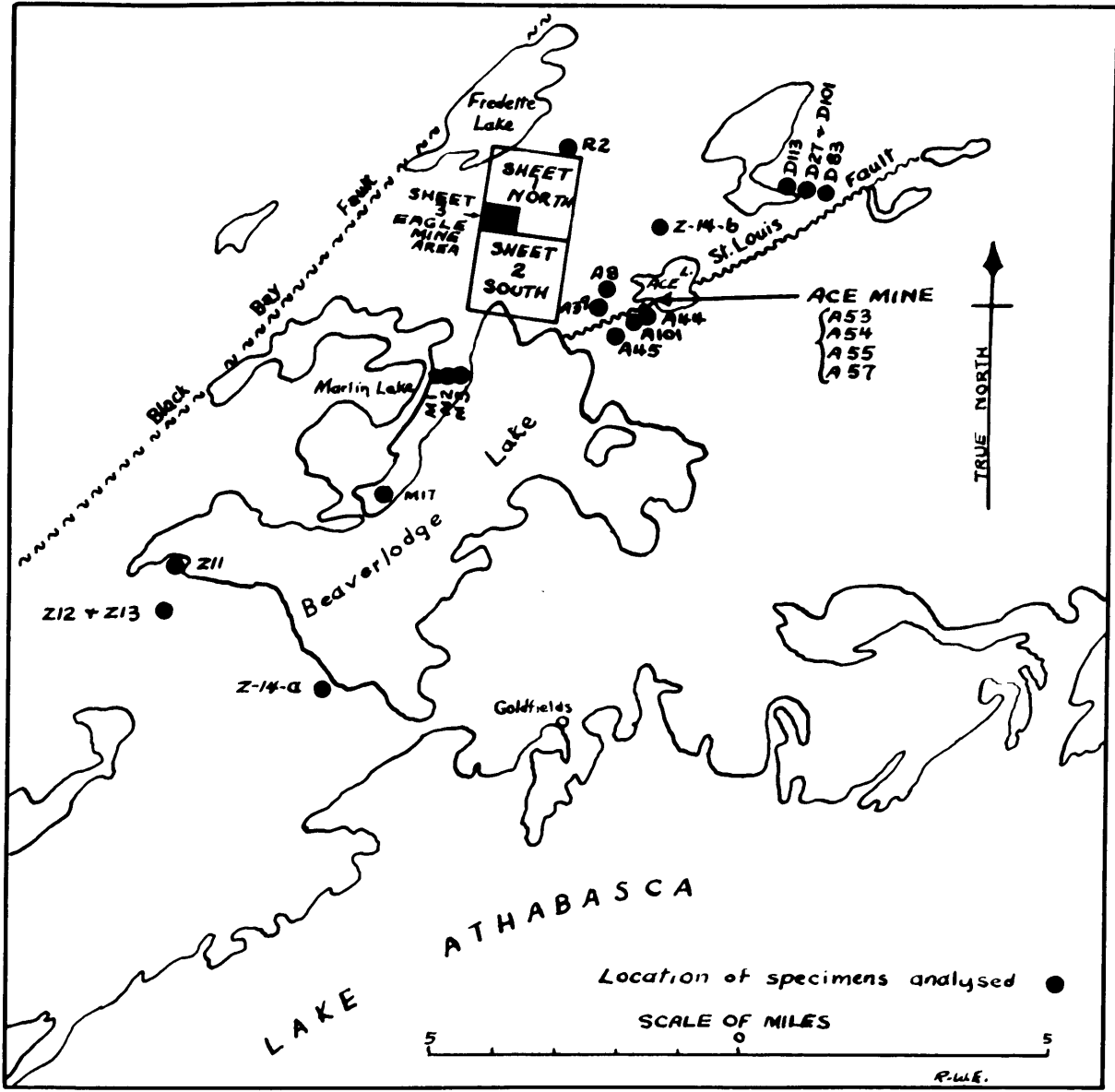


Figure 3. Key Map showing location of rock specimens analyzed and map areas included in thesis

Note: Locations of specimens in the Eagle mine area and Sheet 2 South are shown on their respective geological maps.

Eagle - Ato - Mic Claims

Quartzite. Quartzite outcrops at a number of places in the areas mapped (see sheets 1-3). The quartzite is generally massive and bedding is absent or only faintly recognizable. It is normally white to smokey grey, but locally is purple due to small amounts of disseminated hematite.

An analysis of mylonitized quartzite from the Eagle mine is shown in Table II. The rock analyzed is not bedded and contains quartz, chlorite and epidote. Thin section study suggests that at least part of the chlorite and possibly all of the epidote were introduced hydrothermally into minute fractures. If this is true, then analyses for calcium, magnesium and iron may be higher than typical quartzite in the area. An analysis of quartzite from Cobalt, Ontario, is included for comparison.

The rocks mapped as quartzite may have originally been orthoquartzite, chert beds or local silicified zones. In general, these rocks consist of over 90 per cent quartz with a few shreds of sericite. Of several thin sections examined, none showed secondary enlargement of quartz grains or heavy residual minerals common to orthoquartzites. However, the rocks examined were considerably mylonitized. Such features as secondary enlargement or recognizable heavy residual minerals could have been erased by cataclastic metamorphism. Their absence, therefore, is not significant in determining the origin of the rock.

TABLE II

Analyses and Mineral Composition of Quartzite

	<u>A.</u>	<u>B.</u>
SiO ₂	89.1	95.32
TiO ₂	--	--
Al ₂ O ₃	6.7	2.85
Fe ₂ O ₃	2.1	0.05
FeO	1.4	
MnO	0.1	--
MgO	2.0	0.04
CaO	0.7	--
Na ₂ O	0.5)	0.30
K ₂ O	0.2)	
H ₂ O	--	1.44
CO ₂	<u>--</u>	<u>--</u>
	102.7	100.00
F	0.007	--
Ga ₂ O ₃	0.00075	--
Rb ₂ O	0.0026	--
Quartz	89.5	--
Unidentified opaque	0.4	--
Chlorite and sericite	10.0	--
Calcite	0.1	--
Epidote	<u>Trace</u>	--
	100.0	

- A. Quartzite from Eagle mine, Goldfields Saskatchewan, specimen U50.
- B. Lorrain quartzite, Cobalt series, Huronian, Cobalt Ontario, Pettijohn (1949), p. 241.

Slate. Large areas of slate outcrop southwest of Eagle Lake (Sheet 1) and between Tam and Beth Lakes (Sheet 2).

The slate is generally dark-grey to black. At many localities bedding is not clearly visible. However, in the area immediately to the north of Tam Lake, the slate is finely bedded and bedding is nearly parallel with slaty cleavage.

Microscopic work shows that the slates consist predominantly of chlorite and white mica with lesser amounts of quartz, feldspar and epidote.

The analysis of a typical bedded slate closely corresponds with analyses of Knife Lake slate and Glenwood shale given by Pettijohn (see Table III). The analyses indicate that both the slate from the Goldfields area and the Knife Lake slate probably were originally normal shale type sedimentary rocks.

Plagioclase-amphibolite. Plagioclase-amphibolite is widely distributed in the areas mapped. In a few localities, narrow bands of metamorphosed sediments are found in plagioclase-amphibolite. The sediments (bedded chlorite-sericite schists) are lighter in color than adjacent plagioclase-amphibolite and can rarely be traced more than 20 to 30 feet.

In the areas mapped by the author, no field evidence was observed indicating the mode or modes of occurrence of the plagioclase-amphibolites before metamorphism. They are merely considered as of intrusive or extrusive origin. On the other hand, similar types of rock showing well-defined

TABLE III

Analyses and Mineral Composition of Slates and
Allied Rocks

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
SiO ₂	57.7	77.8	67.7	56.29	60.88
TiO ₂	--	--	--	0.64	0.62
Al ₂ O ₃	22.1	11.3	13.1	19.22	17.78
Fe ₂ O ₃	3.3	0.6	0.7)	4.39	1.94
FeO	5.6	2.1	4.3)		4.07
MnO	0.1	Trace	0.1	--	--
MgO	4.6	1.3	2.6	1.65	3.53
CaO	0.8	1.1	1.0	0.09	2.77
Na ₂ O	2.0	3.6	3.1	0.19	2.65
K ₂ O	4.0	0.6	2.1	10.85	3.16
H ₂ O	--	--	--	5.58	2.04
P ₂ O ₅	--	--	--	--	0.29
SO ₃	--	--	--	0.72	--
C	--	--	--	--	1.70
S	--	--	--	--	0.10
	100.2	98.4	94.7	99.62	101.53
F	0.035	--	--	--	--
Ga ₂ O ₃	0.0043	--	0.0026	--	--
Rb ₂ O	0.061	--	--	--	--

TABLE III
Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
Chlorite	55.6	66.3	--	--	--
Sericite	21.6	--	--	--	--
Chlorite and sericite	--	--	70.1	--	--
Albite	15.1	21.1	8.3	--	--
Quartz	4.6	2.5	13.8	--	--
Epidote	2.1	5.1	7.7	--	--
Calcite	--	--	Trace	--	--
Specularite	1.0	5.0	0.2	--	--
	<hr/>	<hr/>	<hr/>		
	100.0	100.0	100.0		

- A. Chlorite-sericite schist, Tazin group, Precambrian, Ace mine, Goldfields Saskatchewan, specimen A54.
- B. Brown cherty rock, Tazin group, Precambrian, same location as A, specimen A55.
- C. Bedded slate, Tazin group, Precambrian, Ato claims, Goldfields, Saskatchewan, specimen R164.
- D. Glenwood shale, Ordovician, Minneapolis, Minn. Pettijohn (1949), p. 285.
- E. Knife Lake slate, Archaen, Minnesota, Pettijohn (1949, p. 285.

pillow structures are described by Alcock (1936) from the southern part of the Goldfields area and massive coarse grained plagioclase-amphibolites from this same region have been called metagabbro by Christie (1948).

In hand specimen, the coarser grained plagioclase-amphibolites have a speckled appearance due to plagioclase (white) and hornblende (greenish-black). However, the most common type in the areas mapped is fine grained and has a uniformly dark-grey to yellowish-green color.

A study of thin sections shows that the plagioclase-amphibolites have been completely recrystallized. They are composed chiefly of blue-green hornblende and untwinned andesine or oligoclase with minor amounts of chlorite, epidote and opaque minerals.

The grain size depends on the degree of crushing to which these rocks were subjected during late cataclastic metamorphism. Where crushing has been severe, hornblende crystals are splintered and broken and the texture has been transformed into a felted mass of hornblende fragments with interstitial plagioclase.

Analyses of two specimens of plagioclase-amphibolite from the Eagle mine area are shown in Table IV. For comparison an analysis of an olivine basalt is included. Although Johannsen gives a number of analyses of olivine basalt, this particular one was chosen for comparison because the silica content was almost identical to the percentage of silica in the rocks analyzed.

TABLE IV

Analyses and Mineral Composition of
Plagioclase-Amphibolites

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
SiO ₂	44.6	44.4	51.6	45.33
TiO ₂	--	--	--	2.23
Al ₂ O ₃	16.2	16.2	11.2	14.99
Fe ₂ O ₃	1.7	1.9	3.2	3.38
FeO	10.8	10.6	9.2	8.75
MnO	0.3	0.3	0.2	0.20
MgO	7.0	6.0	4.8	6.93
CaO	5.9	5.2	6.6	8.06
Na ₂ O	3.6	3.0	3.0	2.94
K ₂ O	1.6	2.0	1.2	1.00
H ₂ O	--	--	--	5.66
P ₂ O ₅	--	--	--	0.28
CO ₂	--	--	--	0.15
S	--	--	--	0.18
	<hr/>	<hr/>	<hr/>	<hr/>
	91.7	89.6	91.0	100.08
F	0.13	0.15	--	--
Rb ₂ O	0.012	0.019	--	--

TABLE IV

Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
Hornblende	52.8	35.1	65.8	--
Oligoclase	27.0	49.0	--	--
Andesine	--	--	29.2	--
Biotite	--	Trace	--	--
Quartz	--	--	1.4	--
Apatite	--	0.5	0.6	--
Ilmenite	--	--	2.5	--
Chlorite	9.4	12.1	--	--
Epidote	7.9	--	--	--
Calcite	1.0	--	--	--
Specularite	1.9	3.2	--	--
Hisingerite (?)	--	0.2	0.6	--
Pyrrhotite	--	--	Trace	--
	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0	<hr/>

- A. Plagioclase-amphibolite, Tazin group, Precambrian, Eagle mine-area, Goldfields, Saskatchewan, specimen E346.
- B. Plagioclase-amphibolite, Tazin group, Precambrian, Eagle mine-area, Goldfields, Saskatchewan, specimen E421.
- C. Plagioclase-amphibolite, Tazin group, Precambrian, South Shore Beaverlodge Lake, Goldfields Saskatchewan, specimen Z-14-a.
- D. Olivine-basalt, Livingstone Island, Antarctica, Johannsen (1937), vol. 3, p. 305.

Plate II.



Thin-section, typical plagioclase-amphibolite, Goldfields area, Saskatchewan. Oligoclase - greyish-white, hornblende - dark grey. Ordinary light, X50.



Thin-section, typical diabase, Goldfields area, Saskatchewan. Laths of plagioclase (white) and magnetite (black) in fine-grained indeterminate matrix. Ordinary light, X50.

On the whole, the analyses of the plagioclase-amphibolites closely correspond with the analysis of the olivine basalt given. At first glance this would seem to indicate that the original rock was an olive-basalt or equivalent diabase or gabbro. However, there is no method of actually determining the original composition of the plagioclase-amphibolites because the extent of metasomatic changes during regional metamorphism in the area is not known.

Chlorite-sericite schist. Chlorite-sericite schist is found in several widely separated localities on the Eagle-Ato-Mic claims. A typical specimen is pale greenish-grey and has finely laminated bedding.

Microscopic study shows that these rocks are composed chiefly of chlorite and white mica with minor amounts of albite, quartz and epidote. Because of similar mineralogical composition, the chlorite-sericite schists are believed to be slightly higher grade metamorphic equivalents of black slates previously described on page 22.

Garnet-Muscovite schist. A belt of garnet-muscovite schist, several hundred feet wide occurs north of Beth Lake (Sheet 1) and extends northeast as shown on Sheet 2. The rock typically has a honey-yellow color. Dark red garnets up to 1 mm. in diameter are common, but are not easily recognized without a hand lens.

In thin section, this rock is seen to be composed largely of muscovite and quartz with minor amounts of garnet. Smith (1949) found considerable cordierite in rocks of this type, but none was found in thin sections examined by the author.

The mineralogical composition indicates that this rock was probably a shale-type of sedimentary rock and may be a higher grade metamorphic equivalent of slates and chlorite-sericite schists in the area.

Chlorite-Schist inclusions in Alaskite. A few chlorite-schist inclusions occur in all alaskite bodies mapped. Similar inclusions consisting of amphibolite have been noted by Christie and Kesten (1949) in many parts of the Goldfields area. The amphibolite inclusions are commonly altered to biotite gneiss on their contacts.

Drill-core intersections of chlorite-schist inclusions in alaskite in the Eagle mine are speckled white and greyish-green. Microscopic examination shows the inclusions to consist almost entirely of chlorite and untwinned oligoclase. Hydrothermal alteration has apparently altered hornblende and/or biotite to chlorite, but has not affected the oligoclase.

The analysis of a specimen of chlorite-schist inclusion from the Eagle mine is shown in Table V. The analysis indicates that the chlorite-schist is more closely related to plagioclase-amphibolite than any other rocks analyzed.

Alaskite. Alaskite (or granite) is the most common rock type in the areas mapped. The term alaskite is used in preference to granite because, unlike normal granite, the rock generally contains less than 2 per cent ferromagnesian minerals and is composed almost entirely of quartz and feldspar. The feldspar is commonly albite (An_{5-10}) but a specimen of alaskite consisting primarily of orthoclase and quartz was collected from a point about 300 feet southeast of Bill Lake (Sheet 1). The orthoclase- and albite-alaskites are not readily distinguished except in thin section and the areal extent of the orthoclase-bearing type is not known.

A characteristic feature of the alaskite is that it commonly contains "splashes" or irregular bodies of milky-quartz, up to several feet across.

In general, the alaskite is uniform in composition, but locally it grades into granite gneiss showing relict sedimentary bedding.

Alaskite intrudes all of the Tazin rocks described in the preceding pages. Along many of the contacts between alaskite and metamorphosed Tazin rocks, dykelets of alaskite can be seen cutting the "Tazin".

The alaskite is typically salmon-pink, but in a few localities is white. The rocks are generally medium to fine grained and all specimens show evidence of cataclastic metamorphism. A freshly broken surface does not in general show

TABLE V

Analyses and Mineralogical Composition
of Chlorite-schist Inclusions in Alaskite

	<u>A</u>	<u>B</u>
SiO ₂	40.0	42.9
TiO ₂	--	--
Al ₂ O ₃	21.1	22.7
Fe ₂ O ₃	6.6	5.5
FeO	11.5	14.5
MnO	0.3	0.3
MgO	14.6	9.4
CaO	0.6	0.6
Na ₂ O	3.8	3.9
K ₂ O	0.5	0.8
H ₂ O	--	--
P ₂ O ₅	--	--
CO ₂	--	--
	<hr/>	<hr/>
	99.0	100.6

TABLE V

Continued

	<u>A</u>	<u>B</u>
F	0.17	0.035
Rb ₂ O	0.007	0.006
Oligoclase	32.4	50.6
Chlorite	61.5	44.2
Calcite	0.9	--
Apatite	--	0.3
Specularite	5.2	4.8
	<hr/>	<hr/>
	100.0	100.0

- A. Chlorite-schist inclusion in alaskite, Ace mine-area, Goldfields, Saskatchewan, specimen A101.
- B. Chlorite-schist inclusion in alaskite, Eage mine, Goldfields, Saskatchewan, specimen E203.

cleavage faces of feldspar because most feldspar crystals have been broken up and the resulting fragments have a haphazard orientation. The finer grained alaskites grade into mylonites which are not easily distinguished from quartzites. The two rocks are most easily distinguished on the weathered surface. The weathered surface of fine grained alaskite has a chalky outer film up to 1/16 of an inch thick which has a marked kaolin odor. This contrasts with quartzites which are vitreous on weathered surfaces.

Where weathered surfaces are not available, the characteristic salmon pink color of alaskite serves to distinguish it from quartzite. Invariably, microscopic study has shown that fine grained cherty looking rocks with a salmon pink color are alaskite-mylonites. No quartzites of this color have been found on the Eagle-Ato-Mic claims.

An analysis of a typical albite alaskite from the Eagle mine area is shown in Table VI. Included in the same table for comparison purposes is an average of three analyses of alaskite from Johannsen (1932). The analyses closely correspond except for the relative percentages of soda and potash. This is due to differences in type of feldspar present.

Athabaska Conglomerate. Athabaska conglomerate outcrops at several places in the vicinity of Contact Lake (Sheet 1). The largest body of conglomerate lies along the south side of the Conglomerate fault. The dip of the fault as determined by underground mapping is about 30° to the south.

TABLE VI

Analyses and Mineralogical Composition of
Alaskites

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
SiO ₂	73.5	76.5	72.8	75.05
TiO ₂	--	--	--	0.03
Al ₂ O ₃	14.5	13.7	12.8	13.48
Fe ₂ O ₃	0.9	0.8	0.3	0.84
FeO	0.6	0.7	0.8	0.63
MnO	Trace	0.1	Trace	0.04
MgO	0.9	0.9	0.6	0.21
CaO	0.5	0.6	0.4	0.24
Na ₂ O	5.4	5.8	2.2	4.20
K ₂ O	1.0	0.3	7.5	5.03
H ₂ O	--	--	--	0.34
P ₂ O ₅	--	--	--	0.08
ZrO ₂	--	--	--	0.03
	<hr/>	<hr/>	<hr/>	<hr/>
	97.3	99.4	97.4	100.20
F	--	0.001	0.0025	--
Rb ₂ O	--	0.0013	0.019	--

TABLE VI

Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
Albite	57.6	66.9	--	--
Microcline	--	--	73.7	--
Quartz	30.4	30.3	23.2	--
Sericite	10.2	--	1.2	--
Calcite	--	0.3	--	--
Chlorite	1.5	2.0	1.7	--
Epidote	--	0.5	--	--
Unidentified opaque	0.2	--	0.4	--

- A. Albite-alaskite, Ace mine-area, Goldfields, Saskatchewan, specimen A44.
- B. Albite-alaskite, Eagle mine-area, Goldfields, Saskatchewan, specimen E420.
- C. Microcline-alaskite, Ace Creek, Goldfields, Saskatchewan, specimen A45.
- D. Alaskite, Johannsen (1932), vol. 2, p. 108 (average of several analyses).

This indicates that the faulting was of the normal type in order to have preserved the Athabaska rocks from erosion. However, the possibility of a graben type fault slice should not be overlooked.

The Athabaska conglomerate lies unconformably on Tazin rocks and alaskite. The conglomerate consists of pebbles and boulders up to several feet in diameter composed of a number of rock types, including at least two varieties of granite and a number of quartzites of contrasting colors. The conglomerate is well indurated and the matrix consists of dark grey sandy material which in some places appears chloritic and at other localities siliceous. Except where brecciated and highly altered the Athabaska conglomerate does not present any problem in recognition so that no special petrologic study was made of this rock.

Structural breccia. A number of irregularly shaped discontinuous breccia zones occur on the Eagle-Ato-Mic claims, especially on the northern half of the claim group (see Sheet 1). Most of the breccia zones strike northeast. The contacts with other rocks are ragged and insofar as the author is aware, insufficient core drilling or underground work has been done to determine the overall dip of any one zone.

The fragments in the breccia zones range in size from microscopic mylonitized particles to large angular blocks many feet across. The proportion of fragments to matrix varies considerably. In some places, as in the vicinity of the claim

posts (co-ordinates 164,300 N and 93,800 E) the breccia is almost free of recognizable inclusions and closely resembles a black porphyritic trap. However, no phenocrysts are present in the rock and, invariably, white flecks can be shown by microscopic study to be mylonitized fragments of alaskite rather than phenocrysts. At the locality referred to, uniformly fine-grained black rock grades laterally into typical breccia in which large angular to subangular fragments of mylonitized alaskite are crowded together and cemented with the same hard, black matrix.

The fragments in any one locality generally consist of one rock type but in a few places, as in the breccia complex exposed in the Eagle mine, mixed fragments are found. The most common rock fragment consists of mylonitized alaskite. Brecciated quartzite, plagioclase-amphibolite and Athabaska conglomerate have also been noted in various parts of the area mapped. Brecciated Athabaska conglomerate is particularly difficult to recognize in underground exposures, but is more readily recognized in diamond drill core intersections and in surface exposures.

The matrix of the breccia is generally dark grey to black and is extremely fine grained. No flow lines were observed and unlike the Sudbury breccia described by Fairbairn and Robson (1942), the matrix is generally massive rather than schistose.

For some time it was believed that the black matrix was trap (or basalt) which had intruded a breccia zone. However, detailed petrographic study with a high power objective lens, supported by x-ray work convinced the author that the matrix was simply a mylonite with hydrothermally introduced chlorite. The same conclusion was reached by Smith (1949) at Northwestern University.

Shand (1947) describes a similar breccia zone in South Africa which grades into an extremely fine-grained black rock which he had at first mistaken for basalt. He gave the name psuedo-tachylyte to the black rock in view of its resemblance to tachylyte or basalt glass.

Under the microscope, the breccia matrices studied consist of scattered fragments 1mm. or less of mylonitized alaskite in an almost isotropic and nearly opaque groundmass which polarizes in dark greys. The larger fragments exhibit a minute mosaic structure typical of mylonite (see Plate III). Their margins have a serrated appearance and seem to pass imperceptibly into the groundmass. Some thin sections show a few small clusters of porphyroblastic epidote or clinozoisite crystals which like the fragments fade into the groundmass at their margins.

As the groundmass of the breccia matrix is too fine grained to determine the mineral constituents optically, an x-ray investigation was carried out for this purpose. Powder x-ray photographs were taken of uniformly fine grained black

rock, the results of which are shown in Table VII.

The x-ray work shows that the black rock is composed primarily of quartz, feldspar and chlorite. Small amounts of other minerals are also undoubtedly present, but did not give measurable reflections. As orthoclase and plagioclase have nearly identical "d" spacings for their principal reflections, the composition or compositions of feldspar present could not be determined by the method used.

In the Eagle mine, the breccia appears to be a complex. Part of the zone is the common type described in the preceding paragraphs. It consists of angular fragments and blocks of salmon-pink mylonitized alaskite in a hard black matrix. In some localities, the black matrix material appears to have been injected into irregular fractures in the alaskite (see Plate IV.).

Exposed along 101 cross-cut south between stations 105 and 107 in the Eagle mine, the matrix is schistose and contains rounded fragments of pebble to boulder size dispersed like plums in a pudding. The rock has been called psuedo-conglomerate by the author as the rounded fragments consist of white quartz, salmon-pink mylonitized alaskite and grey quartzite, all of which are found in place in larger bodies at other places in the Eagle mine. A sketch (drawn to scale) of an exposed section of similar rock from 101 Drive East of the Eagle mine is shown in Plate V.

TABLE VII

Results of X-Ray Investigation of Black Rock
(Matrix of Structural Breccia)

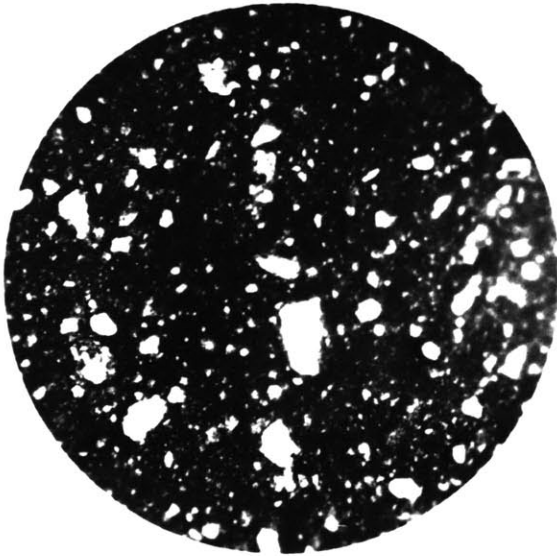
d. Angstroms	i Relative Intensity	Mineral Identification
1.381	3	quartz
1.546	3	quartz
1.828	3	quartz
2.138	1	quartz
2.292	1	quartz
2.471	1	quartz
3.226	2	feldspar
3.352	10	quartz
4.259	4	feldspar
7.138	2	chlorite
14.163	1	chlorite

At still other places in the Eagle mine, small sausage or spindle shaped fragments of grey rock in a black schistose matrix are found. The fragments are commonly $1/4$ to $1/2$ inch in diameter, one to two inches long and constitute about 50 percent of the rock. Microscopic evidence indicates that the elongated fragments are chloritized and sericitized albite-alaskite. A sketch of a diamond drill-core intersection of this type of rock is shown in Plate V.

Propylites are also found in schistose parts of the breccia complex. The propylite occurs as lenticular or tabular bodies commonly many feet in length. In some places nearly flat lying bands of propylite are interlayered with black schistose material carrying isolated rock fragments. The propylite masses undoubtedly were plagioclase-amphibolite inclusions in alaskite which were subsequently deformed and hydrothermally altered along with the alaskite.

A study of the chemical composition of rocks in the breccia complex is considered under the topic of hydrothermal alteration (page 73).

A.



B.



C.

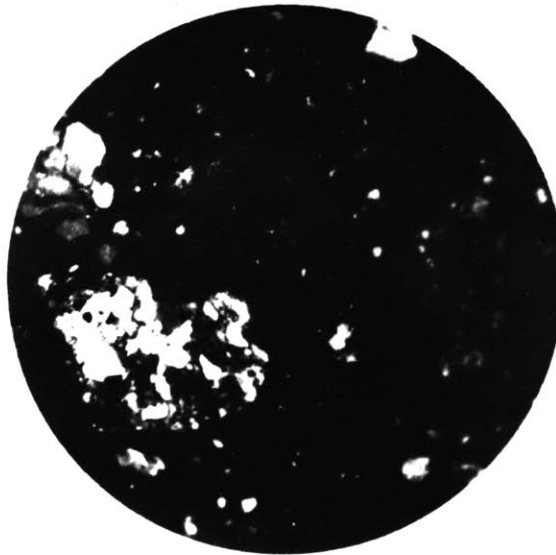


Plate III.

Three views of black trap-like mylonite, Eagle-Ato-Mic claims, Goldfields area, Saskatchewan. Thin-section, specimen RI30. A and B - ordinary light, X50. C - crossed nicols, X50.

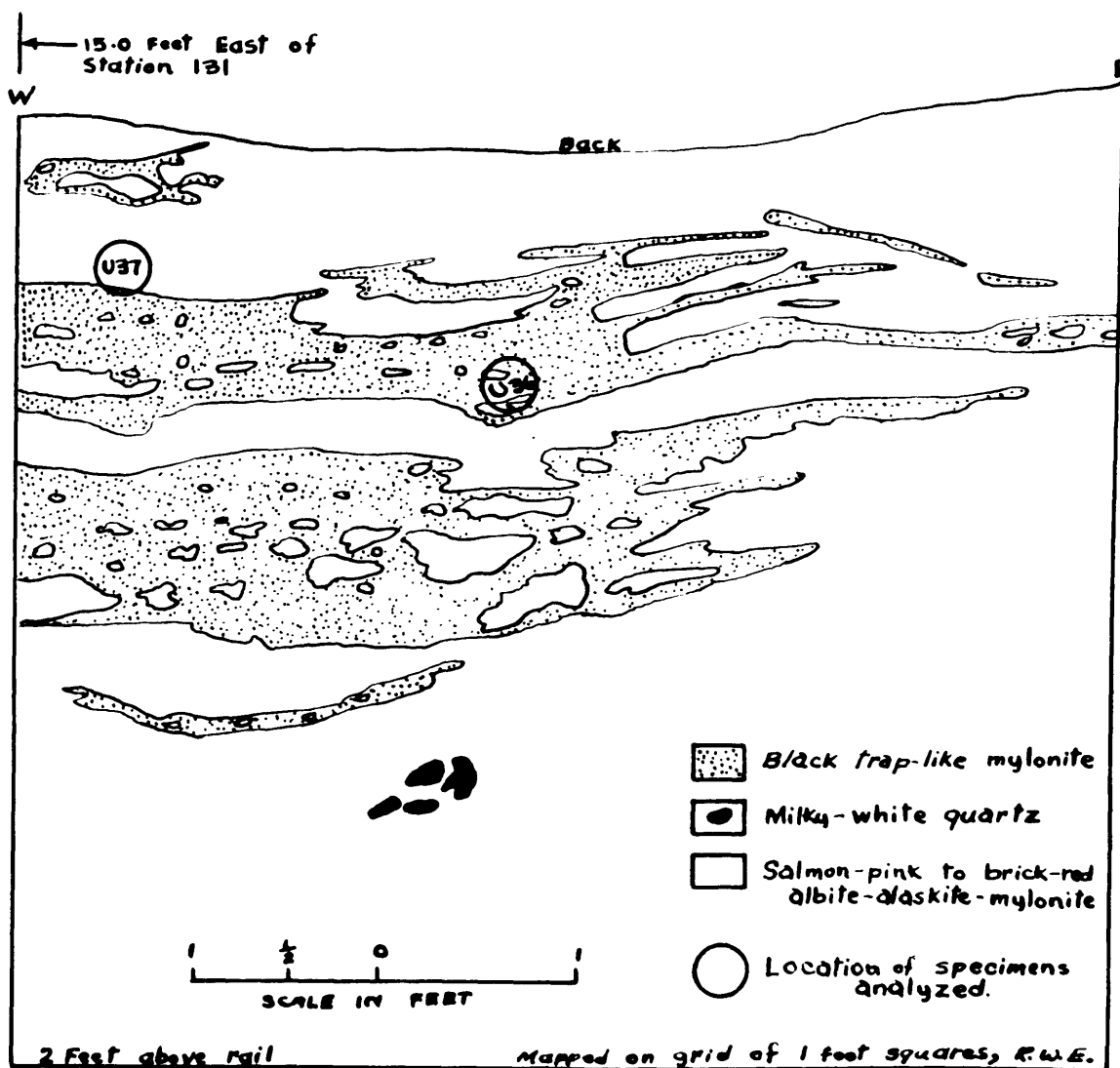


Plate IV. Showing structural relationships of breccia, north wall, IO2 drive west, 1st level, Eagle mine, Goldfields, Saskatchewan.

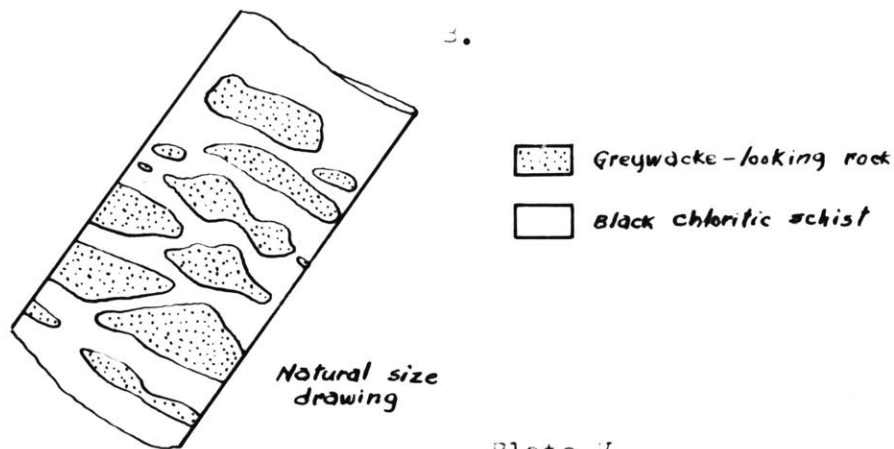
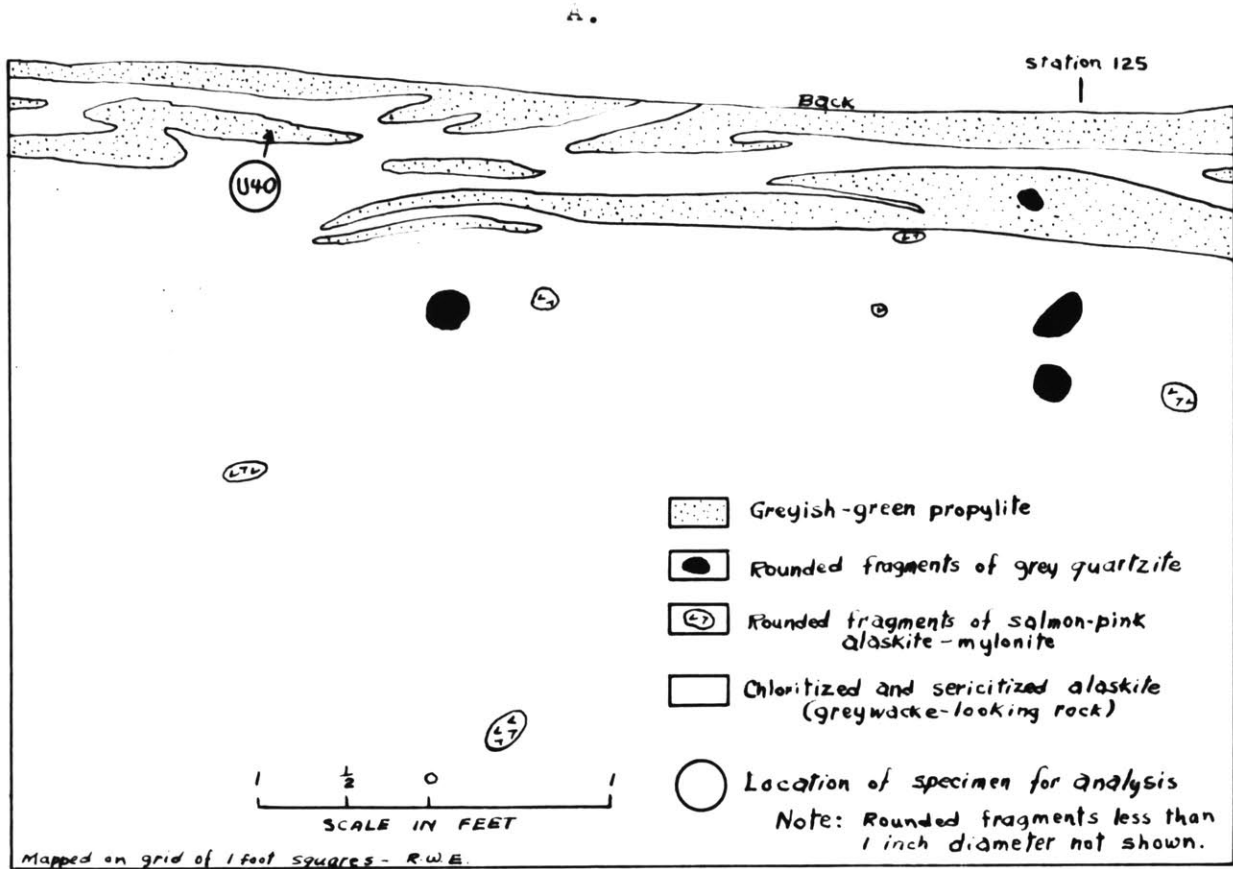
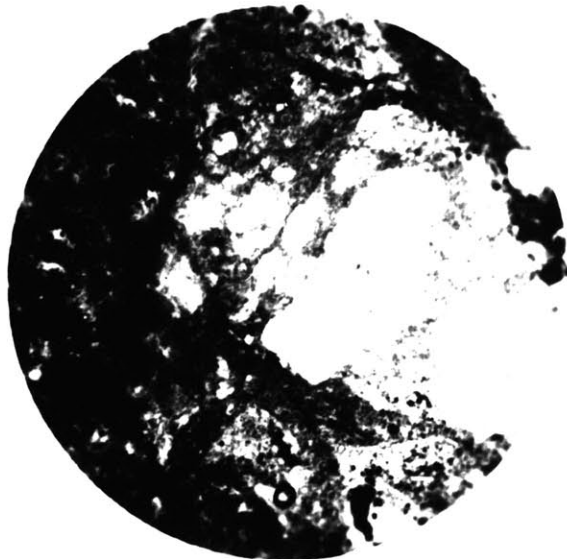


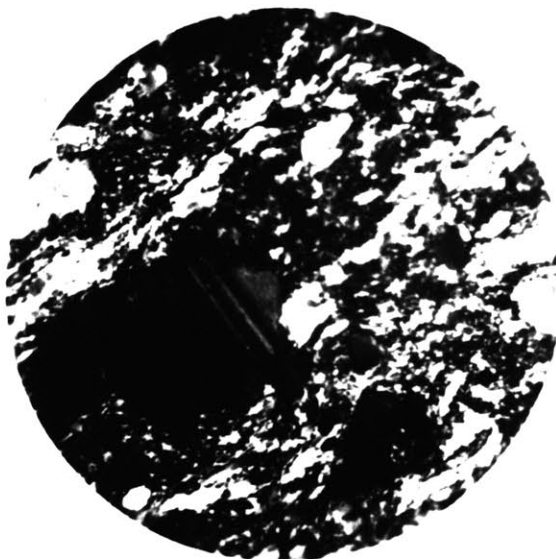
Plate V.

- A. Pseudo-conglomerate south wall, IOI drive east, 1st. level, Eagle mine, Goldfields, Saskatchewan.
- B. Specimen of diamond-drill core showing elongated fragments of chloritized and sericitized alaskite in a black chloritic matrix. D.D.H. B6, depth 138 feet, Eagle mine-area, Goldfields, Saskatchewan.

Plate VI.



Greywacke-looking rock showing large fragment of albite-alaskite partly replaced by an aggregate of chlorite and sericite, thin-section, Eagle mine-area, Goldfields, Saskatchewan. Ordinary light, X50.



Greywacke-looking rock showing porphyroblast of albite (twinned) in mylonitic matrix containing quartz, albite, chlorite, and sericite. Same location as above. Crossed nicols, X50.

Ace Property

Mafic Inclusions in alaskite: Mafic inclusions in alaskite are common in the vicinity of the Ace mine, south of the St. Luis fault. Most inclusions are tabular, a few inches to several feet thick and in places more than 10 feet long. Their volume generally is unimportant, but in the contact zone between alaskite and plagioclase-amphibolite, inclusions comprise up to 50 per cent or more of the rock, in which case the rock as a whole becomes a granite-gneiss.

Close to the St. Luis fault, the inclusions are chlorite-schist but farther south they are plagioclase-amphibolite. This suggests that the inclusions near the fault were also plagioclase-amphibolite, but were sheared and hydrothermally altered to chlorite-schist when faulting took place.

The analysis of a chlorite-schist inclusion in alaskite about 50 feet south of the St. Luis fault is shown in Table V. The analysis is almost identical to one of a chlorite-schist inclusion from the Eagle-mine area shown in the same table.

Plagioclase-amphibolite. Plagioclase-amphibolites occur in the Ace mine-area, but differ in appearance from those found on the Eagle property. In the vicinity of the Ace mine, the plagioclase-amphibolites are fine grained dark

greenish-grey rocks containing 1/16"-1/8" epidote veinlets in an irregular pattern (crackle breccia).

The epidote veinlets are believed to be due to hydrothermal alteration following brecciation. The epidote does not seem to have been introduced from "depth" because the veinlets are more or less confined to plagioclase-amphibolite. The epidote is probably a product of reaction between plagioclase-amphibolite and ascending hydrothermal solutions entering incipient fractures from the St. Luis fault zone. A somewhat similar hypothesis has been postulated by Cooke (1937) for the origin of chrysotile asbestos veins in serpentine bodies in Quebec.

Narrow bands of sediments were noted interbedded with plagioclase-amphibolite in a few localities in the vicinity of the Ace mine. The volume of sediments within the main mass of plagioclase-amphibolite is small and probably comprises less than one or two percent.

The composition of the plagioclase-amphibolites and lack of any evidence of bedding indicates that they were originally igneous rocks before being metamorphosed. However, as on the Eagle property there is no field evidence to suggest whether the original rock was extrusive, intrusive or a complex of both.

In thin section, except for epidote veinlets, plagioclase-amphibolites are very similar to rocks discussed

under the same heading from the Eagle property. The chemistry of plagioclase-amphibolites containing veinlets of epidote is discussed under the topic of epidotization (page 68).

Alaskite. Two types of alaskite occur on the Ace property, a soda-rich type and a less common potash-rich variety which is confined to a narrow zone north of and parallel with ace creek. Both rocks are medium grained, cream to salmon-pink in color and are not readily distinguished in hand specimen. The soda-rich alaskite consists primarily of albite and quartz, whereas microcline occurs in the potash variety in place of albite.

Analyses of the two types of alaskite are shown on page 34. The analysis of the soda-rich alaskite is almost identical to an analysis of an alaskite from the Eagle property, three miles northwest in the same table. As expected, the analysis of the microcline-bearing variety also is closely similar except for relative proportions of K_2O and Na_2O .

Chlorite-sericite-schist. Bands of chlorite-sericite schist occur in plagioclase-amphibolite at several places near the Ace mine. The bands range from a few inches to several feet thick, are thinly bedded and whitish-grey to greenish-grey.

A large mass of chlorite-sericite schist is exposed in the underground workings at the Ace mine. This material is petrographically similar to the chlorite-sericite schist bands in plagioclase - amphibolite and is also thinly bedded.

The chlorite-sericite schist in the Ace mine, like the plagioclase-amphibolite, has been intruded by alaskite. Tabular and lenticular masses of alaskite, now altered to a brick-red mylonite, occur within chlorite-sericite schist. The tabular bodies of mylonite lie in the plane of schistosity of the St. Luis fault zone. This probably does not mean that sill-like injections of alaskite entered the schist parallel to present schistosity. On the contrary, it is likely that original injections were of an irregular nature but were rolled out (mylonitized) into tabular sheets parallel to the newly developed schistosity which was superimposed on all rocks in the fault zone.

Microscopic study shows that the chlorite-sericite-schist consists chiefly of chlorite, sericite and albite, and minor amounts of quartz and epidote. The mineralogical composition is similar to slates, argillites and crumpled chlorite-sericite-schists on the Eagle-Ato-Mic claims.

In the Ace mine, the composition of the large mass of chlorite-sericite is not uniform. Within the schist are bands and streaks of brown to red cherty-looking rock. Under the microscope, a specimen of brown rock appears to be a mechanical mixture of broken veinlets of alaskite in swirls of chlorite-sericite schist. The brown cherty bands were probably lit-par-lit injection gneisses within the main mass of chlorite-sericite-schist before the St. Luis fault zone was developed.

A comparison of an analysis of brown rock (Table III) with that of chlorite-sericite schist in the same table shows an increase in silica with a concomitant decrease in all other constituents except Na_2O and CaO . These chemical differences are probably in large part due to "granitization", but it must be kept in mind that at least some differences are probably due to later hydrothermal alteration.

Donaldson Lake

Alaskite: Alaskites at Donaldson Lake have a uniform salmon-pink color and are similar in all respects to albite-alaskites in the Eagle and Ace mine-areas. On the Emar claims of the Eldorado Mining and Refining Company at Donaldson Lake, alaskites have been mylonitized, and then subsequently hydrothermally altered and recrystallized. The final product is a rock composed almost entirely of coarsely cleavable red albite

and calcite with minor amounts of quartz, specularite and chlorite. The chemistry of this alteration is discussed under the topic of red-alteration page 71.

Granodiorite: The granodiorite on the Emar claims at Donaldson Lake has been altered to a foliated gneiss. It consists chiefly of albite, opalescent quartz, green biotite, muscovite and chlorite. The rock has a distinctive appearance because some of the albite has been stained orange to red due to varying amounts of hydrothermally introduced hematite. This gives the rock an appearance of woven white and green tweed with a fleck of brighter colors.

An analysis of this rock is shown in Table VIII together with an average of 24 analyses of granodiorites by Johannsen. Except for minor differences, the Donaldson Lake granodiorite has a similar composition to the average given by Johannsen.

Analysis and Mineral Composition of Granodiorite

	<u>A.</u>	<u>B.</u>
SiO ₂	68.9	67.86
TiO ₂	--	0.51
Al ₂ O ₃	19.6	14.97
Fe ₂ O ₃	2.7	1.75
FeO	3.6	2.18
MnO	0.1	0.05
MgO	3.0	1.38
CaO	1.1	2.82
Na ₂ O	1.5	3.29
K ₂ O	2.8	3.58
H ₂ O	--	0.84
P ₂ O ₅	--	0.17
CO ₂	--	0.04
	<hr/>	<hr/>
	102.9	99.44
Albite	20.8	--
Quartz	36.8	--
Green Biotite	16.9	--
Chlorite	6.1	--
Epidote	4.2	--
Sericite	12.1	--
Specularite	1.6	--
Pyrite	<hr/>	--
	100.0	

A. Gneissic granodiorite, Emar Claims, Goldfields, Saskatchewan, specimen D83.

B. Granodiorite, average of 24 analyses, Johannsen (1932), vol. 2, p. 331.

SOUTH SHORE OF BEAVERLODGE LAKE

Plagioclase-amphibolite. A specimen of coarse-grained massive plagioclase-amphibolite (amphibolite of Christie and Kesten) from a point on the south shore of Beaverlodge Lake (see Fig. 3) was analyzed. Christie has indicated on his map that the "amphibolite" in this locality is of intrusive origin. The analysis and mineral composition of this rock are shown on page 26. In comparison with analyses of plagioclase-amphibolites from the Eagle mine-area, this rock is slightly more silicic, but on the whole has a similar chemical composition.

Quartz-muscovite-schist. A specimen of quartz-muscovite schist from the Tamblyn property (see Fig. 3) was analyzed for the purpose of determining the effect of hydrothermal alteration in a nearby structural breccia of the same material. The rock is honey-yellow, medium to coarse grained, highly schistose, and bedding is only faintly discernable.

An analysis and mineralogical composition is shown on page 89. The analysis indicates that the mica in the schist is a true muscovite, as potash is high compared to soda.

Structural breccia. The structural breccia zone on the Tamblyn property (see Fig. 3) is radioactive and is important in this study because it differs in many ways from other structural breccias found in the Goldfields area. The

breccia zone strikes northwest and trenching through overburden has exposed a width of at least 10 feet. The dip of the zone is not known, but is probably parallel with the schistosity which dips 70 degrees southwest.

The breccia has physical properties similar to charcoal. It is dull greyish-black, soft, porous and friable. The rock contains easily recognizable 1/8 to 1/2 inch long wisps and lenses of bleached (kaolinized) quartz-mica schist elongated parallel to the schistosity. Joint planes, both parallel and transverse to the schistosity are stained yellow by limonite. No pitchblende or other primary uranium minerals were exposed at the time of the author's visit, but in one trench, yellow and orange uranium stain (gummite) was reported⁽¹⁾. An analysis of the breccia is shown on page , and is discussed under the heading of hydrothermal alteration.

Correlation of Diabase Dykes and Basalt Flows

Basalt flows occur interbedded with arkose and conglomerate in the structural basin at Martin Lake. The series is of Athabaska (Late Precambrian) age.

Numerous narrow diabase dykes occur in the Goldfields area. They occur singly and as dyke swarms. Most of the dykes are 1 foot to 20 feet wide and can rarely be traced for more than 100 feet. Nearly all of the dykes mapped by Christie cut

(1) Dr. A. H. Long, personal communication

rocks of the basement complex where Athabaska rocks have been stripped away by erosion. In general, the dykes strike west to northwest, but a few strike northeast.

Although Christie and Kesten (1949) designate the dykes as post-Athabaska, this age relationship is questionable because as far as the author is aware, no diabase dykes have been observed cutting the youngest Athabaska rocks, although they cut lower members of the series. In view of this structural relationship it was believed that dykes and flows probably belonged to the same period of igneous activity and that dykes in general represented feeders to flows. To test this hypothesis the author analyzed several dykes, flows, and a sill to see if a correlation were possible. Petrographic work (linear analysis) was done on the specimens analyzed and all data are shown in Tables IX and X.

Excellent petrographic descriptions of flows and dykes in the Goldfields area are given by Christie and Kesten (1949) and need not be repeated here. The main point to emphasize is that under the microscope rocks representing both modes of occurrence have similar characteristics. Probably the most convincing evidence that these rocks are closely related is the presence of quartz-calcite-chlorite amygdules in both flows and dykes. Compared with the amygdules in the flows which are commonly 1/8 to 1/2 inch in diameter, the amygdules in the dykes

TABLE IX

Analyses and Mineralogical Composition of
basalt flows

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
SiO ₂	49.9	53.7	49.4	52.6	50.31
TiO ₂	--	--	--	--	2.25
Al ₂ O ₃	13.2	13.7	14.3	13.0	15.54
Fe ₂ O ₃	9.5	8.1	9.0	2.9	3.09
FeO	2.5	2.8	2.6	7.9	7.72
MnO	0.1	0.1	0.1	0.2	0.21
MgO	4.6	4.7	4.0	3.9	6.67
CaO	3.9	3.0	3.1	6.0	9.50
Na ₂ O	4.7	4.3	5.2	3.0	2.94
K ₂ O	2.0	3.0	1.7	4.0	0.68
H ₂ O	--	--	--	--	0.95
P ₂ O ₅	--	--	--	--	0.24
CO ₂	--	--	--	--	0.13
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	90.4	93.4	89.4	93.5	100.24
F	--	--	--	0.45	--
Rb ₂ O	0.012	0.021	0.009	0.030	--
Li ₂ O	0.0032	0.0033	0.0038	0.0025	--
Cu	--	--	--	0.0044	--
Co	--	--	--	0.0013	--
Ni	--	--	--	0.0043	--

TABLE IX - Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
Andesine	60.2	74.8	29.2	--	--
Labradorite	--	--	--	72.3	--
Augite	--	--	--	14.1	--
Devitrified glass	--	--	41.5	--	--
Calcite	2.3	Trace	--	0.4	--
Quartz	1.3	Trace	--	--	--
Apatite	--	--	0.9	2.5	--
Magnetite	--	--	--	5.7	--
Chlorite	11.2	10.9	6.5	5.1	--
Epidote	4.9	5.2	4.6	Trace	--
Sericite	2.1	---	--	--	--
Specularite	18.1	9.1	17.3	--	--
	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>

- A. Flow 1, Athabaska series, near adit portal
R. A. Claims, Martin Lake, Goldfields,
Saskatchewan, specimen M8-9-10.
- B. Flow 2, Athabaska series, next flow east of flow 1,
R. A. Claims, Martin Lake, Goldfields, Saskatchewan,
Specimen M12-13.
- C. Flow 3, Athabaska series, next flow east of flow 2,
R. A. Claims, Martin Lake, Goldfields, Saskatchewan,
specimen M14-15.
- D. Sill (or possibly coarse-grained flow) intercalated
in Athabaska series, near southern part of Martin
Lake syncline, Martin Lake, Goldfields,
Saskatchewan, specimen M17.
- E. Basalt, average of 16 analyses, Johannsen (1937),
vol. 3, p. 261.

TABLE X.
Analyses and Mineral Composition of Diabase Dykes,
Goldfields, Saskatchewan

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
SiO ₂	53.1	52.7	52.9	51.3	55.1
TiO ₂	--	--	--	--	--
Al ₂ O ₃	13.8	17.3	15.2	14.9	14.7
Fe ₂ O ₃	3.3	4.6	1.4	3.4	2.0
FeO	4.8	4.7	6.7	7.7	6.7
MnO	0.1	0.1	0.1	0.1	0.1
MgO	5.4	5.2	6.5	7.6	6.7
CaO	4.2	5.2	4.3	3.7	2.2
Na ₂ O	2.5	3.8	2.4	2.2	4.3
K ₂ O	6.3	5.6	1.6	2.0	0.5
H ₂ O	--	--	--	--	--
P ₂ O ₅	--	--	--	--	--
CO ₂	--	--	--	--	--
	<hr/> 93.5	<hr/> 99.2	<hr/> 91.1	<hr/> 92.9	<hr/> 92.3
F	--	--	0.11	--	--
Rb ₂ O	0.060	0.062	0.009	0.012	0.004
Li ₂ O	0.0054	0.0049	0.0053	0.0049	0.0032
Cu	0.0015	0.0026	0.0099	0.0058	0.0046
Co	0.0011	0.0010	0.0023	0.0024	0.0026
Ni	0.0037	0.0032	0.0081	0.0073	0.0088

TABLE X - Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
Plagioclase	19.2	--	--	33.6	17.0
Andesine	--	60.6	20.1	--	--
Indeterminate matrix	44.1	--	51.2	30.4	61.4
Biotite	--	17.7	--	--	--
Magnetite	10.2	4.9	--	--	--
Ilmenite	--	--	13.3	6.4	--
Pyrrhotite	--	--	Trace	--	--
Apatite	0.04	Trace	--	--	--
Calcite	Trace	--	--	1.1	--
Quartz	1.2	2.3	0.9	--	0.4
Chlorite	8.8	2.3	4.4	19.1	4.4
Epidote	16.5	12.3	10.2	9.5	16.8
Leucoxene	--	--	Trace	--	--

- A. Diabase dyke, Ace mine-area, Goldfields
Saskatchewan, specimen A8.
- B. Diabase dyke, Donaldson Lake, Emar claims,
Goldfields, Saskatchewan, specimen D113.
- C. Diabase dyke, Mic Lake, Eagle-Ato-Mic claims,
Goldfields, Saskatchewan, specimen R2.
- D. Diabase dyke, Tamblyn group, South Shore
Beaverlodge Lake, Goldfields, Saskatchewan,
specimen Z-11.
- E. Diabase dyke, strike group, north of Ace Lake,
Goldfields, Saskatchewan, specimen Z-14-b.

are much smaller ($1/8$ inch or less) and are not readily recognized in the hand specimen. Nevertheless they have the same composition.

The analytical results show that there is a close parallel between analyses of diabase dykes, basalt flows and sill. The greatest difference is the relatively greater amount of ferric iron in the flows. However, this is probably the result of hydrothermal alteration as the flows contain appreciable amounts of specularite in fractures and as replacement of various minerals.

Probably the greatest criticism of this work is that too few dykes were analyzed. However, the overall evidence at hand indicates that the flows, dykes and sill are all closely related and probably all are of Athabaska age.

HYDROTHERMAL ALTERATION

General Statement

Hydrothermal alteration, associated with pitchblende mineralization is widespread in the Goldfields area of Saskatchewan. The most intense alteration is restricted to the immediate vicinity of fault or breccia zones but large areas are affected to a minor extent.

In detail the relationship between alteration and pitchblende mineralization is complex as individual veins do not in general have separate alteration halos. Pitchblende generally occurs in gash-like calcite veins or stringers in wide fractured zones associated with faulting. Large lenticular and tabular masses of slightly altered to intensely altered rock occur in the same wide fracture zones as the mineralized veins. However, vein deposition appears to belong to a later fracturing period after hydrothermal alteration was more or less completed. Generally the veins transect and are confined to highly altered rock, but on the other hand many highly altered zones intersected in diamond drill-core are barren of mineralized veins.

The most conspicuous alteration is red. This type of alteration is found in nearly all the highly radioactive zones in the Goldfields area and also at the Eldorado mine at Great Bear Lake N.W.T. However, other types of alteration which also are closely associated with pitchblende mineralization

are present in the Goldfields area and their recognition may be equally as important in the search for new deposits of uranium.

The color of altered rocks depends at least in part on the original rock-type. For instance mylonitized-alaskites change from a pale salmon-pink color to brick-red with introduction of hematite, yet nearby altered plagioclase-amphibolites, containing as much or more introduced hematite are rarely red, but instead may be yellowish-green, greenish-grey or dark blue.

The dominant types of alteration vary from place to place in the Goldfields area. On the Eagle-Ato-Mic claims, hydrothermal alteration is believed to have taken place in two stages. The first stage, consisting mainly of introduction of chlorite, is believed to have accompanied mylonitization and brecciation during formation of wide structural breccia zones. The second, a more complex stage, was restricted to narrow zones in the breccia and adjacent rocks. This stage seems more closely associated with pitchblende-bearing calcite veins and was studied in detail in the breccia-complex exposed in the Eagle mine.

In some places in the Eagle mine, alaskite fragments within the breccia and also massive alaskite outside of the main breccia zone have been altered brick-red by introduced hematite. At other places fragments and large masses of alaskite are altered to a rock with salt and pepper texture caused by introduction of chlorite and partial sericitization

of albite. The altered rock has the general appearance of greywacke except for absence of bedding. At still other places within the breccia-complex, masses and bands of greyish-green propylite occur which are believed to represent deformed and hydrothermally altered plagioclase-amphibolite.

At the Ace mine, alaskite-mylonite is altered brick-red as at the Eagle property. However, a different rock type is also present at the Ace mine, viz; finely laminated and slightly crumpled chlorite-sericite schists of sedimentary origin. These schists commonly contain augen shaped porphyroblasts of albite which, like albite in altered alaskite, is locally stained red. Furthermore, injections of alaskite within the schist have been rolled out (mylonitized) into sheets or ribbons parallel with the schistosity and in most places have a cherty appearance with a pale brown to brick-red color.

Plagioclase-amphibolites at the Ace mine have two typical altered forms. One is a crackle breccia containing numerous irregular veinlets of epidote; the other is a royal blue schist developed in local zones of shear.

On the Emar claims at Donaldson Lake, alaskite-mylonites are hydrothermally altered and recrystallized to rocks composed largely of coarse cleavable red albite and calcite.

Finally on the Tambllyn property, the dominant type of alteration is due to introduction of carbon (or hydrocarbon) into a breccia zone.

In the following comparisons, it has been assumed that the various rocks under comparison originally had the same composition and that present chemical differences (in excess of probable analytical error) are due solely to later alteration. It must be admitted that this is not always strictly true as the composition of a given rock-type varies from place to place and slight chemical differences which are supposed to distinguish the "fresh" from the "altered" rocks may in fact have already been present in their primary condition. Bearing in mind, therefore, that minor differences may not be due to alteration, only major differences will be stressed in discussing the effects of hydrothermal alteration. Although this places a limitation on a complete study of losses and gains of elements during alteration, the salient features of the various types of alteration will undoubtedly be brought out which is the overall purpose of the present work.

Presentation of Data

In selecting a suitable type of diagram to represent chemical changes in the hydrothermal alteration of rocks, several factors were considered. In the first place, many of the gain and loss diagrams commonly used are based on the assumption that alteration took place at constant volume. Lindgren was a foremost proponent of this assumption in studying metasomatic changes where the original texture of the rock was

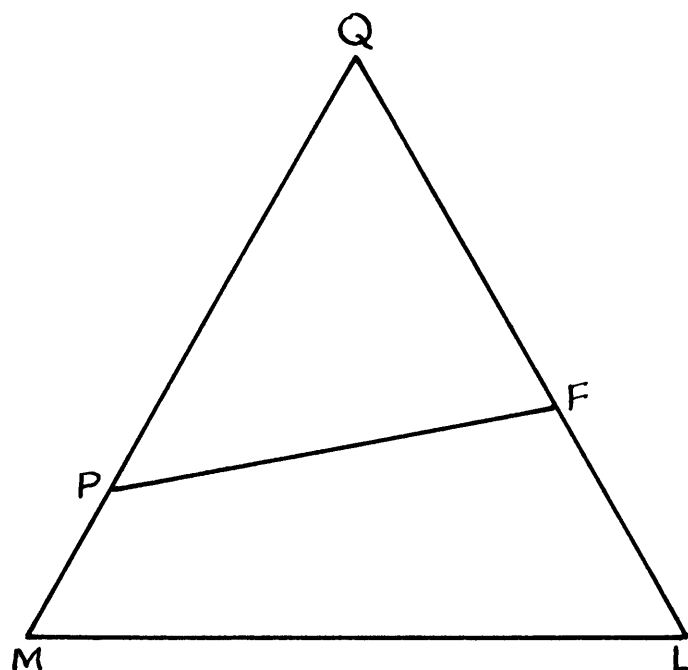
preserved. However, in the Goldfields area of Saskatchewan, no basis for the assumption of constant volume exists as original textures are commonly destroyed and this is especially true where alteration has been accompanied by shearing, mylonitization and brecciation.

In order to avoid the assumption of constant volume during alteration (in this case due to weathering processes), Leith and Mead (1915) represented gains and losses on straight-line diagrams. Straight-line diagrams have also been used to advantage in a number of studies in hydrothermal alteration; among those of chief interest in this work are by Fairbairn and Robson (1942) and by Schwartz (1939). The chief criticism of straight-line diagrams is that where more than two or three analyses are to be compared, as was the case in some of the author's studies, the diagram becomes a maze of intersecting lines and the purpose of the diagram is defeated.

A less confusing method of plotting multiple data is on triangular variation diagrams where each rock analysis can be represented by a point. For instance, complex geochemical changes due to granitization are clearly shown by Reynolds (1946) on triangular variation diagrams of the Von Wolf type.

Burri and Niggli (1945) have developed a variation diagram (QLM) which is similar to that developed by Von Wolf. The system of Niggli, however, has the advantage of bringing out mineralogical changes more directly as it is based on molecular proportions of constituents rather than weight per

cent. For this reason and also because Niggli's tables facilitate calculations, the QLM diagram was used in this work.



Q = Quartz
L = Feldspathoid
M = Olivine
F = Feldspar
P = Pyroxene

Fig. 4 - QLM diagram of Niggli:

Construction of the QLM diagram is shown in Fig. 4. The three corners represent 100 per cent of the three components Q, L and M respectively. The point F on the side QL represents the feldspar molecule and the point P on the side QM represents the pyroxene molecule. The feldspars and the pyroxenes represent the fully saturated condition of the feldspathoidal and olivine molecules L and M respectively. The line PF, therefore, represents the silica saturation line which divides the whole triangle into two parts, the area QPF (oversaturated) and the area PMLF (undersaturated).

An example of the calculations using the Niggli values is shown in Table XI. The nine constituents in the first column have been recalculated to 100 per cent. Each weight per cent is converted to molecular proportions and multiplied by 1000 to remove decimals. In this work, the tables of Burri and Niggli (1945) are very convenient. The number determined for Fe_2O_3 is multiplied by 2 and added to the numbers obtained for FeO, MnO and MgO and the new number is given the symbol fm. The alkali numbers are added together and are represented by the symbol alk. The remaining symbols in the table need no explanation.

In order to calculate the proportions of Q, L and M, equations given by Burri and Niggli (1945) were used and are shown in Table XII. The Q, L and M values obtained by using the appropriate equations are reduced to 100 before the analysis is plotted as a point on the QLM diagram.

TABLE XI.

Example of Calculation of Niggli Values - Diabase from
Great Bear Lake N.W.T. (specimen ~~GB~~ 4).

	Weight %	Mol. x 1000	si	al	fm	c	Alk
SiO ₂	51.3	854	854				
Al ₂ O ₃	13.8	135		135			
Fe ₂ O ₃	4.7	30*					
FeO	6.5	90					
MnO	0.2	3					
MgO	6.3	156					
CaO	10.2	182				182	
Na ₂ O	1.9	31					
K ₂ O	<u>5.2</u>	<u>55</u>					86
	100.0						

al	(135)	=	19.0
fm	(309)	=	43.3
c	(182)	=	25.6
Alk	<u>(86)</u>	=	<u>12.1</u>
	(712)	=	100.0
si	854	=	120
Q	= (65)	=	26.0
L	= (93)	=	37.0
M	= <u>(93)</u>	=	<u>37.0</u>
	(251)	=	100.0

*Multiply by 2 to convert to roughly equivalent
(Mol. x 1000) of FeO

TABLE XII

Equations for determining the values of Q, L and M. (Burri and Niggli - 1945).

$$1. \text{ alk } > \text{ al}$$

$$Q = s_1 - \left[100 - \frac{1}{2} (fm + c) \right]$$

$$= s_1 - \left[50 + \frac{1}{2} (al + alk) \right]$$

$$L = 6 \text{ al}$$

$$M = 3 (\text{alk} - \text{al}) + \frac{3}{2} (fm + c)$$

$$2. \text{ al } \leq (\text{alk} + c)$$

$$Q = s_1 - (50 + 2\text{alk} - \text{al})$$

$$L = 3 (\text{al} + \text{alk})$$

$$M = 3 (50 - \text{al})$$

$$3. (\text{alk} + c) < \text{al} < (\text{alk} + 2c + fm)$$

$$Q = s_1 - (50 + 2\text{alk} - \text{al})$$

$$L = 3 (2\text{alk} + c)$$

$$M = 3 \left[50 - (c + \text{alk}) \right]$$

To supplement the QLM diagram, Burri and Niggli employ several other variation diagrams to show relationships between alkalis, lime, magnesia and iron. The supplementary diagrams, however, were designed to show changes in magmatic differentiation and none seemed entirely suitable for showing hydrothermal alteration effects to best advantage, in particular, the alteration studies of the author. The supplementary diagrams used in this work ($K_2O - Na_2O - CaO$ and $MgO - FeO - Fe_2O_3$), therefore, have been modified after somewhat similar diagrams used by Burri and Niggli. In both diagrams, the molecular values are converted to 100 per cent before plotting.

Plagioclase-amphibolite

Blue-Alteration. Several sheared zones in plagioclase-amphibolite at the Ace property and on the Emar claims, are altered to a greyish royal-blue schist. The color is due to a blue chlorite-like mineral which constitutes most of the rock. Insufficient optical data was obtained to identify the mineral. Other minerals in the rock consist of apatite, specularite, plagioclase, calcite and quartz.

An analysis of "blue rock" in Table XIII shows a large reduction of Al_2O_3 and K_2O and a concomitant increase in Fe_2O_3 compared with analyses of "unaltered" plagioclase-amphibolites in Table IV. Other differences are less pronounced. The alteration trends are also shown on the variation diagrams in Plate VII and require no further comment.

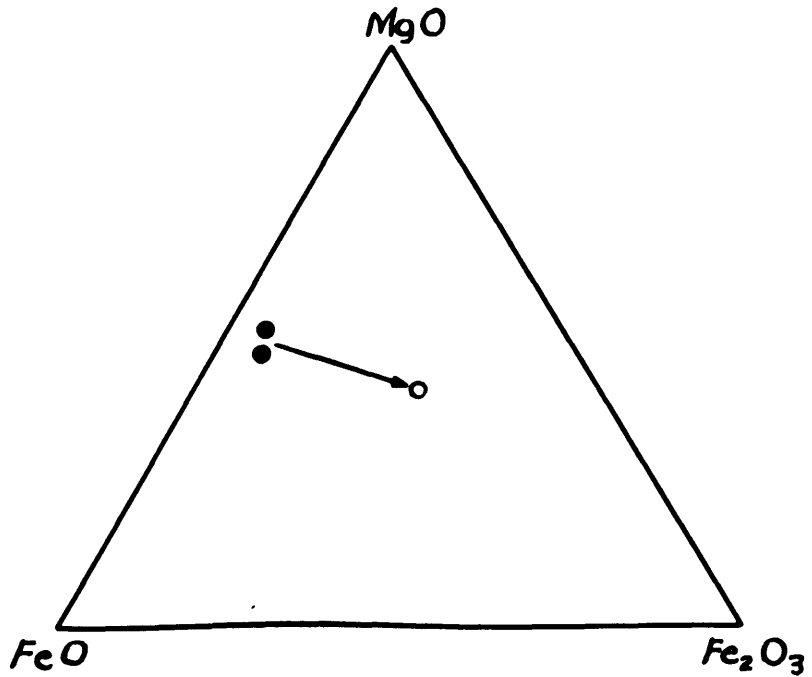
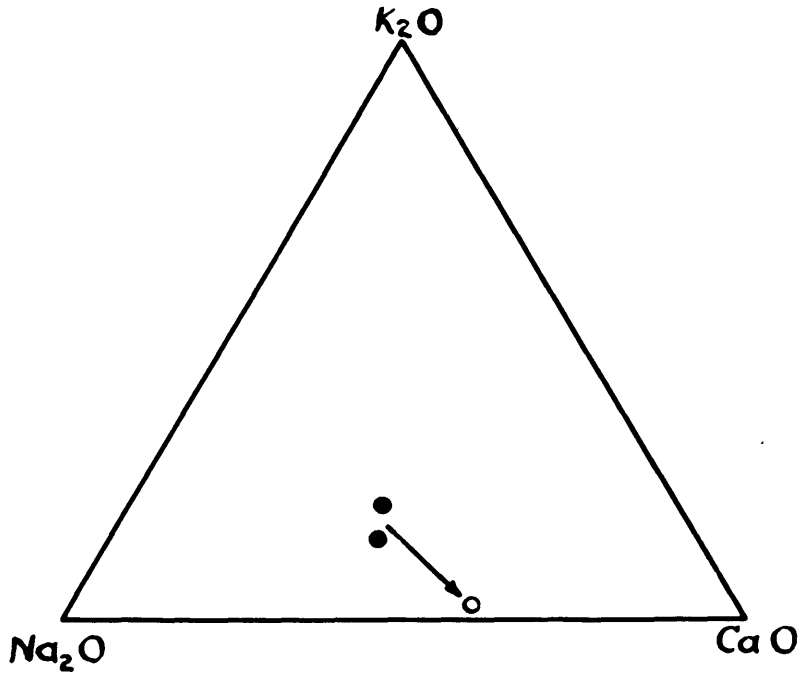
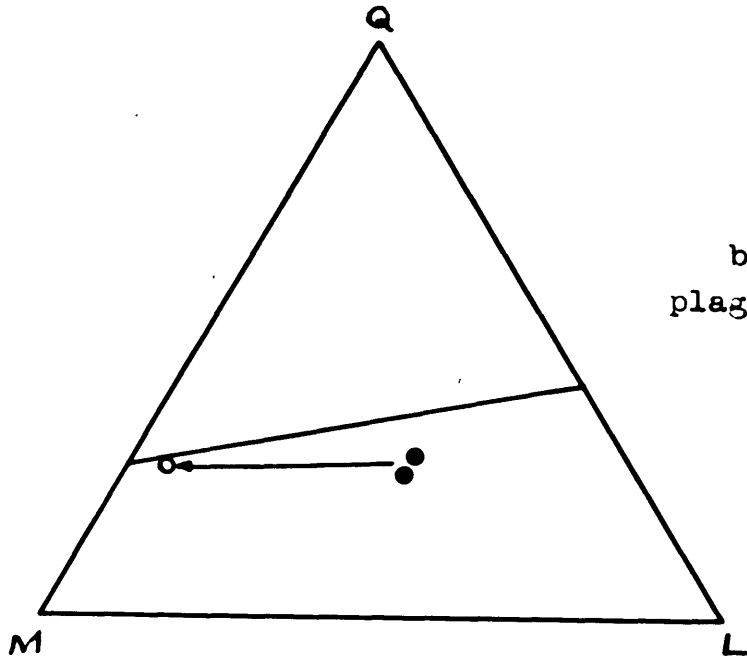
TABLE XIII

Analysis and Mineral Composition of "Blue Rock",
Ace Mine-Area, Goldfields, Saskatchewan (specimen A39).

SiO ₂	49.7
TiO ₂	--
Al ₂ O ₃	1.2
Fe ₂ O ₃	14.5
FeO	9.3
MnO	0.2
MgO	9.4
CaO	7.4
Na ₂ O	2.9
K ₂ O	0.3
H ₂ O	--
P ₂ O ₅	--
CO ₂	====
	94.9
Chlorite (?)	91.1
Apatite	3.4
Specularite	3.3
Plagioclase	1.2
Calcite	0.6
Quartz	<u>0.6</u>
	100.0

Plate VII
Variation diagrams
showing
blue-alteration of
plagioclase-amphibolite

- unaltered
- altered



Epidotization. The common type of plagioclase-amphibolite in the Ace mine-area contains a network of epidote stringers. In some localities intervening rock between stringers has been partly or completely altered to a fine-grained aggregate of chlorite and epidote, yet the epidote stringers are still clearly recognizable in hand specimen.

An analysis of highly altered rock containing a network of epidote stringers is shown in Table XIV and may be compared with relatively unaltered plagioclase-amphibolites in Table IV. With the exception of relative increases in CaO and Fe_2O_3 in the highly altered type, the analyses closely correspond with one another. The increase in CaO and Fe_2O_3 during alteration is also clearly shown on the variation diagrams in Plate VIII.

Propylitization. Propylites, consisting almost entirely of chlorite, epidote and calcite occur in large masses within the breccia-complex at the Eagle mine. The rocks have a characteristic yellowish-green color and generally contain scattered tadpole-shaped lenses of white calcite up to 1/4 inch across. The propylites are believed to have been plagioclase-amphibolites before alteration, chiefly because no other basic rocks from which they could have been derived occur in the vicinity of the Eagle mine.

Analyses of propylites in Table XV correspond fairly closely with analyses of plagioclase-amphibolites in Table IV.

TABLE XIV

Analysis and Mineral Composition of Highly altered
Rock containing a Network of Epidote Stringers,
Ace Mine-Area, Goldfields, Saskatchewan (specimen A53).

SiO ₂	45.2
TiO ₂	--
Al ₂ O ₃	16.7
Fe ₂ O ₃	6.6
FeO	8.3
MnO	0.2
MgO	8.7
CaO	13.3
Na ₂ O	1.9
K ₂ O	1.0
H ₂ O	--
P ₂ O ₅	--
CO ₂	--
	<hr/>
	101.9
Epidote	56.5
Chlorite	40.5
Apatite	0.2
Specularite	<u>2.8</u>
	100.0

Plate VIII
Variation diagrams
showing
epidotization
of
plagioclase-amphibolite

- unaltered
- altered

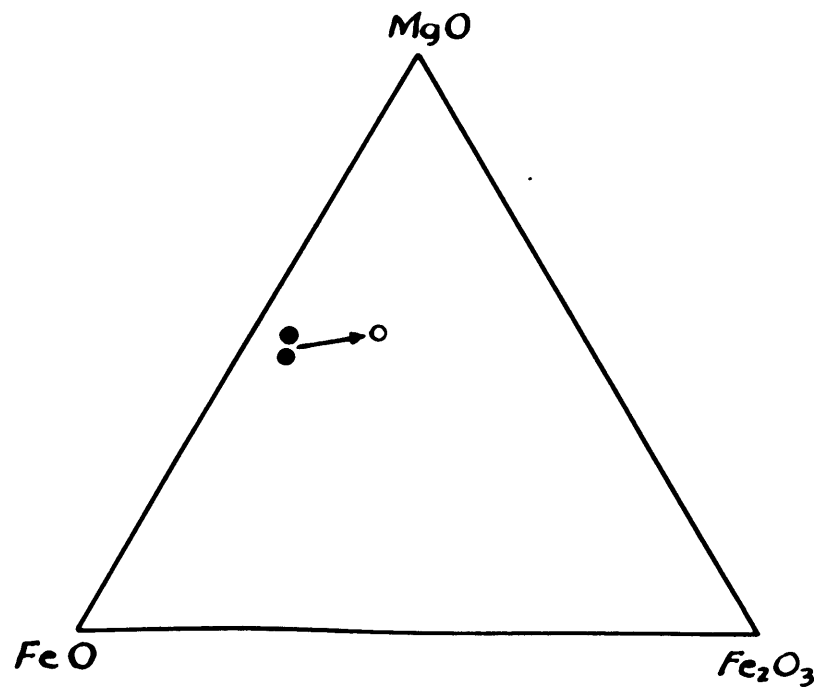
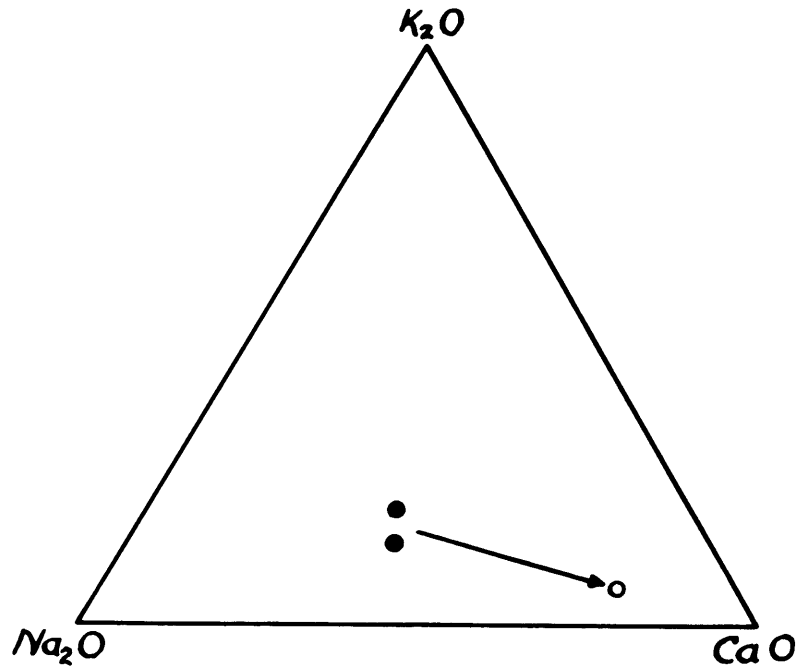
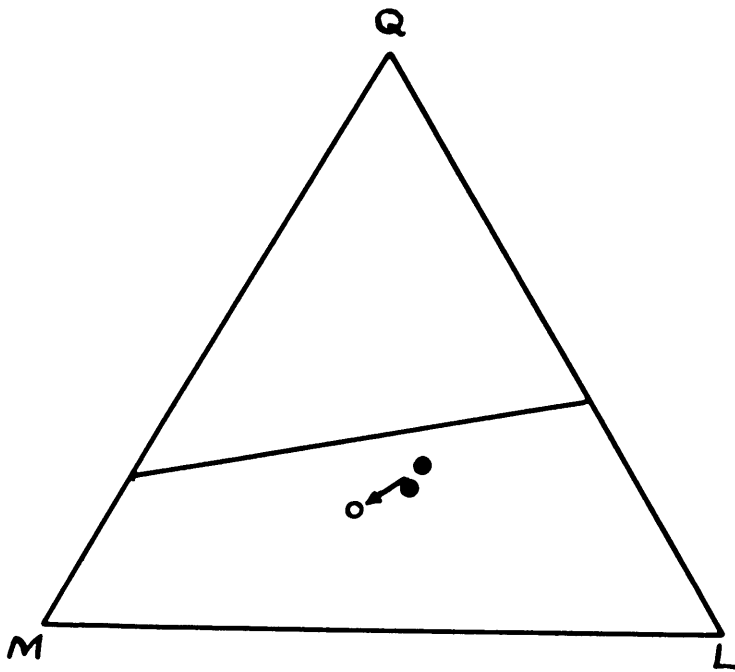


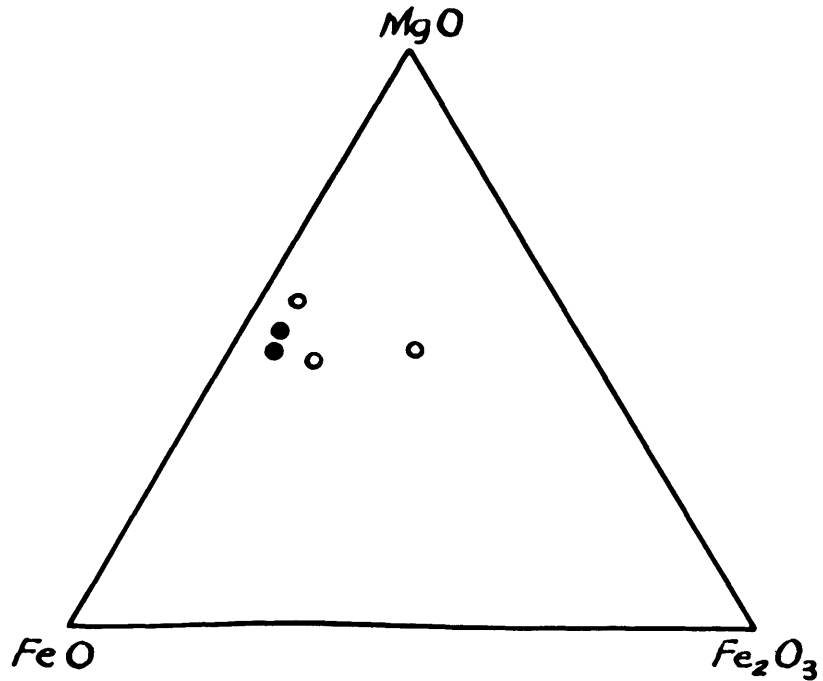
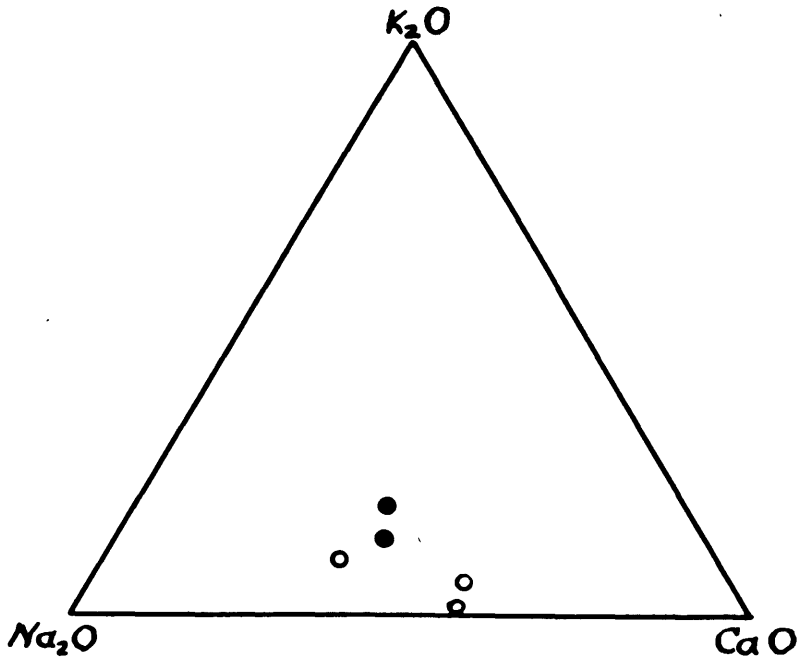
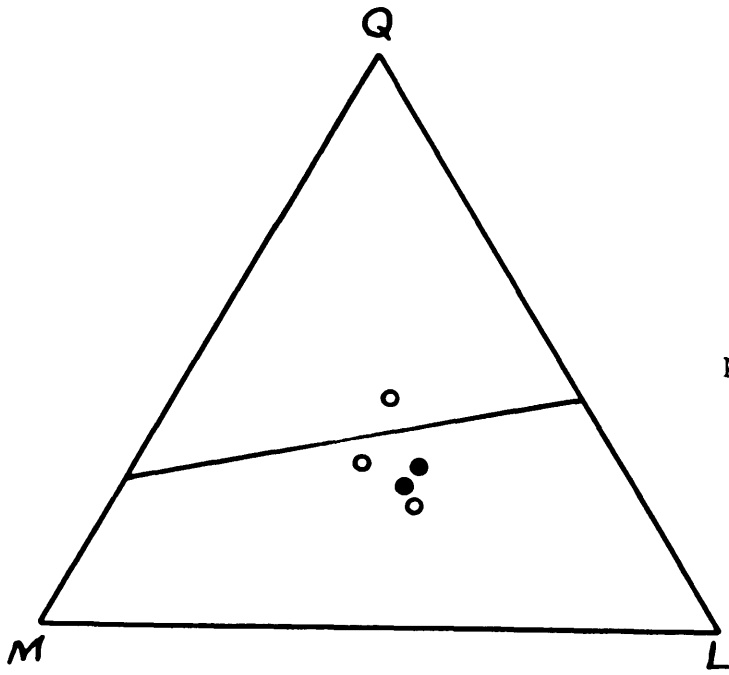
TABLE XV

Analyses and Mineral Composition of Propylites,
Eagle Mine-Area, Goldfields, Saskatchewan

	<u>A.</u>	<u>B.</u>	<u>C.</u>
SiO ₂	45.3	42.2	57.0
TiO ₂	--	--	--
Al ₂ O ₃	13.8	19.4	13.4
Fe ₂ O ₃	4.1	8.5	1.2
FeO	11.6	6.6	7.6
MnO	0.2	0.3	0.2
MgO	7.3	7.1	6.1
CaO	5.9	4.8	6.9
Na ₂ O	2.5	4.4	2.7
K ₂ O	0.2	1.1	0.8
H ₂ O	--	--	--
CO ₂	--	--	--
	<hr/>	<hr/>	<hr/>
	90.9	94.4	95.9
Oligoclase	12.2	48.6	
Plagioclase			2.3
Chlorite	48.1	39.4	
Epidote	10.0	4.6	
Calcite	22.8	4.0	4.6
Quartz	4.9		8.7
Specularite	2.0	3.1	Trace
Pyrite	Trace		0.8
Leucoxene		0.2	
Indeterminate matrix			<hr/> 83.6
	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0
A.	specimen E179		
B.	specimen E269		
C.	specimen U40		

Plate IX
Variation diagrams
showing
propylitization
of
plagioclase-amphibolite

- unaltered
- altered



The greatest differences are SiO_2 in specimen U40 and Fe_2O_3 in specimen E269. These differences, however, cannot be attributed to chemical changes typical of propylitization, as specimen U40 contains streaks and bands of quartz fragments (probably originally vein quartz or quartzite) and specimen E269 contains considerable introduced specularite.

Relationships between various constituents are also shown on the variation diagrams in Plate IX.

The fact that the potash content of the propylites is low, despite an increase in potash during alteration (chloritization and sericitization) of alaskite in the same breccia-complex deserves comment. The low content of potash is probably due to the lack of suitable structure sites for K^+ in any of the mineral constituents of the propylites. This contrasts with sericite (developed from albite) in the altered alaskite, whose structure readily accommodates the large potassium ions.

Alaskite

Red-alteration. In most parts of the Goldfields area, the characteristic alteration of alaskite is red. The red-alteration is invariably preceded by mylonitization and with the exception of rocks on the Emar claims at Donaldson Lake, no appreciable recrystallization has taken place so that the final product in general has the appearance of brick-red chert.

Under the microscope, red chert-like mylonites are seen to consist mainly of a finely crushed aggregate of quartz and albite. Some of the larger porphyroclasts of albite exhibit fine albite twinning, but most albite is so finely crushed and impregnated with hematite that no twin lamellae are recognizable. Hematite occurs as both crystalline specularite and as powdery red hematite. Specularite is present as crystal aggregates up to 1 mm. across, scattered throughout and replacing crushed albite. Specularite also occurs as minute fracture fillings (commonly less than 1/2 mm. thick) in the mylonite. Crystal aggregates of specularite generally have a pronounced dark red halo of red powdery hematite which contrasts with the lighter red color of surrounding albite. Most crushed albite appears to have "absorbed" finely divided hematite fairly evenly with only here and there an "island" of specularite.

Quartz is invariably clear and unaltered in the red mylonites. It shows features characteristic of mylonitization such as suture structure, undulose extinction and lamellae. Lamellae appear as sub-parallel welts in thin-section and are similar to those illustrated by Fairbairn (1949).

On the Emar claims at Donaldson Lake, some alaskite-mylonites have been recrystallized and altered to a red albite-carbonate rock which on freshly broken surfaces exhibits large cleavage faces of albite. As seen under the microscope, large crystals of albite in the recrystallized rock contain corroded aggregates of mylonitized quartz (sieve structure). During

alteration metasomatism appears to have taken place at the expense of quartz, as the recrystallized rock consists largely of albite and calcite with relatively small amounts of quartz, hematite, chlorite and epidote.

Analyses of red altered alaskites are shown in Table XVI and chemical changes during alteration are illustrated on the variation diagrams in Plate X. Red chert-like alaskite-mylonites show little if any chemical changes during alteration except Fe_2O_3 which increases markedly in all instances and CaO which increases in mylonites containing introduced calcite.

On the other hand, recrystallized alaskite-mylonite from the Emar claims shows marked chemical changes with respect to nearly all constituents. On the QLM diagram (Plate X) there is a definite trend toward L due to an increase in feldspar and addition of calcite during alteration. The relative increase in CaO is clearly shown in the $\text{K}_2\text{O}-\text{Na}_2\text{O}-\text{CaO}$ diagram and the effect of introduction of hematite is brought out in the $\text{MgO}-\text{FeO}-\text{Fe}_2\text{O}_3$ diagram.

Structural Breccia

Chloritization. Introduction of chlorite into the mylonitized matrix of structural breccias on the Eagle-Ato-Mic claims is believed to have taken place simultaneously with mylonitization and brecciation. The resulting matrix has a trap-like appearance and has been previously described (page 36).

TABLE XVI
Analyses and Mineralogical Composition
of Red Altered Alaskites

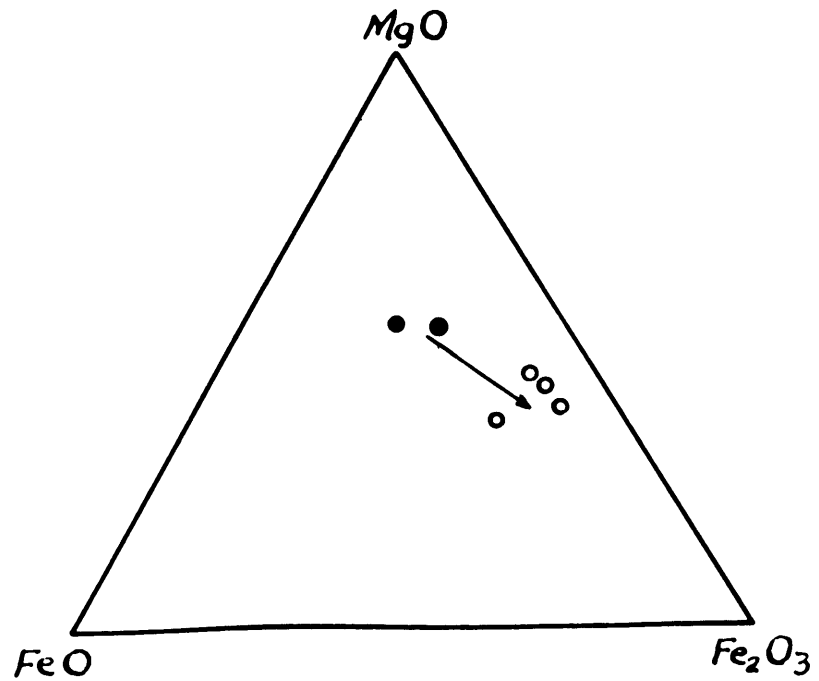
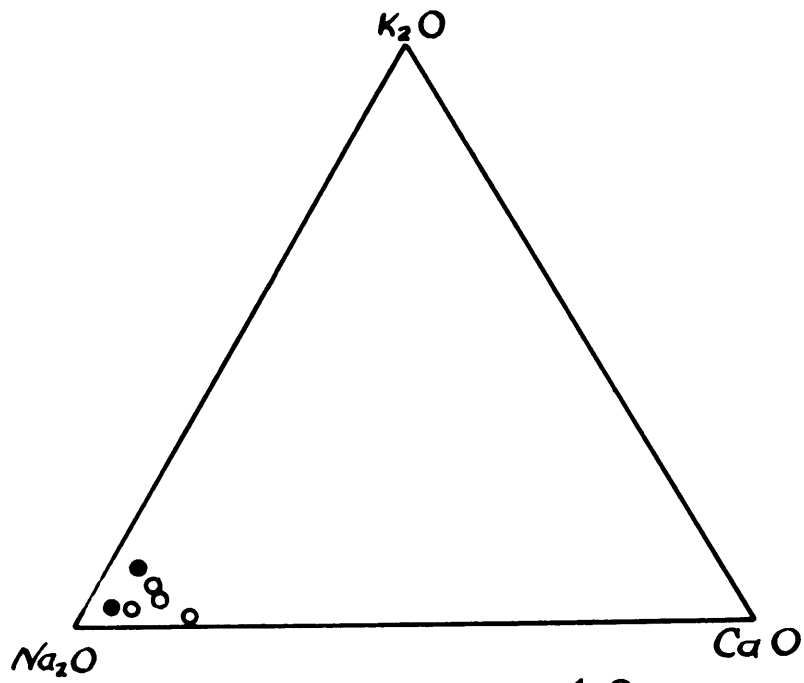
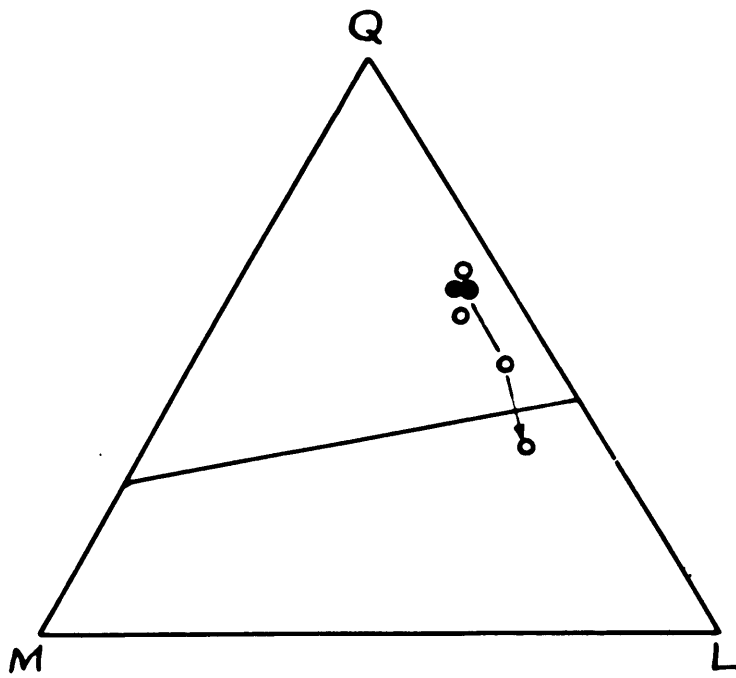
	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>
SiO ₂	74.9	74.0	67.0	57.4
TiO ₂	--	--	--	--
Al ₂ O ₃	13.0	12.7	11.2	17.6
Fe ₂ O ₃	1.2	3.7	1.8	4.7
FeO	0.4	0.7	0.3	0.8
MnO	Trace	0.1	0.1	0.1
MgO	0.5	1.8	0.7	2.1
CaO	1.2	1.1	1.0	2.9
Na ₂ O	5.2	5.6	8.9	9.2
K ₂ O	0.3	0.6	0.5	0.5
H ₂ O	--	--	--	--
CO ₂	--	--	--	--
	<hr/>	<hr/>	<hr/>	<hr/>
	96.7	100.3	91.5	95.3
Albite	68.9	--	69.9	86.0
Quartz	26.7	--	13.7	0.5
Sericite	--	--	0.8	--
Calcite	0.1	5.6	12.8	5.2
Chlorite	3.7	2.9	Trace	2.7
Epidote	--	--	0.1	1.5
Specularite	0.6	5.8	2.7	4.1
Mylonitized Alaskite frag- ments	--	20.2	--	--
Submicroscopic matrix	--	65.5	--	--
	<hr/>	<hr/>	<hr/>	<hr/>
	100.0	100.0	100.0	100.0

TABLE XVI - Continued

- A. Red altered albite-alaskite-mylonite,
Ace mine, Goldfields, Saskatchewan,
specimen A57.
- B. Red altered albite-alaskite-mylonite,
Eagle mine, Goldfields, Saskatchewan,
specimen U37.
- C. Red altered albite-alaskite-mylonite,
Emer claims, Goldfields, Saskatchewan,
specimen D101.
- D. Red altered and recrystallized albite-
alaskite-mylonite, Emer claims,
Goldfields, Saskatchewan, specimen D27

Plate X
 Variation diagrams
 showing
 red-alteration
 of
 albite-alaskite

- unaltered
- altered



Chlorite has also been introduced into narrow structural breccia zones containing rounded fragments at a number of places in the Goldfields area. This type of breccia zone will be referred to as psuedo-conglomerate and is distinct in appearance from other breccia zones which contain angular fragments in a hard black mylonitic matrix. The matrix of psuedo-conglomerates consists of soft black chlorite schist. Excellent examples of this type of structural breccia occur in several sub-parallel zones in the breccia complex of the Eagle mine-area (both at the Spur zone and in the vicinity of the Lost Vein), ABC group of Nesbitt-Labine Uranium Mines and along the Crackingstone fault.

Under the microscope, the chlorite in psuedo-conglomerates occurs as large parallel sheaf-like intergrowths which are responsible for the schistose nature of the rock. The chlorite exhibits an abnormal blue interference color which is typical of penninite. This contrasts with chlorite developed by alteration of hornblende in amphibolitic rocks which generally has interference colors of first order grey and probably is chlinochlore.

In the hand specimen, hydrothermally introduced chlorite can also in general be distinguished from chlorite developed from hornblende. The hydrothermally introduced variety invariably has a shiny black color on freshly broken cleavage surfaces whereas chlorite developed by alteration of hornblende is commonly greenish-grey and forms fine-grained intergrowths

with epidote. The black chlorite in pseudo-conglomerates is probably the same species as chlorite which imparts the black color to the hard black matrix of mylonitic structural breccia zones and both probably represent early hydrothermal phases genetically related to pitchblende mineralization.

At the Eagle mine, psuedo-conglomerate forms local zones within the main wide breccia complex; the pseudo-conglomerate zones like the main breccia strike northeast. The author's impressions are that the psuedo-conglomerate zones dip steeply to the southeast whereas flatly dipping structures characterize the main breccia-complex. Further work should be done on these structural relationships to determine possible structural control of ore deposition.

At the Eagle mine, it is possible that the pseudo-conglomerate represents local zones of movement after the mylonitic phase had developed. This would account for rounding of fragments by attrition and development of schistosity in the same zones. It should be recognized that under such conditions, at least part of the black chlorite in the pseudo-conglomerate zones probably represents recrystallized and re-oriented chlorite which had already been introduced during the mylonitic stage.

Analyses of the black mylonitic breccia matrix and the matrix of the pseudo-conglomerate are shown in Table XVII. In comparison with unaltered albite-alaskites in Table VI, there is a general increase in FeO and MgO due to introduction of

chlorite. This increase in mafic constituents is also shown on the QLM variation diagram of Plate XI where there is a definite trend towards M from unaltered alaskite to altered types. Specimen E324 from the large trench on the Lost Vein is an exception, but was clearly very siliceous and probably was originally vein quartz, as milky white quartz commonly occurs as "splashes" in unaltered alaskite.

Analyses of the black mylonitic matrix show relative increases in K_2O and CaO with a concomitant decrease in Na_2O as compared with unaltered albite-alaskite.

The relative changes of these constituents are also shown on the K_2O-Na_2O-CaO diagram of Plate XI. The $MgO-FeO-Fe_2O_3$ diagram of the same plate does not show any significant changes in the relative amounts of MgO , FeO and Fe_2O_3 during alteration.

Sericitization. In the Eagle mine-area, certain schistose (sheared) zones in the breccia-complex contain elongated fragments and large masses of rock with a salt and pepper texture similar to that of greywacke. The elongated fragments occur in a black-schistose chloritic matrix and the rock as a whole has a definite lineation (caused by parallelism of fragments) which probably indicates the direction of movement in the sheared zones.

From microscopic evidence described on page 41, the greywacke-looking rock is believed to be a chloritized and

TABLE XVII

Analyses and Mineral Composition of Structural
Breccia, Eagle Mine-Area, Goldfields, Saskatchewan

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>
SiO ₂	61.6	70.7	67.4	66.6
TiO ₂	--	--	--	--
Al ₂ O ₃	19.0	13.2	14.7	14.8
Fe ₂ O ₃	3.3	2.8	1.9	2.0
FeO	4.1	4.3	3.7	3.4
MnO	0.1	0.2	0.2	0.2
MgO	4.3	5.7	3.8	4.9
CaO	0.8	0.8	2.5	3.5
Na ₂ O	5.0	1.5	2.2	1.8
K ₂ O	2.4	2.6	5.0	3.7
H ₂ O	--	--	--	--
CO ₂	<u>100.6</u>	<u>101.8</u>	<u>101.4</u>	<u>100.9</u>
F	0.052	0.15	--	0.075
Rb ₂ O	0.014	0.020	0.044	0.038
Li ₂ O	--	--	0.0056	0.0028
Cu	--	--	0.0005	0.0045
Co	--	--	0.0011	0.0013
Ni	--	--	0.0061	0.0050

TABLE XVII - Continued

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>
Alaskite fragments	12.9	60.5	21.9	12.9
Submicroscopic matrix	87.1	39.4	76.8	87.1
Calcite	--	--	0.6	--
Epidote	--	--	--	Trace
Specularite	--	0.1	0.1	--
Quartz veinlets	--	--	0.7	--
	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0
	<u>E.</u>	<u>F.</u>	<u>G.</u>	<u>H.</u>
SiO ₂	59.4	88.3	66.4	47.6
TiO ₂	--	--	--	--
Al ₂ O ₃	16.0	6.6	13.0	15.9
Fe ₂ O ₃	3.6	2.1	4.4	3.3
FeO	3.1	1.2	1.6	11.4
MnO	0.1	0.1	0.1	0.3
MgO	4.3	1.9	3.5	7.6
CaO	0.7	0.6	1.9	3.0
Na ₂ O	6.3	2.2	5.2	3.3
K ₂ O	0.4	0.1	0.3	0.4
H ₂ O	--	--	--	--
CO ₂	--	--	--	--
	<hr/> 93.9	<hr/> 103.1	<hr/> 96.4	<hr/> 92.8
F	0.24	Trace	--	--
Rb ₂ O	0.0026	Trace	--	--

TABLE XVII - Continued

	<u>E.</u>	<u>F.</u>	<u>G.</u>	<u>H.</u>
Quartz fragments	--	45.0	--	--
Alaskite fragments	13.8	--	19.4	54.5
Submicroscopic matrix	79.7	46.1	78.4	--
Calcite	1.2	--	--	2.9
Specularite	2.3	8.9	2.2	2.4
Chlorite	3.0	--	--	36.0
Epidote	--	--	--	4.2
	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0	<hr/> 100.0

- A. Black mylonitic seam in salmon-pink alaskite, has appearance of dyklet of basalt but grades into fine breccia at borders with same black matrix, specimen E200.
- B. Black mylonitic rock containing numerous quartz and mylonitized alaskite fragments up to 1/8 inch across, specimen E239.
- C. Hard black mylonitic rock with appearance of basalt; contains scattered white specks of mylonitized alaskite visible to naked eye; weathers dull grey to pale brown, specimen E316.
- D. Similar to C, grades laterally into breccia containing angular fragments up to several inches across with matrix of same black mylonite, specimen R130.
- E. Hard black mylonitic "dykelet" containing fragments of red alaskite-mylonite, specimen U36.
- F. Hard black siliceous mylonite, has black glassy appearance on freshly broken surface, specimen E324.
- G. Black mylonitic rock similar to C and D but weathers pale brown to bright orange due to introduced hematite and 1/16 inch red albite veinlets, specimen G19.
- H. "Psuedo-conglomerate" - black chlorite schist containing scattered rounded fragments up to 1/2 inch across of mylonitized alaskite, specimen G23.

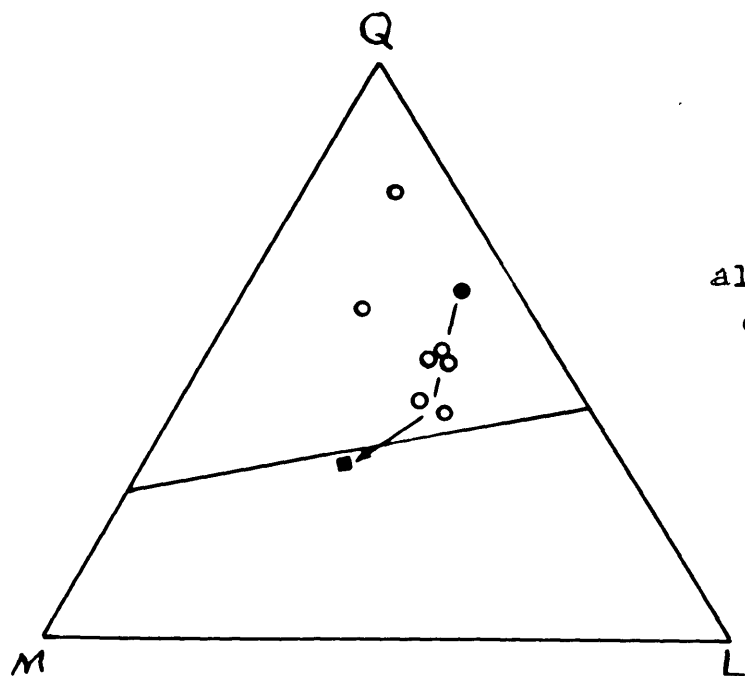
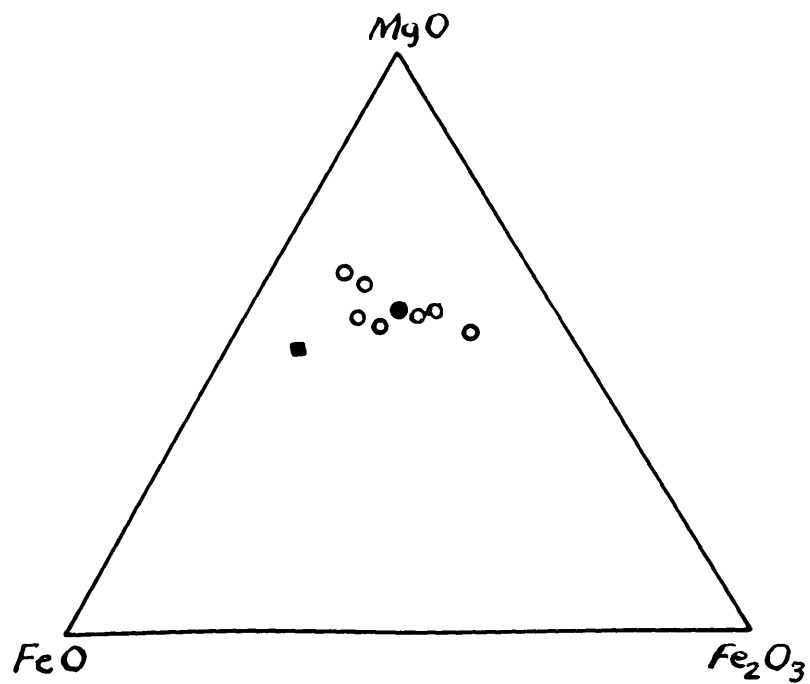
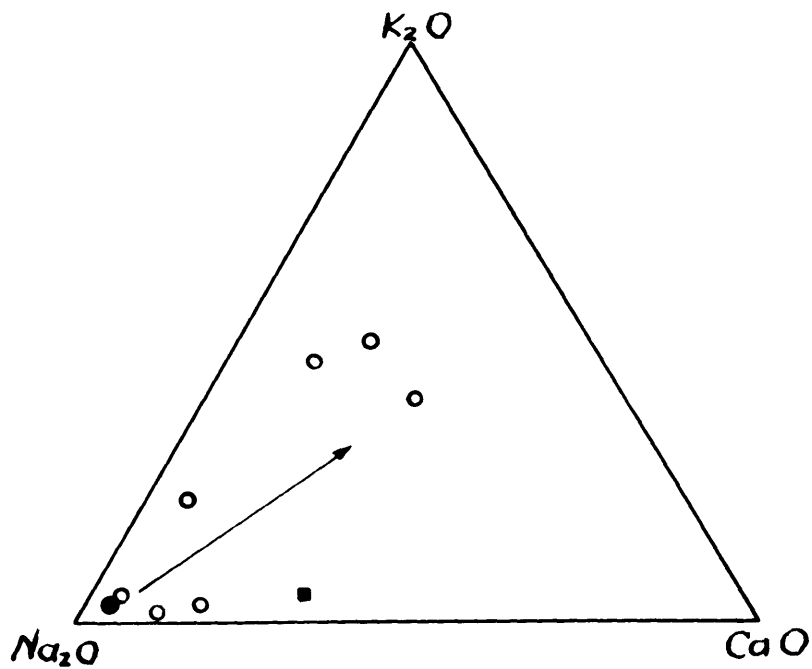


Plate XI
 Variation diagrams,
 chloritization of
 albite-alaskite-mylonite

- unaltered alaskite
- black trap-like rock
- psuedo-conglomerate



sericitized alaskite. It is thought that the zones containing the greywacke-looking rock, like the "pseudo-conglomerate" zones, represent local shears in what had previously been a wide structural breccia consisting mainly of mylonitized alaskite fragments (of salmon-pink color) in a black (chloritized) mylonitic matrix. However, instead of rounding of fragments by attrition during shearing movements, as was the case in the pseudo-conglomerate, it is believed that fragments in the zones referred to were hydrothermally altered (sericitized and chloritized) during the early shearing action and then stretched in the direction of shear.

In the greywacke-looking rock, sericite can be accounted for by sericitization of albite as most of the larger augen-shaped albite fragments (porphyroclasts) contain numerous inclusions of sericite, especially near their margins. Furthermore, all gradations exist between nearly fresh-looking albite and sericite-albite aggregates which in turn pass imperceptibly into a matrix consisting of chlorite, sericite and small fragments of quartz. The matrix in the greywacke-looking rock is identical in mineral composition to the black schistose matrix which holds the greywacke-looking elongate inclusions.

It is difficult if not impossible to determine whether chlorite was introduced from "depth" at the time of sericitization, as chlorite already in the breccia matrix from the earlier mylonitic stage would be expected to be redistributed through fragments and matrix alike within the zones of shearing.

The analyses in Table XVIII show that the greywacke-looking rock is relatively higher in magnesia, iron and potash than albite-alaskites of Table VI and in general the analyses correspond with analyses of the mylonitic structural breccias of Table XVII. If the author's interpretations are correct, then it would appear that alteration of fragments and large masses of alaskite to greywacke-looking rocks did not involve appreciable introduction of material from "depth" but rather involved redistribution of elements already present from the mylonitic stage.

As in variation diagrams of the mylonitic structural breccia, the variation diagrams of the greywacke-looking rock (Plate XII) show relative increases in magnesia, iron and potash as compared with albite-alaskite. With the exception of specimen E166 which is high in albite and contains calcite, there is a definite trend toward M on the QLM diagram from unaltered alaskite to altered types. Likewise on the K_2O-Na_2O-CaO diagram there is a trend toward relative increase in K_2O with the exception of specimen E102 which is relatively high in CaO . Little or no change in the relative proportions of MgO , FeO and Fe_2O_3 has taken place during alteration as shown by the lowermost variation diagram.

Red-alteration. At the Eagle property, black mylonitic breccia is commonly altered red in the vicinity of pitchblende occurrences. The red-alteration is due to two causes:

TABLE XVIII

Analyses and Mineralogical Composition of Chloritized
and Sericitized Alaskite, Eagle Mine-Area, Goldfields,
Saskatchewan

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
SiO ₂	72.3	73.3	77.9	72.3	51.8
TiO ₂	--	--	--	--	--
Al ₂ O ₃	12.7	13.1	14.1	17.5	18.1
Fe ₂ O ₃	2.0	1.4	1.2	1.7	5.2
FeO	3.2	2.6	2.2	3.4	2.8
MnO	0.1	0.2	0.1	0.1	0.1
MgO	2.3	2.9	2.5	2.6	4.5
CaO	0.5	4.5	0.4	0.4	1.7
Na ₂ O	2.5	2.1	3.3	4.0	7.0
K ₂ O	1.7	0.7	0.7	1.4	0.8
H ₂ O	--	--	--	--	--
CO ₂	--	--	--	--	--
	<hr/> 97.3	<hr/> 100.8	<hr/> 102.4	<hr/> 103.4	<hr/> 92.0
F	0.048	--	--	--	--
Ga ₂ O ₃	0.0028	--	--	--	--
Rb ₂ O	0.019	--	--	--	--

TABLE XVIII

Continued

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
Quartz	21.0	26.0	31.0	26.7	3.7
Albite	12.7	17.5	60.4	59.1	70.1
Matrix*	63.7	54.1	5.0	10.6	17.2
Epidote	0.7	1.5	2.8	2.3	3.0
Calcite	--	Trace	--	--	3.3
Specularite	1.8	1.0	0.7	1.4	2.8
Pyrite	--	--	--	Trace	--
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100.0	100.0	100.0	100.0	100.0
	<u>F</u>	<u>G</u>	<u>H</u>	<u>J</u>	<u>K</u>
SiO ₂	71.8	73.7	76.5	80.9	64.8
TiO ₂	--	--	--	--	--
Al ₂ O ₃	15.1	13.3	12.6	9.0	19.5
Fe ₂ O ₃	2.9	2.5	2.5	1.8	2.8
FeO	3.8	3.8	1.6	1.6	3.8
MnO	0.1	0.1	0.1	0.1	0.1
MgO	3.5	2.9	1.8	1.5	3.9
CaO	0.4	0.3	0.5	0.6	0.4
Na ₂ O	2.2	2.1	2.3	3.1	1.2
K ₂ O	1.6	1.6	1.4	0.7	3.2
H ₂ O	--	--	--	--	--
CO ₂	--	--	--	--	--
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	101.4	100.3	99.3	99.3	99.7

TABLE XVIII

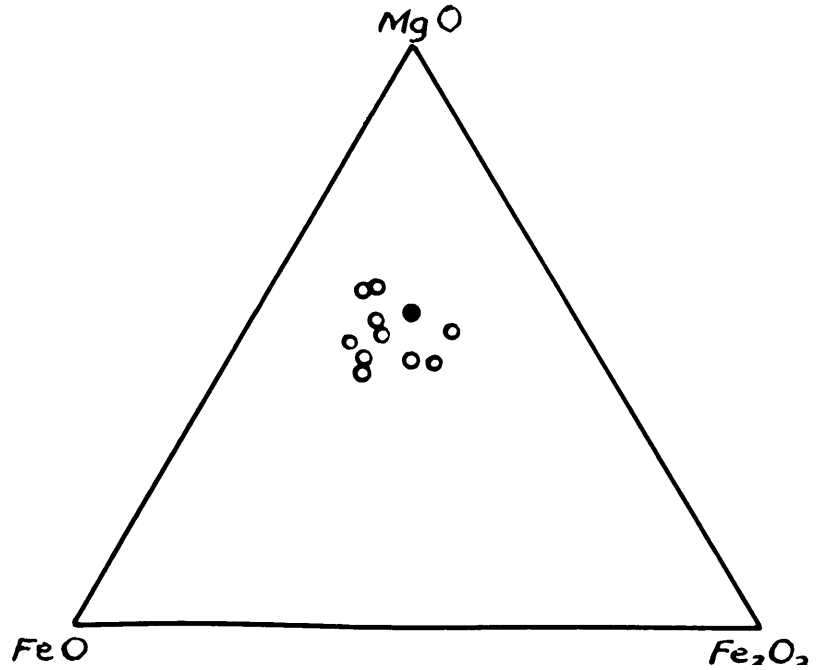
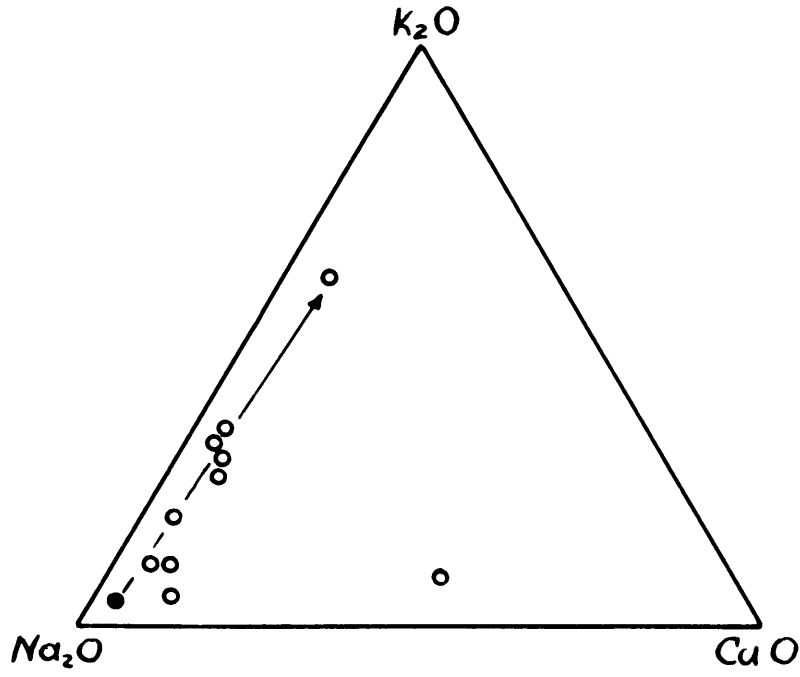
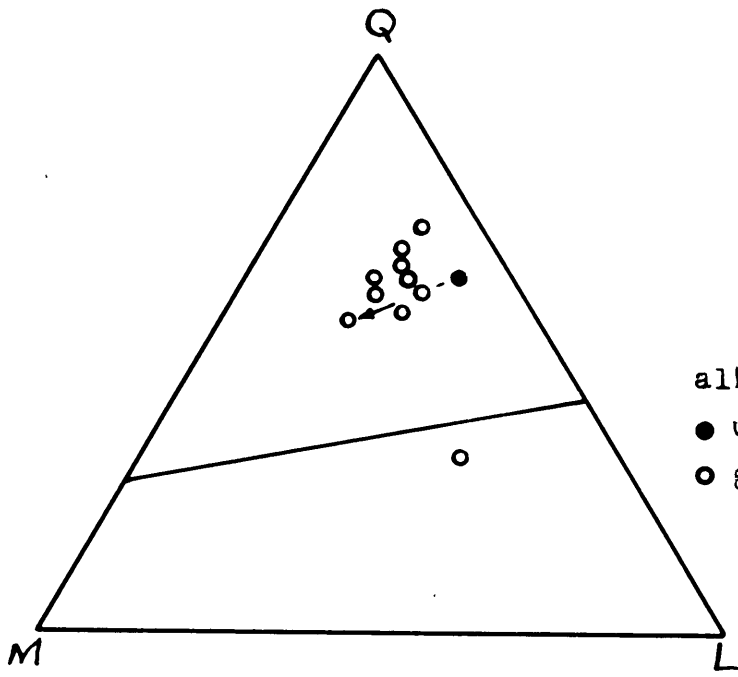
Continued

	<u>F</u>	<u>G</u>	<u>H</u>	<u>J</u>	<u>K</u>
F	0.032	0.020	0.036	0.057	--
Ga ₂ O ₃	--	--	0.0022	--	--
Rb ₂ O	0.020	0.022	0.019	0.005	--
Quartz	22.0	37.3	22.5	41.2	22.9
Albite	3.2	5.7	17.7	13.5	16.0
Matrix*	72.6	56.5	56.2	41.6	58.9
Epidote	1.1	0.2	1.1	0.8	Trace
Specularite	1.1	0.3	2.5	2.8	2.3
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100.0	100.0	100.0	100.0	100.0

*Matrix consists of fine-grained intergrowth of chlorite, sericite and albite

- | | |
|------------------|------------------|
| A. specimen E1 | F. specimen E171 |
| B. specimen E102 | G. specimen E172 |
| C. specimen E107 | H. specimen E211 |
| D. specimen E164 | J. specimen E216 |
| E. specimen E166 | K. specimen E369 |

Plate XII
 Variation diagrams
 showing
 chloritization and
 sericitization of
 albite-alaskite-mylonite
 ● unaltered alaskite
 ○ greywacke-looking rock



- (1) Hematite staining of albite in mylonitized-alaskite fragments.
- (2) Network of introduced veinlets of red albite.

Alteration from the first cause has been previously described with reference to red-alteration of alaskite. Staining by hematite is found at all localities where the breccia is altered red but in places the effect of veinlets of albite is also superimposed on the rock. Veinlets of albite have also been noted in slates and quartzite at the Tam Lake zone of the Eagle-Ato-Mic claims.

The veinlets of albite range in thickness up to about 1 mm. and rarely constitute more than a few per cent of the rock. The veinlets extend through fragments and matrix alike.

On the weathered surface, slightly red-altered trap-like rock is orange colored, but the same rock on a freshly broken surface is generally black. Furthermore, even where the trap-like rock is altered brick-red on weathered surfaces, there is little indication of red-alteration on fresh surfaces except for veinlets of red-albite. Apparently the effect of hematite staining is largely masked by finely divided chlorite in the mylonitic matrix. This has been responsible for at least some of the difficulties of correlating red-altered zones in surface-mapping and core-drilling and contrasts with red-altered alaskite which is red on both fresh and weathered surfaces.

An analysis of orange-weathering trap-like rock is shown in Table XVII and is labelled G (specimen G-19). Compared with analyses of similar rocks which weather pale grey to pale brown (C and D of the same table), the orange weathering type as expected contains slightly more Fe_2O_3 .

Introduction of Carbon. In the structural breccia on the Tamblyn property previously described on page 49, black carbonaceous material cements finely brecciated to pulverized quartz-muscovite schist. From its physical properties the carbonaceous material appears to be graphite but as no analysis for hydrogen was carried out, the author feels that part or all of the carbon might be present as hydrocarbon.

It is of interest to note that graphite occurs on slickensided slip or minor fault surfaces in the Eagle mine-area and as a one inch seam in the main fault zone on the Mic claims. Christie and Kesten (1949) also report that amorphous carbon is associated with pitchblende at one of the Fish Hook Bay showings on Lake Athabaska and that graphite occurs in the St. Luis fault zone at Christie Lake.

A comparison of analyses of quartz-muscovite schist and structural breccia (Table XIX) show an increase in SiO_2 and drastic decreases in K_2O and Al_2O_3 accompanying the introduction of carbon.

The change in relative proportions of the constituents referred to is also indicated on the variation diagrams of

TABLE XIX

Analyses and Mineral Composition of Muscovite
Schist and Structural Breccia, Tamblyn Property,
Goldfields, Saskatchewan

	<u>A</u>	<u>B</u>
SiO ₂	67.7	76.3
TiO ₂	--	--
Al ₂ O ₃	19.3	7.7
Fe ₂ O ₃	1.2)	1.8
FeO	0.1)	
MnO	Trace	Trace
MgO	0.8	1.0
CaO	0.3	0.5
Na ₂ O	0.4	0.3
K ₂ O	5.0	0.3
H ₂ O	--	--
CO ₂	--	--
C* (non-carbonate)	--	8.5
	<hr/> 94.8	<hr/> 96.4
Ga ₂ O ₃	0.0040	--

TABLE XIX

Continued

	<u>A</u>	<u>B</u>
Quartz	51.5	--
Muscovite	45.8	--
Unidentified opaque	1.1	--
Epidote	1.6	--
Schist fragments	--	31.3
Opaque matrix	--	68.7
	-----	-----
	100.0	100.0

A. Muscovite-schist, specimen Z13.

B. Structural breccia containing bleached fragments in black carbonaceous matrix, specimen Z12.

Plate XIII

Variation diagrams
showing chemical changes
accompanying introduction
of carbonaceous material

- unaltered mica-schist
- black breccia

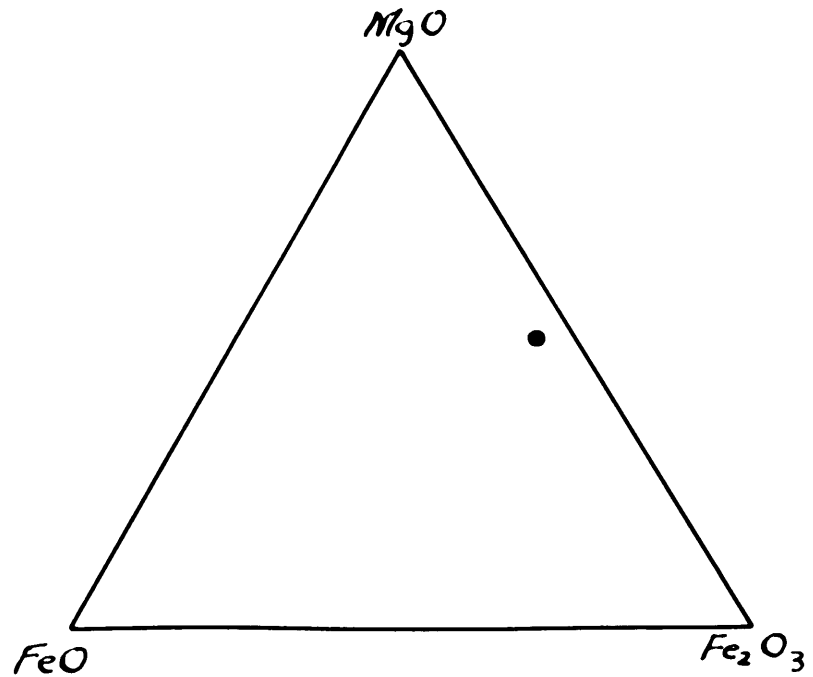
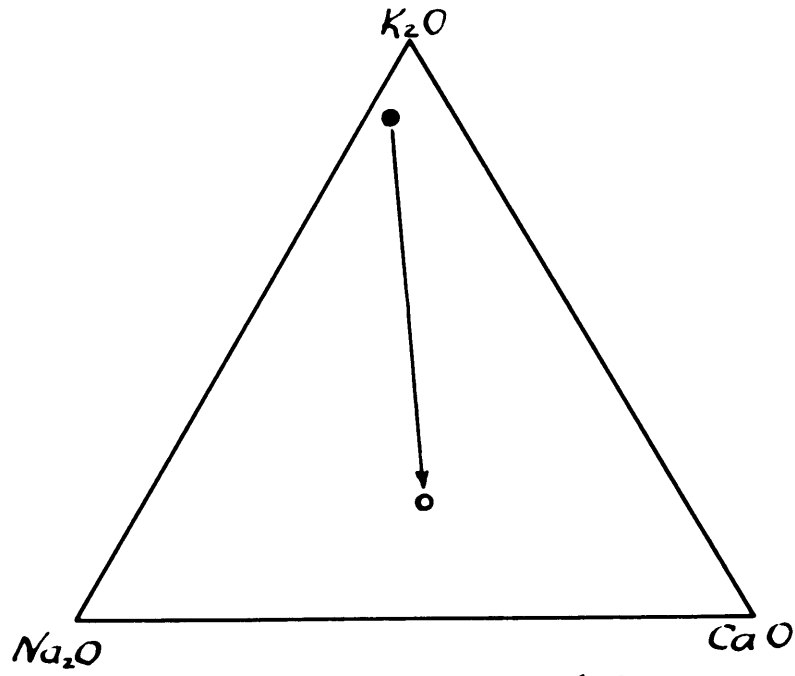
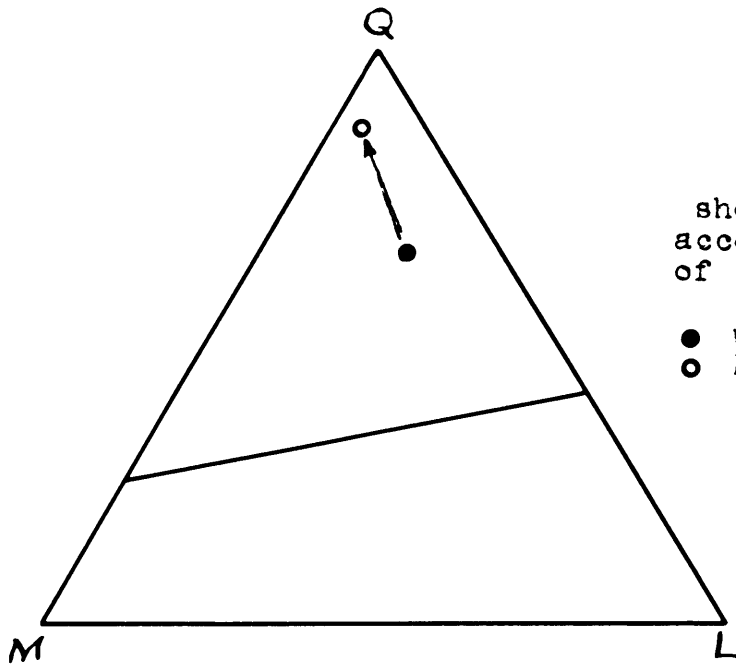


Plate XIII. With reference to these diagrams, the analyses of major constituents (without carbon) was recalculated to 100 per cent before conversion to the Niggli values.

As the ferrous iron was not determined, the relative proportions of FeO, Fe₂O₃ and MgO in the breccia could not be plotted on the lowermost diagram. However, the analysis of total iron and magnesia in Table XIX indicate little change if any in these constituents.

Alteration of Diabase at Great Bear Lake

In order to compare chemical changes during alteration in the Goldfields area with those at Great Bear Lake, fresh and altered diabase from the latter area were analyzed. The comparison is incomplete because as shown by studies in the Goldfields area, chemical changes during hydrothermal alteration depend to a large extent on the original composition of the rock. For a more complete comparison, therefore, alteration of acid igneous rocks at Great Bear Lake should also be studied.

The relatively unaltered diabase analyzed consists of laths of labradorite (showing multiple albite twinning) in a matrix consisting mainly of chlorite and magnetite.

In hand specimen, the altered rock has retained the same textural appearance as "fresh" diabase except that feldspar is more easily recognized and is a brick-red color.

The greatest changes during red-alteration of the diabase are in the content of K₂O, Na₂O and CaO (Table XX).

TABLE XX

Analyses and Mineralogical Composition of
Diabase Dykes, Great Bear Lake, N.W.T.

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
SiO ₂	45.4	54.1	55.2	51.5
TiO ₂	--	--	--	--
Al ₂ O ₃	14.5	12.6	16.8	13.9
Fe ₂ O ₃	5.7	2.0	1.5	4.7
FeO	9.0	7.0	3.6	6.5
MnO	0.4	0.3	0.1	0.2
MgO	5.6	3.5	9.5	6.3
CaO	6.7	0.5	0.6	10.2
Na ₂ O	2.7	0.4	0.4	1.9
K ₂ O	2.5	9.1	6.3	5.2
H ₂ O	--	--	--	--
CO ₂	--	--	--	--
	<hr/>	<hr/>	<hr/>	<hr/>
	92.5	89.5	94.0	100.4
Rb ₂ O	0.015	0.069	0.052	0.042
Li ₂ O	0.0092	0.0034	0.0039	0.0027
Cu	0.010	--	0.015	0.007
Co	0.0025	--	0.0004	0.0022
Ni	0.0047	--	0.0046	0.0097

TABLE XX

Continued

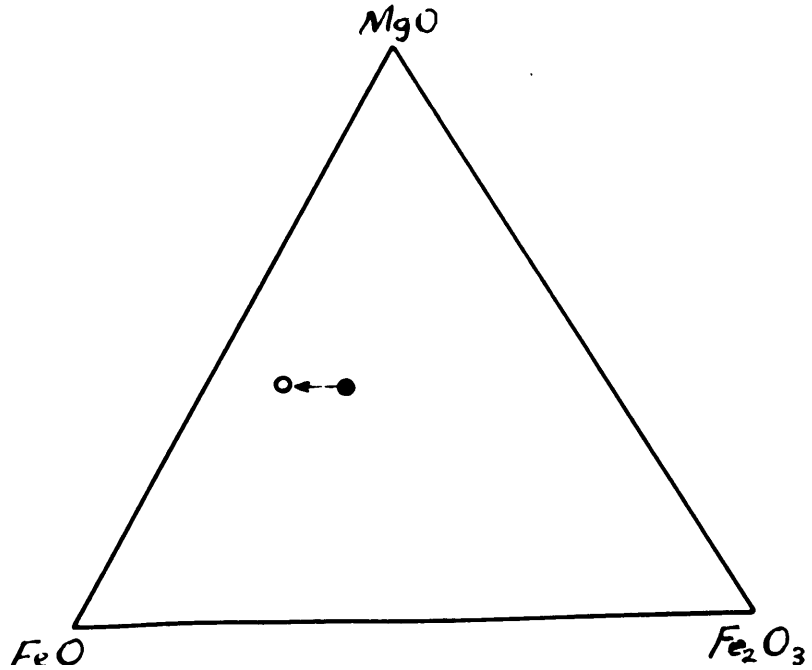
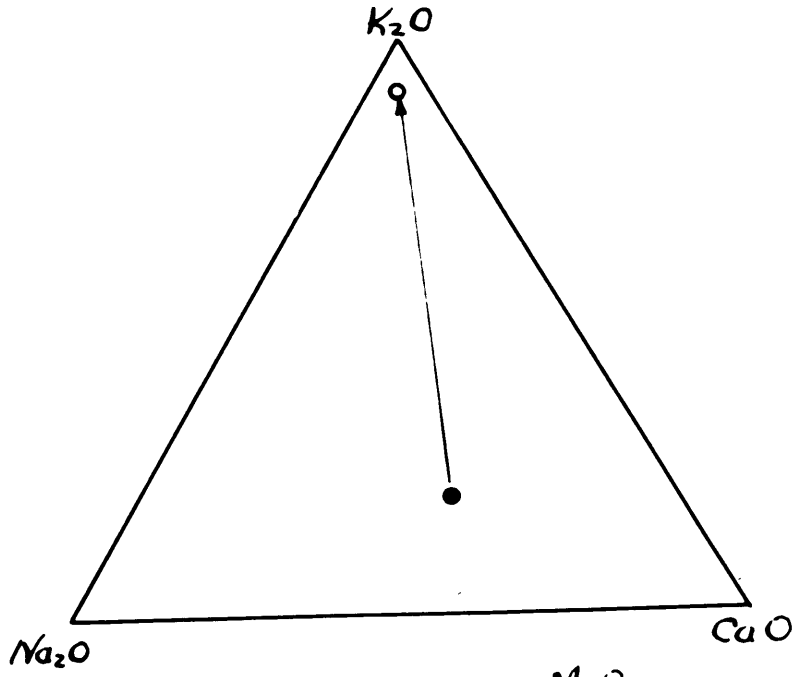
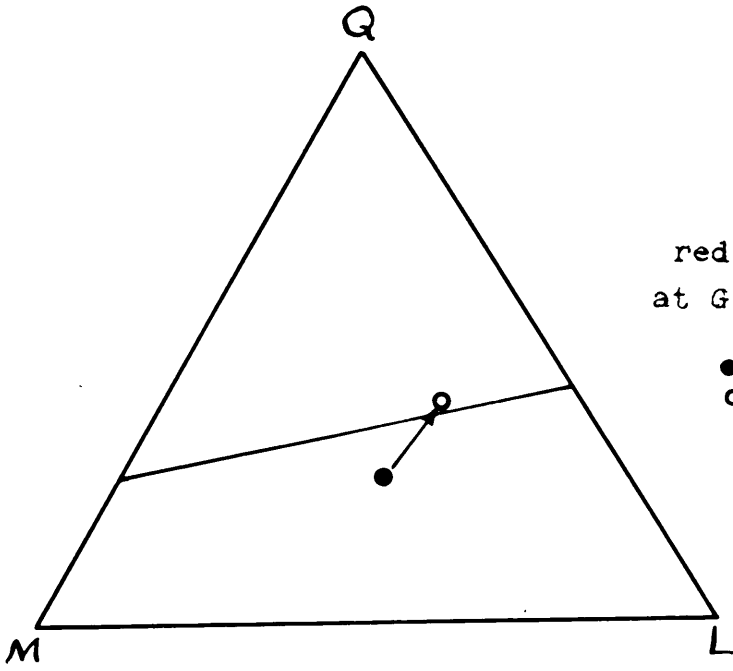
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
Labradorite	38.5	--	--	60.2
Feldspar (altered)	--	73.1	--	--
Augite	--	--	--	29.2
Magnetite	9.3	--	--	4.1
Unidentified opaque	--	7.2	--	--
Chlorite	50.7	19.7	--	2.6
Epidote	1.5	--	21.7	3.7
Sericite	Trace	--	36.1	0.2
Calcite	--	--	--	Trace
Matrix*	--	--	42.2	--
Quartz amygdules	--	--	Few	--
Pyrite	--	--	Trace	--
	100.0	100.0	100.0	100.0

*Matrix consists of fine intergrowth of chlorite, sericite and unidentified opaque minerals and probably represents devitrified glass.

- A. "Early Diabase", coarse grained steeply dipping dyke in Eldorado Mine N.W.T., specimen GB 1.
- B. Same as A but red-altered; rock still has typical ophitic texture but laths of feldspar are brick-red with interstitial dark-green chlorite, specimen GB 2.
- C. Fine-grained altered diabase or basalt dyke, now largely altered to grey-green chlorite schist, Eldorado Mine, N.W.T., specimen GB 3.
- D. "Younger Diabase", coarse grained flat lying intrusive near Eldorado Mine, N.W.T., Harvard University Collection, specimen GB 4.

Plate XIV
 Variation diagrams
 showing
 red-alteration of diabase
 at Great Bear Lake N.W.T.

- unaltered diabase
- altered diabase



K_2O has been sharply increased whereas drastic reductions in CaO and Na_2O have taken place. This is probably due to replacement of plagioclase by orthoclase although feldspar in the altered rock is too heavily stained with finely divided hematite to determine the species optically.

Replacement of plagioclase by orthoclase is not known to occur during alteration in the Goldfields area although potash increases during alteration of alaskites on the Eagle property due to sericitization of albite.

A moderate increase in SiO_2 during alteration of diabase at Great Bear Lake is also recorded but Fe_2O_3 has decreased considerably. The increase in silica probably accompanied conversion of plagioclase to orthoclase, but the mineralogical changes accompanying the decrease in Fe_2O_3 are not known.

The decrease in Fe_2O_3 appears particularly unusual compared with red-alteration in the Goldfields area where red-alteration is invariably accompanied by an increase in Fe_2O_3 .

Summary and Conclusions

In the Goldfields area, it can be shown that except for the introduction of carbon, chemical changes during alteration were at least in part governed by the composition of the "unaltered" rock. It is possible that most solutions which caused hydrothermal alteration contained essentially the same elements or ions including K^+ , Fe^{+++} , Fe^{++} , Mg^{++} , Ca^{++} and CO_3^{--} . It should be pointed out that this list does not include Si^{+4} (or SiO_2) as no instance of hydrothermal alteration due to silicification has been observed associated with pitchblende mineralization although quartz occurs in pitchblende-bearing veins with calcite. In accord with generally accepted principles of metamorphism, new mineral assemblages developed which on the one hand were governed by the bulk composition of the "unaltered" rock and on the other hand developed in response to changed environmental conditions of stress, temperature and composition of available hydrothermal solutions.

The introduction of potassium is an interesting feature of alteration in certain places in the Goldfields area and at Great Bear Lake. At the outset, however, it should be stated that the increase in potassium cannot be considered as a unique feature of alteration associated with pitchblende deposits for as shown by Schwartz (1939) an increase in K_2O is an almost universal feature of hydrothermal alteration.

On the Eagle-Ato-Mic claims introduction of potassium appears to have taken place during the formation of the black mylonitic rock. From microscopic staining techniques it appears that albite in mylonitized alaskite fragments has been partially replaced by orthoclase, especially near the margins of fragments. This involves substitution of potassium ions for those of sodium accompanied by adjustments of the feldspar structure. At a later stage, during shearing action in local zones of the breccia (formation of the greywacke-looking rock), orthoclase and albite were unstable and potassium entered the structure of newly developed sericite.

At Donaldson Lake, sericite did not form nor did K_2O increase during alteration of alaskite. The absence of sericite is possibly due to absence of intense shearing action at the time of alteration. The stable mineral assemblage was albite, calcite, chlorite and hematite; quartz was unstable and was largely replaced; only corroded remnants remain to attest to its former presence.

In the Goldfields area, the stable mineral assemblage of altered basic rocks is chlorite, epidote and calcite, but at Great Bear Lake the stable mineral assemblage in one dyke is orthoclase and chlorite, and in another dyke (obviously sheared), sericite and chlorite. In both dykes alteration is accompanied by remarkable increases in K_2O .

During alteration of plagioclase-amphibolites in the Goldfields area, the K_2O content decreases in all altered

specimens studied. The apparent reason for this is that the structures of epidote and chlorite can tolerate still less amounts of the large potassium ions than the mineral assemblage plagioclase and hornblende. However, as shown by Buerger (1948), temperature undoubtedly is an important factor in determining the amount of substitution possible in a given crystal structure by excessively large ions. This factor is probably largely responsible for the decrease in K_2O owing to lower temperature conditions during alteration as compared with temperature required for amphibolite grade of metamorphism.

Ca^{++} , Mg^{++} and Fe^{++} were introduced into alaskites on an extensive scale on the Eagle-Ato-Mic claims during mylonitization. Mg^{++} and Fe^{++} apparently reacted with silica and alumina in the rock (in the presence of water) to form chlorite. The mineral in which Ca^{++} occurs is not known but probably is epidote as a few porphyroblasts of this mineral were observed in thin-section although as mentioned previously, the black mylonitic groundmass within which clusters of epidote crystals occur is too fine grained to be resolved under the microscope.

Ca^{++} has also been introduced on an extensive scale during alteration of alaskites at Donaldson Lake where it forms calcite with introduced CO_3^{--} . At the Ace property Ca^{++} has also been introduced during alteration of plagioclase-amphibolite to epidote and chlorite; the introduced Ca^{++}

apparently entered the epidote structure along with other elements (including some Ca^{++}) already present in the rock.

Probably the most consistent feature of hydrothermal alteration (associated with deposits of pitchblende) in the Goldfields area is the introduction of Fe^{+++} in the form of hematite. Appreciable quantities of hematite were introduced in nearly all of the altered rocks studied regardless of composition. In some of the rocks, especially those containing abundant chlorite and epidote, the effect of hematite staining was masked. However, at nearly every pitchblende occurrence, at least one rock-type is conspicuously altered red although it may contain no more hematite than other rocks present.

At Great Bear Lake, red-altered diabase contains less Fe_2O_3 than the equivalent "unaltered" type. This anomaly probably is not typical of chemical changes during red-alteration at Great Bear Lake as the character of red-alteration of felsic rocks appears similar to that of equivalent rock-types at Goldfields.

The introduction of albite into fractures in the breccia at the Eagle property and metasomatic replacement by albite at Donaldson Lake presents a problem of genesis. It is possible that the albite is derived from the same source (presumably magmatic) as pitchblende. However, as the composition of the albite is identical to albite in unaltered alaskite, the author believes that the albite probably

represents material picked up by the hydrothermal solutions in sheared or fractured alaskite below and redeposited at a higher level in the earth's "crust".

After a detailed study of petrology and hydrothermal alteration in the Goldfields area, the author cannot agree with Christie and Kesten (1949) that the chemical composition of available host rocks determines in large part the deposition of pitchblende and that in general mafic rocks are more favorable to ore deposition than acidic types. In the first place the generalization referred to is based to some extent at least on faulty observation. The original discovery vein at the Ace property is not in red-altered chlorite-epidote rock, but in red alaskite-mylonite. In fact, it can be shown at the Ace property that the chlorite-epidote rocks are probably the most unfavorable rocks to ore deposition of those present; the most favorable are alaskite-mylonite and partially "granitized-sediments". At the Eagle property too, the most basic rocks (prophyrites), even considering their restricted occurrence, are the least favorable to ore deposition of any rocks present.

The author believes that the primary requirement for control of ore-deposition besides a set of faults (see Allen, 1950), is the presence of two or more rock-types of contrasting competency. For instance, at the Ace Creek zone, pitchblende occurs at the locus of two intersecting fracture

systems and the contact of alaskite with amphibolite; no ore is found in either the amphibolite or the alaskite except near the contact of the two rock-types. At the Fay Zone, the favorable setting is the presence of two intersecting faults and a zone of granite-gneiss consisting of interfingering alaskite and chloritized amphibolite of contrasting competency.

Although much more information will be forthcoming with further study of deposits in the Goldfields area, the author believes that from present information there is little to suggest that chemical composition of host rocks is of importance in ore deposition; the important feature appears to be the mechanical manner of fracturing. Actually, this is the reasonable attitude to take as most veins appear to be simple fissure filling with little or no replacement of wall-rocks which could have materially affected the composition of ore-bearing solutions.

PART II

THE GENESIS OF PITCHBLENDE

INTRODUCTION

General Statement

As it has been in the past, opinion today on the origin of the cobalt-nickel-native silver and associated pitchblende type of deposit is sharply divided. Some geologists hold that this type of deposit is in some way genetically related to intrusive diabase; others are of the opinion that the deposits are related to granite. The controversy, like many others of a similar nature, probably will not be settled satisfactorily for many years to come, but in the meantime it is recognized that with respect to most deposits of the type referred to, altogether too few facts are known to accurately draw conclusions on genesis. To contribute in a small way to factual data on this whole problem, the author analyzed diabase from several districts in Canada in which the aforementioned type of mineral deposit is also present. For comparative purposes, the copper, cobalt, and nickel content of diabase from Cornwall, Pennsylvania and of norite from the Sudbury basin of Ontario was also determined.

Insofar as is known, none of the analytical work undertaken had been previously carried out.

ANALYSES OF DIABASE

General Statement

Of the diabase specimens analyzed, most appeared fresh, a few which were obviously hydrothermally altered are so designated in the tables which follow. Information on the location of specimens is given in footnotes and in the appendix.

Of the major elements, Al, Fe, Mn, Mg, Ca, Na and K were analyzed spectrochemically; SiO₂ and FeO were determined chemically for the author at the University of Minnesota. Linear analyses are given for diabases in which major elements were determined. To supplement data on major analyses, a few rock analyses have been drawn from the literature and are properly acknowledged.

The minor elements Rb, Li, Cu, Co and Ni were all analyzed spectrochemically. Radioactive determinations were made by means of an alpha counter (thick-source method) and the results are quoted in terms of equivalent radium per gram of rock.

Major Elements

The analyses of major elements of unaltered diabase in Tables X, XX and XXI show that, with minor differences, all of the rocks represented are closely allied in composition. It is of interest to note, however, that diabase in certain districts shows marked characteristics; that at Goldfields is high in K₂O and low in CaO and diabase from Theano Point is consistently low in K₂O.

TABLE XXI

Analyses and Mineral Composition of Diabase Dykes,
Theano Point Area, Ontario

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>	<u>E.</u>
SiO ₂	54.3	50.2	47.3	50.2	49.3
TiO ₂	--	--	--	--	--
Al ₂ O ₃	12.9	13.6	13.3	16.4	13.8
Fe ₂ O ₃	6.0	2.0	12.5	7.1	6.0
FeO	8.4	11.4	5.6	6.9	9.1
MnO	0.2	0.2	0.2	0.2	0.2
MgO	4.2	5.2	5.5	8.9	6.9
CaO	6.0	8.5	4.3	7.6	5.8
Na ₂ O	3.5	2.8	3.3	2.7	2.8
K ₂ O	1.0	0.9	0.9	0.8	0.6
H ₂ O	--	--	--	--	--
CO ₂	96.5	94.8	92.9	100.8	94.5
Rb ₂ O	0.0083	0.0074	0.0073	0.0067	0.0074
Li ₂ O	0.0020	0.0020	0.0023	0.0022	0.0024
Cu	0.014	0.005	--	0.015	0.014
Co	0.0019	0.0027	--	0.0027	0.0033
Ni	0.0039	0.0045	--	0.0085	0.0091

TABLE XXI - Continued

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>	<u>E.</u>
Andesine	44.8	--	--	61.3	--
Labradorite	--	45.0	--	--	50.4
Plagioclase (altered)	--	--	55.8	--	--
Orthoclase*	4.5	--	--	--	1.0
Quartz	4.4	--	0.2	--	--
Augite	37.5	36.0	24.5	28.2	38.7
Biotite	Trace	3.9	--	--	--
Magnetite	6.3	--	--	6.8	3.5
Ilmenite	--	8.4	--	--	--
Magnetite and specularite	--	--	15.3	--	--
Pyrrhotite	--	Trace	--	--	--
Chlorite	<u>2.5</u>	<u>6.7</u>	<u>4.3</u>	<u>3.7</u>	<u>6.4</u>
	100.0	100.0	100.0	100.0	100.0

*Orthoclase forms interstitial granophyric intergrowths with quartz.

- A. "Ranwick dyke", coarse grained diabase, Theano Point Area, Ontario, specimen Th 1.
- B. "Jalore dyke", coarse grained diabase, Theano Point Area, Ontario, specimen Th 2.
- C. "Damascus dyke" (from main showing), coarse grained diabase altered to reddish-brown color, Theano Point Area, Ontario, specimen Th 3.
- D. "Camray, Discovery Dyke", coarse grained diabase, Theano Point, Ontario, specimen Th 4.
- E. Dyke with no name but like A, B, C, and D has closely associated pitchblende occurrences, coarse grained diabase, Theano Point area, Ontario, specimen Th 5.

In Table XXII, analyses of diabase, norite and gabbro have been drawn from the literature. An average analysis of Triassic diabase in New Jersey is included because Spencer (1908), Newhouse (1933) and others have proposed (with good reason) that numerous deposits of the Cornwall, Pennsylvania type (magnetite-chalcopyrite-cobaltiferous pyrite) in the Eastern United States are genetically related to Triassic igneous activity consisting of intrusions of diabase and associated outpourings of basalt lava. An analysis of Duluth gabbro has been included because the general consensus on the genesis of the Michigan copper deposits (see Butler, Burbank, et al., 1929) is that these deposits are genetically related to the Duluth gabbro. Finally, analyses of norite from Sudbury, Ontario, and of diabase from Cobalt, Ontario, have also been included because of the close relationship between norite and diabase respectively with mineral deposits at these two localities.

A comparison of these analyses (Table XXII) show that with minor variations, the chemical composition of all rocks represented, are little different than those of diabases previously referred to.

Minor Elements

Minor element analyses of diabases are shown in Table X, XX, XXI and XXIII. At first glance, all of the data appear to be completely erratic, but a few observations are worthy of note.

TABLE XXII.

Analyses of Diabase, Norite and Gabbro
drawn from Literature

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>
SiO ₂	50.63	54.84	50.12	48.20
TiO ₂	0.90	--	0.55	0.65
Al ₂ O ₃	18.16	15.82	15.70	19.53
Fe ₂ O ₃	1.44	3.36	1.42	Trace
FeO	9.32	7.02	6.89	10.60
MnO	0.19	--	--	0.14
MgO	5.23	6.02	9.50	9.28
CaO	11.14	5.71	11.30	8.51
Na ₂ O	1.83	3.87	2.91	2.52
K ₂ O	0.51	2.31	1.07	0.32
H ₂ O	0.83	1.27	1.24	0.73
P ₂ O ₅	0.13	--	--	0.19
CO ₂	<u>--</u>	<u>Trace</u>	<u>--</u>	<u>0.02</u>
	100.31	100.22	100.50	100.69

- A. Average of ten analyses of Triassic diabase, Virginia, Watson (1923).
- B. Norite, 30 feet from basic edge, Murray mine, Sudbury, Ontario, Report of the Royal Ontario Nickel Commission (1917), p. 119.
- C. "Normal" Nipissing diabase, O'Brien mine, Cobalt, Ontario, Bowen (1910).
- D. Duluth gabbro, type area, Duluth Minn., Grout (1933).

TABLE XXIII

Minor Element Analyses of Diabases and Norite

	<u>A.</u>	<u>B.</u>	<u>C.</u>	<u>D.</u>	<u>E.</u>	<u>F.</u>	<u>G.</u>	<u>H.</u>	<u>J.</u>
Cu	0.012	0.011	0.014	0.011	0.012	0.013	0.006	0.005	0.006
Co	0.003	0.016	0.004	0.003	0.003	0.004	0.002	0.004	0.003
Ni	0.013	0.024	0.018	0.008	0.010	0.010	Trace	Trace	0.007

- A. Nipissing diabase, near granite, 460' level, Beaver mine, Cobalt, Ontario, (Harvard University collection No. Co 26), specimen Co 1.
- B. Nipissing diabase, 500' level Keely mine, Cobalt, Ontario, (M.I.T. collection No. 2371), specimen Co 2.
- C. Nipissing diabase, approximately 200 feet above lower margin of sill, King Edward mine, Cobalt, Ontario, (M.I.T. collection No. 2227) specimen Co 3.
- D. Triassic "trap", South side Big Hill near wall, Cornwall, Pennsylvania, (Harvard University collection No. Cw 1237), specimen US 1.
- E. Triassic "trap", farther from contact than D, Cornwall, Pennsylvania, (Harvard University collection No. Cw 1238), specimen US 2.
- F. Triassic "trap" near contact with ore, Cornwall, Pennsylvania, (M.I.T. collection No. 7745) specimen US 3.
- H. Norite, Sudbury, Ontario, (M.I.T. collection, collected by H. W. Fairbairn) specimen S 1.
- G. Norite at basic border, R. R. cutting, C. P. R. near Wendy Lake, Sudbury district, Ontario, (M.I.T. collection No. 4563), specimen S 2.
- J. Norite near Blezard mine, Sudbury district, Ontario, (M.I.T. collection No. 4563), specimen S 3.

Because of the close similarity in geochemical behavior of rubidium and potassium, the rubidium content varies directly with that of potassium, the average potassium-rubidium ratio as shown on page 198, is about 130.

Although the lithium content of diabases analyzed varies considerably, the lithium content of all diabases analyzed from the Theano Point area of Ontario is consistently low. Although there seems to be no obvious geochemical reason for the low lithium content of diabases from this area, it probably should be pointed out that potassium and rubidium contents are also lower than average in these rocks.

With regard to copper, results are particularly erratic, both with respect to diabase in a given district and in comparing diabase from one district with that of another.

Cobalt and nickel analyses are also erratic, but it is of interest that specimens from Cobalt, Ontario, contain a greater than average amount of these metals. Peculiarly enough, the lowest nickel content of any of the rocks analyzed was that of two norite specimens from Sudbury which recorded only trace of nickel (less than 0.001 per cent). A third specimen of norite carries 0.007 per cent nickel, an amount roughly equivalent to that in several diabases analyzed, but considerably less than the nickel content of diabase from Cobalt, Ontario (0.013-0.024 per cent).

According to Goldschmidt, as quoted by Rankama and Sahama (1950), the average content of cobalt in gabbro is

gm/metric ton (0.0079 per cent) and of nickel is 158 gm/metric ton (0.0158 per cent). The average copper content of basic igneous rocks, according to Sandell and Goldich, is 149 gm/metric ton or 0.0149 per cent (Rankama and Sahama, 1950).

Radioactivity

The radioactivity measurements of diabase shown in Table XXIV range from 0.41 to 1.89 Ra equiv $\times 10^{-12}$ gm/gm. The radioactivity measurements give an indication of the total uranium plus thorium content; the proportion of radioactivity due to either the thorium series or the uranium series, however, was not determined.

As is well known, the radioactivity¹ of acidic igneous rocks is considerably greater than that of basic types and this is further brought out in Table XXV in which alaskites are the most radioactive of all specimens determined.

Conclusions

The available analytical data suggest that diabase in the metallogenic provinces referred to is no different compositionally than diabase in many parts of the world. Furthermore, from a geochemical point of view, it is concluded that mineral deposits containing copper, cobalt, nickel and radioactive elements could be derived from magma of composition similar to diabase or basalt provided that a mechanism of separation, transportation and deposition was available.

TABLE XXIV

Radioactivity Measurements of Diabases and Basalts,
Thick Source Alpha Count, expressed as Radium
Equivalent $\times 10^{-12}$ gm/gm

<u>Specimen</u>	<u>Name and Location of Rock</u>	<u>Radio-activity</u>
GB 1	Early diabase, Eldorado mine, N.W.T.	0.90
GB 2	Same as GB 1 but red-altered	1.05
GB 3	Narrow dyke, Eldorado mine, N.W.T.	0.87
GB 4	Younger diabase, Eldorado mine, N.W.T.	0.41
A 8	Diabase dyke, Ace claims, Saskatchewan	1.89
D113	Diabase dyke, Emar claims, Saskatchewan	1.93
R2	Diabase dyke, Mic claims, Saskatchewan	1.04
Z11	Diabase dyke, Pitch claims, Saskatchewan	0.47
Z14-b	Diabase dyke, Strike claims, Saskatchewan	1.47
M17	Diabase sill, Martin Lake, Saskatchewan	1.93
M8-9-10	Basalt flow 1, Martin Lake, Saskatchewan	3.63
M12-13	Basalt flow 2, Martin Lake, Saskatchewan	1.07
M14-15	Basalt flow 3, Martin Lake, Saskatchewan	3.12
Th-1	Ranwick dyke, Theano Point, Ontario	0.69
Th-2	Jalore dyke, Theano Point, Ontario	0.68
Th-3	Damascus dyke, Theano Point, Ontario	0.63
Th-4	Camray dyke, Theano Point, Ontario	0.39
Th-5	(No name) dyke, Theano Point, Ontario	1.13

TABLE XXV.

<u>Specimen</u>	<u>Name and Location of Rock</u>	<u>Radio-activity</u>
A44	Albite-alaskite, Ace claims	2.47
E420	Albite-alaskite, Eagle claims	6.76
A45	Microcline-alaskite, Ace claims	8.92
E200	Structural breccia, Eagle mine-area	2.95
E239	Structural breccia, Eagle mine-area	2.98
E316	Structural breccia, Eagle mine-area	3.75
R130	Structural breccia, Eagle mine-area	3.68
E346	Plagioclase-amphibolite, Eagle mine-area	0.47
E421	Plagioclase-amphibolite, Eagle mine-area	0.27

However, even though analytical data indicate that basaltic (or diabasic) magma could be a source of the cobalt-nickel-native silver-pitchblende type of mineral deposit, this is not proof that deposits of the type referred to actually were derived from basaltic magma. Many other facts of a geological nature enter the picture and deposits in each district or metallogenic province must be considered in their own geological setting. With this idea in mind, the author has reviewed the available literature, a summary of which is presented in the next section.

REVIEW OF LITERATURE

General Statement

The genesis of pitchblende and closely related nickel-cobalt-native silver minerals has long been a subject of study. Early geological work on deposits of this type was carried out in the Erzgebirge of central Europe by Von Cotta and students of the Freiberg School of Mines as early as 1850. Since that time studies of similar types of deposits have been made in many parts of the world. An excellent overall review of the problem was made by Bastin (1939). Since this publication, however, a number of articles have been published on deposits of this type, particularly in the post-war years on deposits of pitchblende (or uraninite) in Canada and the United States. It seems desirable, therefore, to bring together recent information which bears on this problem and, in the light of recent findings, to examine critically some of the older literature. The information summarized here is believed to be representative and an effort has been made to present information considered to be of special genetic significance.

With reference to terminology it should be pointed out that at present there is no agreement on the names of the uranium-oxide minerals, pitchblende and uraninite. In most of the literature, the name "pitchblende" has been restricted

to colloform varieties of uranium oxide and the word "uraninite" reserved for well defined crystals of uranium oxide exhibiting crystal form. However, some American authors in recent literature refer to the colloform variety as uraninite, presumably on the basis of x-ray studies.

In the following summaries, no reference has been made to classification of deposits described; the description given will allow the reader to form his own opinion on where the deposits fit into a classification. Most of the deposits probably would be classed by Lindgren as mesothermal (of shallow to intermediate depth) or as leptothermal (between Lindgren's epithermal and mesothermal zones) by Graton (1933).

Furthermore, only one or two references are made to age measurements of pitchblende because, as shown by Lang (1951), much more must be learned about age measurements by the lead-uranium ratio before they can be considered as reliable.

Northwest Territories of Canada

The veins at the Eldorado mine on the east shore of Great Bear Lake occur in brecciated fault zones which transect a gently folded complex of "sediments", lavas and porphyries of Precambrian age. The veins are composed primarily of quartz, carbonate and hematite in varying proportions, with a minor amount of chlorite. Ore shoots consist of lenses or seams of pitchblende that parallel the walls of the zones and

with which are associated a great variety of metallic minerals, including chalcopyrite, nickel-cobalt arsenides, native bismuth and native silver.

According to Kidd and Haycock (1935), pitchblende was deposited early in the sequence, and silver was the latest mineral deposited; other minerals were deposited at intermediate stages.

The metallic minerals are not co-extensive; silver ore-shoots are confined to a few hundred feet of the surface, whereas pitchblende ore-bodies extend to much greater depths.

Both wall-rocks and veins are stained red by hematite. The alteration affects nearly all rocks in the vicinity of the mine, but is most intense along the fault zones in which the veins occur.

Kidd and Haycock (1935) were of the opinion that the mineralization was related to granite exposed near the mine. However, later geological work has shown that pitchblende-bearing veins formed during an intermediate period between the intrusion of diabase of two different ages, both of which are younger than granites exposed in the area. The earlier diabase is represented by several steeply dipping dykes in the mine which, according to Murphy (1946), are older than pitchblende bearing veins. The later diabase, according to Campbell* comprises a narrow set of dykes which are associated intimately with the veins and cross-cut them.

*D. D. Campbell, mine geologist Eldorado mine, written communication accompanying diabase specimens, January 1951. Analyses of specimens are shown on page 92.

In the vicinity of the Eldorado mine are isolated exposures of a large flat-lying diabase dyke, and it has been suggested by a number of authors that this dyke before erosion was continuous across the country. Murphy (1946) believes the narrow dykes which cut the veins in the mine are offshoots of the large flat-lying intrusive, but his evidence for this is not stated. In any case, at least some mineralization occurred in the district and possibly in the mine-area, after the intrusion of the flat-lying diabase, for according to Murphy (1946) a few calcite veins carrying cobalt and nickel minerals, but no silver or pitchblende, cut the flat-lying intrusive on Cobalt Island, Great Bear Lake.

At Contact Lake, about 8 miles southeast of the Eldorado mine, native silver, pitchblende and a variety of iron, copper, cobalt and nickel minerals occur in veins of quartz and carbonate. The veins follow fracture zones in granodiorite. According to Furnival (1939) several periods of hydrothermal alteration, fracturing and mineral deposition have taken place. In the early stage, zones of granodiorite were partially replaced by chlorite and siderite, and a number of minerals, including magnetite, hematite, chlorite and siderite, were deposited in fractures. This was followed by the intrusion (?) of two narrow aplite dykes less than two inches wide which cut the altered rock and are in turn cut by quartz veins and still younger carbonate veins. It is the carbonate veins which contain the nickel-cobalt-silver minerals and pitchblende.

Hematite is abundant and was deposited with every period of mineralization throughout the formation of the deposits. Hematite is also heavily disseminated in the wall-rocks adjacent to pitchblende shoots and is responsible for red alteration. The red-alteration of wall-rocks accompanies all the pitchblende shoots, but is absent elsewhere along the veins.

Of the metallic minerals in the carbonate veins, pitchblende was the earliest mineral deposited and the last mineral deposited was native silver. Complex arsenides and sulphides of iron, copper, cobalt and nickel came in during intermediate stages. Some silver may have also formed during the intermediate stage.

At Contact Lake, the veins lie wholly within granodiorite and the age of the mineralization relative to other igneous rocks in the district is not known. However, on the basis of mineralogically similar veins which cut flat-lying diabase at several places in the Great Bear Lake area, Furnival (1939, page 776) states "The silver and pitchblende (at Contact Lake) are either co-magmatic with the late quartz-dykes and sills of probably Keeweenawan age, the youngest exposed intrusives in the region, or are related to some younger unexposed intrusive".

Kidd (1936) reported pitchblende in a giant quartz vein about 100 miles south of the Eldorado mine between Beaverlodge and Hottah Lakes N.W.T. However, Henderson (1949), who has studied the mineral occurrences in detail is of the opinion

that the "giant quartz vein" referred to by Kidd is a brecciated belt of quartzite within a sedimentary-volcanic complex and even where the "giant quartz vein" is bounded on both sides by granite, Henderson believes the so-called giant quartz vein represents an inclusion of quartzite in granite.

Henderson's findings are summarized as follows. Between Beaverlodge and Hottah Lakes N.W.T. pitchblende, together with hematite, occurs in a number of narrow quartz veins, commonly one inch to eight inches wide, in which comb structure is common. The veins cut a sedimentary-volcanic complex intruded by basic sills and dykes and still later by granite. All rocks are believed to be of Precambrian age. Members of the sedimentary-volcanic complex occur as inclusions or roof-pendants in the granite and the basic intrusives have been metamorphosed to plagioclase-amphibolite (gabbro of Henderson). Most of the pitchblende-bearing veins occur either in the metamorphosed basic intrusives or in brecciated quartzite (giant quartz vein of Kidd) of the sedimentary-volcanic complex. Few veins can be traced more than ten to twenty feet. A swarm of diabase dykes also occur in the vicinity of the mineralized veins and cut all of the rocks mapped.

Henderson (1949) does not state whether pitchblende is younger or older than the diabase, but Kidd (1936) reports that vuggy quartz veins containing hematite cut a diabase

dyke in the same locality studied by Henderson. Of further interest are statements by Kidd that at the time of early prospecting, small amounts of pyrite, chalcopyrite, native bismuth and stains of cobalt and nickel bloom were found associated with pitchblende and hematite in the same deposits later studied by Henderson.

Haycock (1935) has also studied polished sections of the ore from Beaverlodge Lake N.W.T. He found that pitchblende is peppered with numerous tiny inclusions of hematite. Hematite is also present in minute fractures in pitchblende and as separate crystalline aggregates. Small amounts of chalcopyrite, pyrite, covellite and a hard creamy-white unidentified mineral were also found in specimens studied. An analysis of pitchblende ore from the same locality is shown on page 127.

Goldfields, Saskatchewan

Two types of mineral deposits have been superimposed on the Goldfields area, separated by a long time-interval. The earlier deposits consist of gold-quartz veins within and near granite stocks. All of the gold-quartz veins known are confined to a small area on the north shore of Lake Athabaska and those upon which most work was done are on the Box property of Consolidated Mining and Smelting and the property of Athona Mines.

The granite stocks (with which the gold-quartz veins are closely associated) and other granitic bodies intrude a sedimentary-igneous complex (Tazin-group). After a long interval of erosion in which large areas of granite were exposed, the Athabaska series ("sediments" with intercalated flows and sills) was laid down on the unconformity. After a period of folding, the area was faulted on a regional scale and veins containing pitchblende were deposited in fractures in or near the regional fault zones. Both shear fractures and tension fractures are mineralized. Tension fractures commonly contain brecciated fragments of wall-rock, and some tension fractures in which quartz is present exhibit comb structure.

The most common type of occurrence consists of pitchblende in narrow calcite veins. In many veins, however, the gangue consists of calcite with one or more other non-metallic minerals including quartz, chlorite and albite. Hematite is commonly present in the veins with pitchblende and some veins consist almost entirely of intimately associated hematite and pitchblende with little or no gangue minerals. Locally, pitchblende also occurs as wisps in thin chlorite seams in brecciated and highly altered rock.

The mineralogy of pitchblende deposits in the Goldfields area is of two types. In the most common type pitchblende and hematite are generally the only primary metallic minerals recognized in the hand-specimen and deposits of this

kind are associated with east to northeast striking fault zones. The other type is characterized by the presence of massive arsenides of nickel and cobalt with pitchblende and is associated with north to northwest trending fault zones. Only a few occurrences of this type are known and they are located in the southern part of the area on the Nicholson property and the Fish Hook Bay property of Eldorado Mining and Refining.

According to Robinson (1950), the deposits which do not contain massive arsenides of cobalt and nickel, characteristically contain in addition to pitchblende and hematite, small amounts of sulphide minerals including chalcopryrite, pyrite and galena. Several deposits in the western part of the area contain selenides of copper, and a deposit at Martin Lake contains gold which is later than the pitchblende. Pitchblende and hematite are the earliest minerals deposited but at some localities pitchblende contains inclusions of sulphide minerals which were probably deposited simultaneously with pitchblende and hematite.

In veins on the Nicholson property which are associated with north to northwest trending faults, Robinson (1950) found a variety of minerals including, besides cobalt-nickel minerals and pitchblende, thucholite, chalcopryrite, pyrite, galena, platinum and gold. A few small specks of silver were also identified by Robinson in polished section but, other than that, pitchblende deposits in the Goldfields area are

characterized by absence of silver. At the Nicholson property the cobalt-nickel arsenides are younger than pitchblende.

The chief types of rock alteration associated with pitchblende deposits are red-alteration (introduction of hematite) and chloritization (introduction of chlorite). At some deposits, calcite veins are stained pink to red. Alteration is widespread in the Goldfields area and red-alteration is conspicuous in the vicinity of nearly all mineralized fault zones.

Of interest from a genetic standpoint is the Tamblyn property (Pitche claims) south of Beaverlodge Lake (see page 49). On this property, a highly radioactive breccia zone contains hydrothermally introduced black carbonaceous material (probably finely divided graphite) which literally cements the breccia. Lang (1951) reports that radioactive material from trenches assayed (0.16 - 0.30) per cent U_3O_8 and (0.05 - 4.2) per cent V_2O_5 . Lang also states that carnotite and two other unidentified vanadium minerals are present in the deposit. The presence of vanadium and uranium together in a typically hydrothermal deposit is of especial interest as it is recalled that carnotite deposits in the Colorado Plateau of the Western United States have long been attributed to circulating ground water rather than to a hydrothermal (hypogene) origin.

Insofar as genesis of pitchblende and other primary uranium minerals in the Goldfields area is concerned,

the only positive statement that can be made is that deposits of these minerals are related to faulting. Christie and Kesten (1949) arrived at the conclusion that pitchblende deposits in the Goldfields area are not genetically related to any exposed intrusives with the possible exception of late diabase dykes. Hundreds of diabase dykes occur in the Goldfields area, but as pointed out by Christie and Kesten, their distribution has no apparent connection with the deposits. The chemistry of some of these dykes and their possible relationship with flows at Martin Lake has been previously discussed (page 51).

Theano Point, Ontario

In the Theano Point area of Ontario, (north shore of Lake Superior), pitchblende occurs in a number of localities and every occurrence known is closely associated with medium to coarse-grained diabase dykes considered to be of Keweenawan age. The dykes range in width from 20 to 300 feet wide and cut an older Precambrian complex of granite and granite-gneiss. In the same area are exposures of basalt flows which lie on the truncated surface of granite and diabase dykes. With the exception of one dyke, all dykes mapped in the area are believed by Nuffield (1950) to be older than the basalt flows. The single exception is a fine-grained basalt-like dyke of different appearance than those with which pitchblende is associated. All pitchblende deposits have been

found in fractures in diabase dykes or in adjacent granite and no pitchblende has been found in granite more than a few feet from a diabase dyke.

Recognizable joints occur in the diabase, but no pitchblende mineralization has been found in them. Aplite stringers cut diabase in several places in the area and Nuffield considers them to be a differentiate of diabase magma. In at least one locality aplite occurs in fractures in a diabase dyke associated with typical vein material which is highly radioactive.

Typical vein material consists of calcite, hematite and pitchblende. Some veins contain quartz. No native silver or cobalt-nickel arsenides have been reported, but in at least one deposit chalcopyrite has been reported and Robinson (1950) mentions that selenides are present in vein material.

In most deposits the walls of fractures are only slightly altered (Kesten, 1950). Diabase is commonly altered to chlorite-schist along shear fractures and in some places rock adjoining fractures is brown to red due to impregnation of small amounts of hematite.

With reference to the genesis of the pitchblende deposits, the following is extracted from the report by E. W. Nuffield (1950).

Pitchblende occurs in structural features that are always in or close to diabase. These structural features are post-diabase (Lower Keweenawan) and pre-lava (Middle Keweenawan) and indicate that the deposits are early Keweenawan in age. A genetic as well as a structural relationship between pitchblende and diabase is indicated by the age of the deposits relative to diabase and by the proximity to diabase of all pitchblende occurrences in the area.

Cobalt, Ontario

The deposits of the Cobalt district, Ontario are well known, but for the sake of comparison with deposits in other districts, a summary of the geology will be presented here.

The oldest rocks, known as the Keewatin, comprise a complex of greenstone, schists, and slates intruded by granite. On the eroded "Keewatin" were deposited the Cobalt series (Huronian) consisting of conglomerate and greywacke. A thickness of 300 feet of these gently dipping strata is exposed at Cobalt. After deposition of the Huronian beds, the so-called Nipissing diabase was irrupted, and at Cobalt assumed the form of a sill-like intrusive up to 1100 feet thick. Locally, narrow dykes of aplite or granophyre, a few inches to two feet wide, cut the Nipissing diabase and at one point near Cobalt, a granite dyke fifty feet wide cuts the diabase. Bowen (1910) analyzed a specimen of this granite dyke along with specimens of aplites and granophyric red-rock closely associated with Nipissing diabase at Gowganda, some 75 miles north-east of Cobalt. All of these acidic rocks are believed by Bowen to represent residual sialic segregations of diabase magma as it cooled in place. However, Bastin (1935) believes the aplites at Gowganda are of hydrothermal origin.

The veins at Cobalt are closely associated with flatly dipping faults or shear zones at or near the upper and lower contacts of the diabase sill and along the Huronian-Keewatin

unconformity. Whitehead (1920) classified the veins on a structural basis. He found that nearly all veins in flatly dipping faults or shear zones are barren, whereas steeply dipping to vertical veins in tension fractures, joints, and minor faults are commonly mineralized. Veins in tension fractures characteristically contain brecciated fragments of wall-rock. Calcite and dolomite are the common gangue minerals, but some veins also contain quartz, which generally exhibits comb structure. Barite forms the principle gangue mineral in some veins, but most of these are barren.

Most of the carbonate is white, but some is pink to red. An analysis of pink carbonate vein material from Cobalt is given by Ellsworth (1916). The specimen analyzed contained 2.3 per cent iron and 0.8 per cent cobalt.

In typical veins at Cobalt, arsenides and sulpharsenides of cobalt and nickel occur with native silver in a calcite gangue. More rarely the veins also contain a number of other metallic minerals including native bismuth, argentite, ruby silver, galena and chalcopyrite.

It is of interest that a discovery of pitchblende was recently reported¹ from the Cobalt district of Ontario. The pitchblende occurs in veins containing calcite, arsenides of cobalt and nickel, native silver and native bismuth. The veins occur near the upper contact of a diabase sill. The discovery is located 22 miles northwest of Cobalt.

¹Northern Miner, Toronto, Canada, October 11, 1951, page 17.

With regard to paragensis, Ellsworth (1916) and Bastin (1917, 1925) report that of the veins studied, the cobalt and nickel arsenides were deposited first, then followed sulpharsenides of these elements, and finally native silver. The native silver is believed to be primary.

Hydrothermal alteration accompanying the mineralization is generally confined to within an inch or two of vein walls and in most places is scarcely noticeable. In some places the walls of veins have a bleached appearance. Chlorite, sericite, calcite and epidote are the principle hydrothermal minerals developed in the wall-rocks.

In the Cobalt district there is some suggestion of vertical mineral zoning. It is well known for instance that during the early years of activity, mining was generally stopped when rich silver ore gave out, yet at the bottom of many mines, veins continued "strong" and carried massive cobalt-nickel arsenides.

With regard to genesis, Miller (1913) early recognized that the silver-cobalt veins throughout the Cobalt district were invariably close to or within diabase sills and this close association throughout an area some 70 miles long and 30 miles wide has convinced most observers that the veins and diabase are in some manner genetically related. Many of the early writers were of the opinion that the deposits were formed through differentiation of the sill-like magmatic intrusive in place. However, Whitehead (1920) showed that the intrusive was completely

solid and had been fractured before the period of mineralization. If a magmatic origin is accepted, therefore, then the evidence suggests that either

- (1) The mineral deposits were derived from the same deep lying source of basaltic (diabasic) magma as the diabase sill, but represent a later hydrothermal phase of igneous activity after the sill (completely solid) had been fractured.

or

- (2) The deposits are genetically related to some unknown later igneous activity.

(1) seems most probable in the light of geological evidence available, but (2) should be regarded as a distinct possibility.

Silver Islet, Ontario

The geological relationships of the native silver deposit at Silver Islet on Lake Superior (Thunder Bay district of Ontario) have been described by Tanton (1920). The original islet was about 80 feet across and rose at its highest point 10 feet above Lake Superior; the islet is three quarters of a mile from the lake shore. Over three million dollars worth of silver were recovered during mining operations between 1868 and 1884; since that time the mine has been flooded.

According to Tanton, the ore-body occurred in a divided vein, 20 feet wide, which followed a steeply dipping fault. The fault showed a relative horizontal displacement of 80 feet and transected (nearly at right angles) a steeply dipping diabase dyke (300 feet wide) and flat lying Animikie "sediments" of late Precambrian age. Silver Islet was a small outcrop of the diabase dyke which projected above Lake Superior.

Tanton (1920) states that the veins are enclosed in aplite, which presumably was introduced into the fault zone before the vein minerals. The aplite is soft and contains much graphite.

In the Silver Islet mine, bonanzas of silver ore occurred in the fault structure where the fault intersected the large diabase dyke; the fault was barren where it intersected Animikie "sediments". The fault was traced to the mainland and calcite-quartz veins were found where the fault intersected other diabase dykes. Small amounts of native silver were found in these veins, but none of the veins were productive.

In the main vein in the Silver Islet mine, the gangue minerals were calcite, dolomite, quartz, fluorite and rhodochrosite. The metallic minerals were chiefly native silver, argentite, arsenides of nickel and cobalt, galena, sphalerite, pyrite, marcasite, chalcopyrite and tetrahedrite. The silver minerals were the last minerals deposited. Bain (1950)

reports anomalous radioactivity from the Silver Islet vein; the mineral responsible for the radioactivity, however, is not stated.

With regard to genesis, Tanton (1920) shows that there is a close analogy between the geological relationships at Silver Islet and Cobalt, Ontario. Near Silver Islet a flat-lying diabase sill some 300 feet thick occurs on the mainland and, before erosion, probably extended over the present site of Silver Islet. As is well known, a similar diabase sill is present at Cobalt. At the time of Tanton's investigation, it was the popular belief that the silver ores at Cobalt were derived directly from the slowly cooling sill-like intrusion of "diabase" magma and Tanton postulates a similar origin for the Silver Islet deposit. However, in view of present concepts of the origin of the deposits at Cobalt, Ontario, it would seem more in accord with known facts to state that the Silver Islet ore minerals have probably been introduced from great depth along the fault zone and that the deposit may have been derived from the same magmatic source as the diabase.

Wilberforce, Ontario

The uraninite deposit near Wilberforce, Ontario, although occurring in a pegmatite, has certain features which are strikingly similar to many vein deposits of pitchblende, and a short description will be included here for comparative

purposes. The deposit is described by Spence and Carnochan (1930) and by Ellsworth (1932).

The general geology of the region consists of Grenville gneisses and crystalline limestones intruded by granite and syenite (Adams and Barlow, 1910). The deposit occurs in a band of sedimentary gneiss near a contact with crystalline limestone. At the main showing, a large pegmatite dyke consisting mainly of feldspar contains a central vein or core containing fluorite and calcite. No quartz is reported from the main body of pegmatite or in the central filling. Imbedded in the calcite-fluorite filling occur, in order of decreasing abundance, crystals of apatite, hornblende, magnetite, biotite and uraninite. At the time of early prospecting, small amounts of molybdenite and chalcopyrite were also reported from the western extension of the main pegmatite.

An interesting feature of the uraninite deposit is the change of color of gangue minerals close to uraninite. Calcite, normally pink, deepens to brownish-red close to crystals of uraninite. In a similar manner, fluorite which is normally reddish-purple to violet deepens to almost black at the contact with uraninite. Spence and Carnochan (1930) believe that the darkening near uraninite is due to radioactive emanations.

A specimen of uraninite from the deposit contains about 11 per cent ThO_2 and 3 per cent rare earth oxides (see Table XXVI). The composition thus differs considerably from

TABLE XXVI

Analyses of Uraninite and Pitchblende-Ore

I		II	
PbO	10.95	U ₃ O ₈	52.40
UO ₂	39.10	Fe ₂ O ₃	37.91
UO ₃	32.40	SiO ₂	2.80
ThO ₂	10.60	Pb	2.35
(Ce, La, Di) ₂ O ₃	1.88	Mn	0.09
(Yt, Er) ₂ O ₃	2.14	CaO	1.03
Fe ₂ O ₃	0.43	MgO	trace
MnO	0.03	S	0.10
BeO)	0.09	CO ₂	0.66
Al ₂ O ₃)		Al ₂ O ₃	1.14
CaO	1.01	Ag (oz/ton)	0.15
MgO	0.08	Combined H ₂ O	present
SiO ₂	0.19		
H ₂ O (-110°)	0.05		98.63
H ₂ O (+110°)	0.65		
He	0.31		
Insol.	<u>0.15</u>		
	100.06		

I. Analysis of uraninite crystal from Wilberforce, Ontario, Ellsworth 1932, p. 268.

II. Analysis of Pitchblende-ore from Beaverlodge Lake N.W.T., Haycock (1935). Note: Material analyzed consisted of a hand-picked shipment of vein material from surface trenches and consisted of intimately associated pitchblende and hematite in a siliceous gangue. For description of occurrence see page 113f.

vein uraninite or pitchblende, which characteristically contains practically no thorium or rare earths.

Spence and Carnochan believe the uranium-bearing pegmatite, like many other pegmatites in the region, is genetically related to intrusives of syenite or granite.

British Columbia

Uranium-bearing veins at the Victoria property near Hazelton, British Columbia, are described by Stevenson (1949). The veins occur near the contact of a large granodiorite mass, strike normal to the contact and extend from granodiorite into a hornfels contact zone. According to Stevenson, the granodiorite is of early Cretaceous age.

The No. 1 vein which will be described in detail in the following paragraphs, consists of a hornblende-filled fracture that ranges in width from a few inches to 2 feet. At one locality, the vein becomes a sheeted zone up to 4 feet wide that consists of parallel stringers of hornblende sandwiched between bands of altered wall-rock.

The vein tends to follow an andesite dyke 18 inches to 2 feet wide. In general the vein occurs along the footwall contact of the dyke, but in some places is entirely within the dyke and at other places as much as 5 feet in the footwall rocks.

The vein material consists of cobalt-nickel sulpharsenides, uraninite, and gold in a gangue that is predominantly

hornblende. The gangue also includes "pegmatitic" material in streaks and lenses (commonly a few inches wide and up to several feet long). The "pegmatitic" vein material consists principally of quartz, orthoclase and plagioclase. Both the "pegmatitic" and surrounding hornblende vein material contain small amounts of other minerals including apatite, titanite, allanite and scapolite.

The cobalt-nickel sulpharsenides occur finely disseminated in the hornblende and "pegmatitic" vein material and as short discontinuous streaks of solid sulpharsenide one inch to two inches wide. The gold is apparently closely associated with the sulpharsenides.

Molybdenite occurs as films and nodules up to 2 inches in diameter.

The uraninite occurs as small black crystals, a few of which are as much as an inch across. The crystals occur either individually or as streaks of crystals up to an inch long. Uraninite generally occurs with films or nodules of molybdenite near lenses of "pegmatitic" quartz and feldspar.

Short sections of the wall-rocks and, in places, feldspar within the vein, have been hydrothermally altered. The alteration products consist largely of carbonate and sericite; quartz was not affected. At the No. 1 vein (Victoria Property) there is no sign of red-alteration but feldspar in granodiorite walls of another uraninite vein

on the same property is altered from white to pink in the vicinity of the vein. No information is available on the cause of the pink color.

At the Little Gem property in the Bridge River district, some 300 miles south of Hazelton, uraninite occurs in discontinuous veins or lenses in sheared and sericitized granodiorite (Stevenson, 1948). The vein material consists of an intergrowth of the following minerals, listed in approximate decreasing order of abundance; iron-cobaltsulpharsenides, allanite, apatite, orthoclase, quartz, chlorite, sericite, calcite, molybdenite, and uraninite. The vein material contains appreciable amounts of gold.

Wide carbonate zones occur near the main showings, but these are barren and appear to be later than cobalt-gold-uranium veins.

In discussing the geological relationships of known uraninite-bearing veins in British Columbia, Stevenson (1951) concludes that veins in all districts discussed are genetically related to granodiorites and granites of the Coast Range Batholith. However, the author believes that information available does not warrant such a sweeping conclusion. It is well known for instance that the so-called Coast Range Batholith is a complex of successive eruptions, varying in composition from granite to gabbro (or even more mafic phases) and ranging in age from as early as post-Jurassic (or possibly earlier) to as late as early Tertiary. Furthermore, throughout all this

period of time, the whole cordilleran region of British Columbia was the scene of intermittent volcanism. Although the writer assumes that the uraninite-bearing veins had a magmatic source, little geological evidence is available to indicate where the period of vein formation fits into the overall sequence of igneous activity in any one district. In most districts referred to by Stevenson (1951) all that can be said with certainty is that the veins are younger than intrusions of granodiorite or granite. At the Victoria property in the Hazelton district, the No. 1 vein has followed, how closely is not known, the intrusion of an andesite dyke. The dyke is younger than a granodiorite intrusion in the district. With reference to deposits on the Victoria property, therefore, it would seem entirely possible that the uranium mineralization represents a hydrothermal afterphase of the intrusion of the andesite dyke.

Gilpin County, Colorado

The geology of Gilpin county and parts of adjacent counties (Central City Quadrangle) is described by Bastin (1917). The mineralized section of the Central City Quadrangle forms part of a large mineralized belt, known for its wealth during early mining in the western United States. The belt was primarily a gold and silver mining region, but deposits of uranium, tungsten, copper and iron also attracted the attention of early prospectors and mining men. Pitchblende was reported

from about 8 mines in Gilpin County, but at the time of Bastin's examination mining activity had been suspended at most of the mines and unfortunately no detailed geological relationships of the pitchblende bearing veins is available. The mines in which the pitchblende occurred were worked primarily for gold and silver. According to Bastin, two types of ores carrying gold and silver ore are present in the region, an early pyrite ore and a later galena-sphalerite ore. Some of the veins contained gold tellurides.

The rocks of Gilpin and adjacent countries in Colorado consist of a Precambrian complex of schists, gneisses and granite which has been intruded in late Cretaceous or early Tertiary time by a series of intrusives of various compositions. The earliest and most extensive of these are stocks of monzonite and monzonite porphyry. These were followed by dykes of porphyritic monzonite, bostonite, andesite, diorite, and basalt. The detailed age relationship between the veins and intrusive rocks is not known although a number of veins cut stocks of monzonite porphyry.

Bastin has studied a number of polished ore specimens from Gilpin County. However, specimens containing pitchblende were not collected from vein material in place but were obtained from museum collections. In these, pitchblende is intimately associated with chalcopyrite and pyrite and Bastin believes all three minerals are approximately of the same age. The pitchblende specimens studied did not contain gold so that the

relative age of gold and pitchblende is not known. In one or two specimens pitchblende was brecciated and traversed by veinlets of pyrite, sphalerite and galena.

Although Bastin believes that all metallic mineral deposits in the Silver City Quadrangle are genetically related to monzonite stocks, the geological evidence is far from conclusive. In arriving at this belief, he assumes for instance that younger dyke rocks including bostonite, andesite, diorite and basalt are all products of differentiation of "monzonite" magma. Most petrologists today, however, probably would not consider this assumption valid. Furthermore, in view of the unknown age relationships between metalliferous veins and dykes (and this applies in particular to the pitchblende deposits), the author believes it would be more logical simply to state that the mineral deposits are probably related to igneous activity of late Cretaceous or early Tertiary time. Such a statement specifically avoids the generalization that pitchblende is genetically related to any particular set of intrusives in the region.

Coeur d'Alene, Idaho

A description of the uraninite deposits of the Coeur d'alene district is given by Thurlow and Wright (1950). The general geological relationships of the district are given by Ransome and Calkins (1908).

The district is underlain by quartzites, argillites and impure limestones of the Belt series, believed to be of Precambrian age. These rocks have been intensely folded and faulted and intruded by monzonitic stocks. Diabase and lamprophyre dykes cut the sedimentary series.

The ore deposits in the Silver Belt of the Coeur d'Alene occur in broad shear zones which cut the folded rocks of the Belt series. In the lead-silver deposits the principal ore mineral is galena. Accessory metallic minerals include tetrahedrite, pyrite, arsenopyrite, chalcopyrite, stibnite, sphalerite, specularite and gersdorffite (sulpharsenide of nickel and cobalt). Siderite is the most common vein mineral. Ankerite and quartz are also common and barite occurs in places with other gangue minerals.

Throughout the Silver Belt, the principal wall-rock alteration is development of sericite. Altered rocks commonly have a bleached appearance.

In the Sunshine mine the main vein (silver-lead) consists of a mineralized shear or fault zone typical of veins in the Coeur d'Alene. In some of the lower workings of the mine, uraninite veins occur close to and roughly parallel with the main vein. According to Robinson¹, uraninite-bearing veins are cut by siderite veins containing tetrahedrite.

The walls of uraninite-bearing veins are stained red. The red-alteration is characteristic of uraninite-bearing veins only; it is not associated with the main Sunshine vein. The

¹Robinson, R. F. (1950) Uraninite in the Coeur d'Alene district, Idaho, Econ. Geol. Vol. 45, p. 818.

red-alteration is believed to originate in finely disseminated hematite.

Except for uraninite the mineralogy of uranium-bearing veins is similar to that of the main Sunshine vein. The gangue is also similar and consists of siderite cut by minute veinlets of quartz. The uraninite replaces finely crushed quartz and exhibits colloform structure.

According to Thurlow and Wright (1950) the paragenesis of sulphides in uraninite-bearing veins is: pyrite, arsenopyrite, tetrahedrite and finally chalcopyrite. This sequence is the same as that in the main Sunshine vein. The position of uraninite in this sequence is not clear. Thurlow and Wright believe that uraninite came in after tetrahedrite, but exactly the opposite relationship can be deduced from underground observations previously referred to. It is possible that more than one generation of tetrahedrite is present.

It is not clear whether the uraninite represents a separate phase of the main silver-lead mineralization or whether the uraninite was introduced during a separate metallogenic epoch. Anderson (1951) for instance, believes that in Idaho at least three metallogenic epochs are represented in Tertiary time, each following a separate period of igneous activity manifested by the intrusion of stocks or intrusion of dykes and associated volcanism.

As for the genesis of the lead-silver veins, it is well known that the veins are cut by lamprophyre dykes. Although the origin of the dykes is a moot question, most observers believe that they were intruded soon after the lead-silver mineralization and that both dykes and mineral deposits are genetically related to the monzonite stocks. Furthermore, as Lindgren has pointed out, contact metamorphic deposits containing galena, sphalerite, pyrite, chalcopyrite and magnetite in a gangue of biotite, garnet and diopside occur in contact with monzonite in the Coeur d'Alene district. Lindgren was of the opinion that these contact metamorphic deposits served to connect with lead-silver deposits of intermediate conditions.

Marysvale, Utah

The uranium deposits near Marysvale, Utah, are described by Gruner, Fetzner and Rapaport (1951).

As shown by Callaghan (1939), the region in which the deposits occur is largely underlain by volcanic rocks of three ages, an earlier Tertiary group of latitic breccias, tuffs and flows; second, a later Tertiary group of rhyolites, quartz latites, latites, and tuffs; and third, thin basalt flows of late Pliocene or early Pleistocene age.

The first volcanic rocks were laid down on an eroded sequence of late Paleozoic and early Mesozoic strata. The region was then intruded by monzonite stocks which extended

up into the first volcanic series. After a period of erosion which exposed the monzonite intrusives, the second volcanic series was laid down. Only scattered remnants of the third volcanic sequence remain, and none are exposed in the immediate vicinity of known uranium deposits.

The uranium deposits occur in veins in single or sheeted minor fault zones. The gangue minerals consist of chalcedonic calcite. Some of the veins contain brecciated fragments of wall-rock. Near the surface only secondary weathering products of the metallic minerals occur in the mineralized zones. These include secondary uranium and molybdenum minerals and limonite. Pyrite, pitchblende and jordisite (molybdenum sulphide) occur at greater depths. No information has been published on the paragenesis of the primary minerals.

Most of the known veins occur in fracture zones in exposed intrusives of quartz monzonite, but some extend up into the younger volcanic series (second volcanic series of Callaghan). On the basis of this structural relationship, Gruner, Fetzner and Rapaport place the mineralization as Late Tertiary.

The rocks exposed near the veins have been affected by both hydrothermal alteration and weathering. Feldspars in the rocks are completely altered to sericite and kaolin minerals; no mention has been made of red-alteration near uranium bearing veins.

The pitchblende is believed to be of hydrothermal origin, though the source is not known. The structural relationships of the veins and host rocks indicate that the uranium mineralization probably is not genetically related to the monzonite intrusions but rather that the mineralization belongs to a hydrothermal after-phase of later volcanic activity.

The Erzgebirge of Germany and Czechoslovakia

The so-called Erzgebirge of Germany and Czechoslovakia has recently assumed strategic importance for its production of uranium, but in the past this metalliferous belt had achieved worldwide recognition not only for radium and uranium production, but for a wealth of other minerals including tin, lead, iron, manganese, cobalt and silver. Most of the recorded radium and uranium production has come from the Joachimsthal district of Bohemia, but small amounts have also been produced from time to time at Schneeberg, Annaberg, and one or two other points in adjoining Saxony.

The rocks exposed in the Erzgebirge are mainly Precambrian schists and gneisses which have been intruded by granitic masses believed to be of late Carboniferous age. Stocks and larger bodies of granite are surrounded by metamorphic aureoles. All of these rocks are cut by dykes of quartz-porphyry and lamprophyre, both of which are commonly assumed to be related to the granitic intrusions. The youngest

intrusives are dykes of nepheline-basalt, leucite-basalt and phonolite. A few of the basaltic intrusives are plug-like in form. The basaltic intrusives clearly cut dykes of quartz-porphyry and lamprophyre. Intrusive basalts are correlated with scattered outcrops of Tertiary basalt and phonolite flows.

Throughout the Erzgebirge, there is a uniform age sequence as follows:

- (a) tin ores (oldest)
- (b) pyritic - lead ores
- (c) cobalt - silver ores
- (d) iron - manganese ores

In general, the tin veins occur mainly in and close to the granites. The pyrite-lead veins and cobalt-silver veins occur mainly in the schists and gneisses, but many of the iron-manganese veins occur in granite or along the contact of granite and schists. With the exception of the tin veins, it cannot be said that any zoning relationship holds around exposures of intrusive granite; it is apparent, however, that several types of mineralization have been successively superimposed upon the same districts.

The pyritic-lead veins show transitions to the tin veins and have been regarded by most observers as closely related to them in age and origin. From age relationships as determined by vein intersections, the cobalt-silver veins and the iron-manganese veins, which in places seem to grade into one another, are clearly younger than the tin and pyritic-lead veins.

The iron-manganese veins occur in stockworks and breccia zones up to 100 feet wide and consist mainly of rock fragments, quartz, hematite, and minor amounts of pyrolusite and psilomelane. The walls of the veins are strongly impregnated with red hematite. Some iron-manganese veins contain barite and carbonates with minor amounts of native bismuth, cobalt and silver ores, and more rarely, pitchblende.

The cobalt-silver veins, characteristically contain cobalt-nickel arsenides, native silver and pitchblende. Other metallic minerals include bismuthinite, native bismuth, argentite, ruby silver, chalcopyrite, galena, specularite and psilomelane. At Joachimsthal the gangue consists mainly of quartz (both chert-like and coarsely crystalline), calcite, dolomite and fluorite. At Annaberg barite is also found with the first-named minerals.

At Schneeberg the cobalt-nickel-bismuth ores are associated with quartz and chert; the silver ores (in the same veins) are associated with calcite. Within the veins, small amounts of chalcopyrite and galena accompany erratically distributed lenses and stringers of pitchblende, but elsewhere chalcopyrite and galena are rare.

At Annaberg, the cobalt-silver veins occur in gneiss intruded by dykes of granite and lamprophyre. The veins intersect the gneiss, granite dykes, and lamprophyre dykes, but are in turn cut by dykes of basalt. According to H. Müller (1894) the general paragenesis of the veins is as

follows:

- I. Barite, fluorite and quartz (oldest)
- II. Dolomite and cobalt-nickel-bismuth ores
- III. Calcite and pitchblende
- IV. Silver ores and native arsenic

An important feature at Annaberg is the presence of so-called "schwebenden". These are flat lying to gently dipping crush zones up to two meters thick which transect the gneiss and are colored blackish by fine carbonaceous material and often contain small amounts of disseminated pyrite and more rarely chalcopyrite. At the intersection of steeply dipping veins and "schwebenden", especially rich ores were found and according to H. Müller (1894) at least half of the production of silver and cobalt came from such intersections.

At Joachimsthal, all of the early mining was carried out in an area 5 kilometers long (east-west) and two kilometers wide (north-south). In this area the rocks are predominantly mica schist with minor intercalated layers of calcareous mica schist, crystalline limestone and hornblende schist. Dykes of porphyry, lamprophyre and basalt are also present. Within this same area too is a large dyke-like body of so-called "putzenwacke" which transects the schists and contains inclusions of porphyry, schists, and granite in a basalt matrix. Step and Becke (1904) believe that the putzenwacke represents the earliest stage of volcanism because

it is cut by basalt dykes and at one locality a dyke of phonolite was found within the putzenwacke. From its description, the putzenwacke appears to be an explosion breccia, mainly because silicified tree trunks have been encountered in it during mining operations; the deepest one found was at a depth of some 900 feet below the present surface.

At Joachimsthal, the cobalt-silver veins form two separate systems, one striking roughly north-south (Mitternachtgänge) and the other striking roughly east-west (Morgengänge). Krusch (1920) believes that the Morgengänge are older than the Mitternachtgänge.

In the "Mitternachtgänge" carbonates form the greater portion of the gangue; in the Morgengänge quartz occurs in addition. Quartz is the earliest gangue mineral. In general both classes of veins are narrow; most veins are a few inches to two or three feet wide. Stringer systems are common and many of the veins contain brecciated inclusions of wall-rocks. The veins are commonly banded and in those containing quartz comb structure is common. The metallic minerals are erratically distributed within the veins and the early records show that most of the pitchblende came from the Mitternachtgänge.

At Joachimsthal, Step and Becke (1904) found that the oldest minerals deposited were cobalt-nickel arsenides, and the youngest mineral deposited was native silver. Pitchblende was found to be of intermediate age. The overall paragenesis is also confirmed by Zuckert (1926).

Judging from the available literature, very little work has been done on wall-rock alteration in the Erzgebirge and, with the exception of the iron-manganese veins, no mention is made of red hematite alteration so conspicuous in the vicinity of Canadian pitchblende deposits. However, it is interesting that calcite and dolomite within the veins become red to reddish-brown near lenses and stringers of pitchblende.

Opinions vary as to the genesis of the pitchblende-bearing veins; some authors believe the deposits were genetically related to the late Carboniferous granites, others are of the opinion that the veins closely followed Tertiary volcanism. It may be stated at the outset that an age determination of pitchblende from Joachimsthal by the lead-uranium ratio indicates an age of 220 million years and Holmes (1937) uses this determination in dating the geological time scale. Holmes assumes the age determination to be equivalent to late Carboniferous time. Partial confirmation of the age determination used by Holmes was obtained by Nier (1939). Nier obtained a value of 227 million years using the ratio $Ra\ G/U^{238}$ and 140 million years from the ratio AcD/RaG for Joachimsthal pitchblende. Although these age measurements, even allowing for considerable error, seem to preclude the possibility of a Tertiary age for the pitchblende mineralization, the field evidence has not yet confirmed this.

With reference to the veins at Joachimsthal, Von Cotta (1870) states: "The silver lodes have two lines of strike,

nearly at right angles to each other, and are distinguished as morgengänge and mitternachtgänge. The morgengänge of which about 17 are known around Joachimsthal all strike nearly parallel to the mica schist (NNW). Twenty-one mitternachtgänge are known. The veins frequently do not come to surface, but wedge out toward it, while they increase in breadth with depth. The morgen lodes intersect the mitternacht lodes, but Maier states that the reverse also takes place. Both classes always intersect the mica schist with all its subordinate strata, the quartz porphyry, and in places even the dykes of basalt and putzenwacke. Nevertheless, these dykes appear to have intersected lodes, or have penetrated their fissures; from which it may be deduced that the silver veins were almost contemporaneous with the basalt in that their fissures in part follow the basalt dykes, in part are intersected by the basalt."

Posepheny (1895) who also studied the deposits at a later date was of the same opinion for he states: "At Joachimsthal, in Bohemia, we can recognize pre-and post-basaltic ore deposition. We find here two vein systems at right angles; one striking N-S and accompanied with porphyry dykes; the other striking E-W and accompanied with dykes of basalt and (according to recent views) phonolite. The E-W fissures are occupied partly by basaltic dykes, partly by ore veins which were deposited some before and some after the basalt, a satisfactory proof that the fissures were formed at the period of basaltic eruption".

About the turn of the century, the problem of the age of the cobalt-silver veins was much in dispute, for Stelzner (1906) writes (translated by the author):

"According to Müller, the older ores (tin and pyrite-galena) are definitely related to Lake Carboniferous granite, and Dalmer believes the younger ores (silver-cobalt and iron-manganese) are also about the same age. On the other hand, Laube and Babanek believe that the younger ores have formed during middle Tertiary."

To support his thesis that the "younger" ores were of Late Carboniferous age, Dalmer uses as evidence the presence of iron-manganese pebbles in a Cretaceous conglomerate which he correlates with the iron-manganese veins of the Erzgebirge. However, Laube and Babanek found that at several localities in the Joachimsthal district narrow fractures in basalt dykes and putzenwacke contained small amounts of ruby silver, native silver, and at one locality, pitchblende. Laube and Babanek were, therefore, convinced that the silver-cobalt mineralization was of Tertiary age. However, Step and Becke (1904), in reviewing this same problem, state that all occurrences of silver minerals in diabase and putzenwacke are of a minor nature. They believe that silver occurrences in diabase and putzenwacke are best explained by secondary solution and re-disposition at the time of Tertiary volcanism. Step and Becke also point out that wherever basalt dykes were found in the Joachimsthal mines, the dykes cut the veins. This, of course,

is not in accord with earlier observations referred to by Von Cotta and Posepheny. In any case, Step and Becke apparently convinced most writers that the silver-cobalt ores at Joachimsthal were genetically related to the Carboniferous granites and this has been accepted as fact in later works, including modern economic geology texts. It should be kept in mind, however, that even if the ores are pre-Tertiary, they are not necessarily genetically related to the Carboniferous granites, but rather might be derived from an unknown source at any time between the intrusion of the granite in late Carboniferous time and the period of Tertiary volcanism.

Cornwall, England

An excellent review of the geology of Cornwall is given by MacAlister (1908). The rocks consist mainly of slates and grits of Paleozoic age which have been intruded by five stocks of granite scattered along the Cornwall peninsula. The granites are late- or post-Carboniferous in age. Surrounding the stocks are contact metamorphic aureoles; here the slates are metamorphosed to hornfels, locally known as "killas". Intruding all of the rocks and closely associated with the granites are quartz-porphry dykes called "elvans".

Several types of ores have been mined in Cornwall, these are listed as follows:

- (1) tin ores
- (2) copper ores
- (3) silver-lead ores
- (4) iron ores

The tin and copper ores occur in more or less east-west fracture zones, whereas the silver-lead ores and iron ores are distinctly later and occur in fracture zones striking roughly north-south.

The tin veins occur in and near granite masses and the copper ores appear to be closely related to those of tin. At several mines copper ores in upper levels gradually changed over to tin ores in the lower levels.

Unlike the tin and copper ores, the silver-lead ores and iron ores are not zonally arranged around the granite stocks. Silver-lead ores and iron ores occur in the slates, in the contact aureoles around granite stocks and even within the granite stocks.

With regard to the iron lodes MacAlister (1908) states: "They are generally of great width ----- are brecciated and composed largely of hematite and limonite with a little manganese ore."

The silver-lead ores contain galena, rich-silver minerals, pyrite, arsenopyrite, copper-minerals, more rarely cobalt, nickel, bismuth and uranium minerals. The gangue is composed of quartz, siderite, calcite and fluorspar.

As shown in a map by Dines (1930), occurrences of pitchblende have been recorded in some 15 different localities along the Cornwall peninsula; actual production is recorded from at least 5 of these. One of the richest deposits of pitchblende known in Cornwall (South Terras deposit) is described by Robertson and Dines (1929).

The South Terras deposit occurs a short distance south of the Austell granite stock; here the slates are traversed by numerous mineral lodes. Most of the lodes trend approximately east-west (parallel to the margin of the granite), but a number strike roughly north-south. The lodes with east-west trend are mainly tin and copper bearing; those trending north-south carry cobalt, nickel, lead, uranium and iron minerals, more rarely arsenopyrite and chalcopyrite.

With reference to the relative age of the lodes Robertson and Dines (1929) state: "These lodes" (containing pitchblende) "may be regarded as of later date than the tin and copper lodes, an assumption that is borne out by the fact that in many cases, the north-south lodes are known to be mineralized cross-courses dislocating the east-west lodes. These later lodes fall naturally into two classes; namely those carrying iron and those carrying cobalt, nickel and uranium, and it is probable that the two classes are not contemporaneous".

With further reference to the pitchblende deposit at South Terras, Robertson and Dines (1929) state: "Quartz

generally occupies the full width of the lode and shows a comb structure indicating successive stages of deposition. In places there are inclusions of killas, often silicified, occurring either as a fault breccia or as shear lenticles. On the foot-wall in many places, occurs one or two inches of a soft greenish clayey material.----- apart from the ore-shoot, metallic minerals are scanty. They occur usually as small scattered crystals either in the quartz or lining vugs. There is no indication of the pitchblende having been confined to any particular portion of the width of the lode, though it is said to have occurred as stringers near the walls. The metallic minerals recorded are as follows: pitchblende, torbernite, autunite and zippeite, together with pyrite, chalcopyrite, arsenopyrite, galena and traces of nickel-cobalt and chromium minerals."

The paragenesis of veins containing pitchblende has apparently never been worked out. Furthermore, except for the typical greisenization which accompanies the tin veins, no reference in available literature was found pertaining to wall-rock alteration of the Cornwall veins. It may perhaps be deduced that red hematite alteration is absent from pitchblende-bearing veins in Cornwall, for such alteration where it occurs is normally quite conspicuous.

The genesis of the pitchblende and related minerals is not clear. It has long been conceded, and with good reason, that the tin and copper lodes are genetically related to the

granite. The granite is post-Carboniferous and pre-Triassic in age. On the other hand, the silver-lead veins and iron lodes are distinctly later than the tin and copper veins, but how much later is a matter of some dispute. The idea which seems most popular at present is that all of the metallic mineral deposits in Cornwall are genetically related to the granitic intrusions. However, MacAlister (1908) who has studied the regional geology, believes the younger mineralization took place in Tertiary Time. MacAlister states: "The ores (silver-lead) occur in a series of approximately north and south cross-courses or faults of Tertiary age crossing the general strike of the rocks at right angles and thus belonging to a quite different set of movements to that to which the tin and copper lodes owe their origin."

From the foregoing geological evidence, the author concludes that:

- (1) The pitchblende bearing veins are later than tin-copper veins.
- (2) The pitchblende probably is not genetically related to any exposed intrusive rocks.

Katanga, Belgian Congo

The uranium deposits at Shinkelobwe, Katanga, are described by J. Thoreau and R. Trieu de Terdonck (1933). The deposits are located near the northern extremity of the Copper

belt of Northern Rhodesia and the Belgian Congo. As the uranium deposits occur in the same series of sedimentary rocks as the copper deposits ("Serie des Mines"), an outline of the overall geological relationships of the Copper belt will be presented here.

The "Serie des Mines" (Schisto-Dolomitique of Katanga, see Robert, 1949) was laid down on an eroded basement complex of ancient schists, granites and gneisses. Conformably overlying the "Serie des Mines", but separated according to Robert by a bed of tillite, is the Kundulungu series, of Paleozoic age. Following the deposition of the Kundulungu beds, the rocks were folded into a belt of pitching anticlines and synclines whose axes trend northwest. Erosion has cut away the anticlines and only synclinal remnants of the "Serie des Mines" and overlying Kundulungu beds remain.

In the copper deposits, the ore minerals are linnaeite, chalcopyrite, bornite and chalcocite; these are in general finely disseminated in slightly metamorphosed sedimentary rocks. At any one locality, the ore is generally confined to a certain section of the "Serie des Mines". In Northern Rhodesia, the copper deposits occur in the lower part of the "Serie des Mines"; in the Belgian Congo to the north, they occur in the upper part of the series. The mineralized beds are commonly shales or sandy shales but at places along the Copper belt, the mineralized section consists of such diverse rock types as arkose, conglomerate or dolomitic shale.

At Shinkolobwe, the uraninite deposits occur in highly contorted and much faulted rocks belonging to the "Serie des Mines"; these rocks are nearly surrounded by the younger Kundelungu series. At this locality, the "Series des Mines" consist of thick bedded dolomitic limestone, dolomitic schist with carbonaceous or graphitic horizons and siliceous dolomitic limestone with interbedded chert. No igneous rocks are known to outcrop within 25 miles of the Shinkelobwe deposits.

The uraninite and secondary uranium minerals occur partly in massive veins without apparent gangue and partly disseminated in the rocks.

The minerals in the deposits include, besides uraninite and secondary weathering products, pyrite, linnaeite, chalcopyrite, bornite, chalcocite, covellite, molybdenite, gold, monazite and wulfenite.

The mineralization according to Thoreau and Trieu de Terdonck (1933) (who believed in a hydrothermal origin) commenced with introduction of vein quartz and silicification of adjacent rocks. Monazite, tourmaline, apatite, chlorite and talc developed at this stage. The second stage is that of the uraninite which partially replaced quartz and impregnated the carbonate wall-rocks. Following the uraninite, sulphides were introduced in the following order: pyrite, linnaeite and finally chalcopyrite. The position of molybdenite in this group is not known, and the genesis of

bornite is uncertain. They have formed by veining and replacing earlier minerals. The final stage of the primary mineralization was the formation of abundant carbonate, which replaced all the earlier minerals, but somewhat overlapped the sulphide mineralization. The deposit contains small amounts of gold. Chalcocite, covellite, and perhaps bornite are believed to be supergene. It is of interest that the uraninite deposits, like copper deposits of the main copper belt, contain the cobalt sulphide linnaeite. Cobalt-nickel arsenides and native silver which characterize many of the pitchblende deposits in other parts of the world are absent. There is, furthermore, no red-alteration of wall-rocks..

The origin of the copper deposits has long been a controversial issue. At the time of the early exploration and development, geologists working on the deposits believed that some of the granites were younger than the Roan series ("Serie des Mines"). Believing the deposits to be of hydrothermal origin, they considered them to be derived from the granite. This was also the conclusion reached by Bateman (1930). Schneiderhöhn (1932) on the other hand was unconvinced that any of the granites exposed were younger than the lower members of the Serie des Mines.

Schneiderhöhn (1932) was of the opinion that the copper minerals were of sedimentary origin (syngenetic) and that all rocks in the Copper belt were subjected to post-Kundelungu deformation. The deformation was accompanied by moderately low

grade (biotite-grade) metamorphic changes; biotite developed in shale-type sedimentary rocks and metallic constituents recrystallized. The deformation, which consisted mainly of folding, also resulted in the opening of minor fractures and, in these, rock-forming minerals and sulphides were deposited by processes analogous to lateral secretion.

The detailed geological studies of Garlick and Brummer (1951) confirm the observation of Schneiderhöhn that no granites in the Copper belt are younger than the Lower Roan Series. This, of course, does not prove a sedimentary origin for the copper deposits, even though a sedimentary origin seems most likely.

From the point of view of a hypogene origin, it is of interest that numerous sill-like intrusions of basic rocks with gabbroid to diabasic texture occur within the Roan series. However, except for the fact that the basic intrusives are younger than the Roan series, there is little if any geological evidence to suggest that the copper deposits are a hydrothermal after-phase of the basic intrusions.

The genesis of the uraninite deposits, of course, may or may not be the same as the main copper deposits, although the overall relationships certainly suggest a common origin. In view of conflicting ideas on the origin of the copper deposits, the author believes that the genesis of the uraninite deposits should remain an open question pending more information on the whole problem.

SUMMARY AND CONCLUSIONS

A study of the literature shows that deposits containing pitchblende are in general complex. In many of the deposits the characteristic association is pitchblende, arsenides and sulpharsenides of cobalt and nickel and native silver. An important feature to recognize is that in deposits of this type these minerals form three distinct phases: a pitchblende phase, a cobalt-nickel arsenide phase and a native silver phase. In some districts as at Great Bear Lake and Joachimsthal all three phases occur together. At Cobalt and Silver Islet, Ontario, the dominant phases appear to be cobalt-nickel arsenides and native silver, although some anomalous radioactivity has been reported from Silver Islet and the recent pitchblende discovery at Cobalt, Ontario, shows that here too the three phases are locally present. At Goldfields, Saskatchewan, the dominant phase is pitchblende; a few veins, however, with different structural features and confined to the southern part of the district contain massive cobalt-nickel arsenides with pitchblende; the native silver phase is, however, absent in both types of veins. At Hottah Lake N.W.T. and Theano Point, Ontario, only the pitchblende phase is present.

A characteristic feature of these deposits is that where more than one phase is present, the younger phases enter the vein structures only after renewed periods of fracturing.

Furthermore, where more than one phase is present, vertical zoning relationships are evident. For instance, at Great Bear Lake and Joachimsthal, rich silver ores occur in general only in the upper levels of the mines; at greater depths pitchblende forms the dominant ore minerals. At Cobalt, Ontario, mining of many veins was stopped when rich silver ores gave out, yet the veins continued downward with cobalt and nickel arsenides. The fact that in certain mining districts or parts of mining districts some phases are missing can probably be thus explained by erosion of upper zones or that, after deposition of an early phase, a renewed period of fracturing did not take place. In any case, the author believes there is a sound mineralogical basis for assuming that the uranium deposits of the Erzgebirge, Great Bear and Hotta Lakes N.W.T., Goldfields, Saskatchewan, Cobalt, Theano Point and Silver Islet, Ontario, all have a similar origin.

In the Cornwall district of England, the western Cordillera of North America and at Shinkelobwe, Belgian Congo, sufficient differences in associated minerals exist as to suggest the possibility that these deposits may have altogether distinct origins. It should be kept in mind, however, that a given mineral association may be the product of two types of mineralization superimposed upon a given district (or metallogenic province) during successive metallization epochs. Furthermore, the mineralogy of the deposit at Shinkelobwe is distinctly different than all other deposits reviewed and

there is good reason to assume that the genesis of pitchblende is closely tied up with that of copper deposits of the same region.

Pitchblende deposits associated with cobalt-nickel arsenides and native silver have many features in common. They were probably all deposited at relatively shallow depths as indicated by the irregular branching nature of the veins, brecciation, vugginess and comb structure. With respect to mineralogy, chalcopyrite and hematite invariably accompany the pitchblende phase; and bismuth, bismuthinite and argentite commonly accompany the native silver phase. The arsenide phase commonly includes both the white arsenides of cobalt, nickel, and iron and the copper coloured arsenide niccolite. Gold is rare in the deposits although it occurs in some pitchblende deposits at Goldfields, Saskatchewan.

The paragenesis appears to be somewhat variable although the sequence in deposits of the Canadian shield follow a consistent pattern. At Great Bear Lake, pitchblende is the oldest metallic mineral and native silver the youngest; the cobalt-nickel arsenide phase was deposited during an intermediate stage. At Goldfields, Saskatchewan, pitchblende is again the oldest mineral, followed in turn by cobalt-nickel arsenides. At Cobalt, Ontario, as at Great Bear Lake, cobalt-nickel arsenide deposition was followed by the native silver phase. In the Erzgebirge on the other hand, the paragenesis, although admitted to be very complex, is believed to be as

follows: cobalt-nickel arsenide phase, the oldest, followed by pitchblende and finally at a still younger stage, native silver.

In general, the deposits are characterized by carbonate gangue. The carbonates include calcite, dolomite, ankerite and siderite; calcite and dolomite are the most common. Quartz is almost invariably present. It occurs as fine-grained porcelainous quartz or as coarsely crystalline quartz exhibiting comb structure. Some of the deposits contain fluorite and a few contain barite.

Red-alteration of wall-rocks is a conspicuous feature of pitchblende deposits at Great Bear Lake N.W.T., Goldfields, Saskatchewan and Coer d'Alene, Idaho. In the Erzgebirge and Cornwall, England, no mention of red-alteration of wall-rocks is made in the literature though small amounts of hematite were deposited in the veins and in both metallogenic provinces the deposits are believed by most authors to be closely related to hematite deposits in breccia zones. It is thus evident that in both Cornwall, England, and the Erzgebirge of central, Europe hematite was hydrothermally introduced into fracture zones, but in general entered different structures than those carrying uranium.

While discussing red-alteration of wall-rocks, it is of interest that at Joachimsthal carbonate vein material becomes brownish-red near pitchblende. The cause of this alteration is not known, but a similar phenomenon occurs in pegmatites at Wilberforce, Ontario, where the calcite gangue

near uraninite crystals is altered deep red.

Although the deposits of British Columbia carry arsenides of cobalt and nickel besides uraninite, certain features of these deposits set them in a class by themselves. Most noteworthy is the hornblende and chlorite "gangue" which was deposited in the ore-bearing fractures during a period preceding the introduction of arsenides. This "gangue" appears particularly unusual, yet it has certain features in common with other deposits of uranium. At Goldfields, Saskatchewan, for instance, large amounts of chlorite have been introduced into breccia zones during a period preceding the deposition of pitchblende and even in the veins themselves small amounts of chlorite are common.

The presence of aplite veins or dykes in the same fracture zones as the mineralized veins is a noteworthy feature at Contact Lake N.W.T., Cobalt district, Ontario, and at Silver Islet, Ontario. These aplites contain quartz and alkali feldspar. It probably should be pointed out too that the structures at the British Columbia deposits also contain quartz and feldspar, although this is in addition to hornblende or chlorite.

There is certainly no common agreement on the origin of the aplites; Furnival believes the aplite at Contact Lake N.W.T., was derived from granite, at Silver Islet, Tanton believes the aplite is a differentiation product of diabase and at Cobalt, Ontario, Bastin is of the opinion that the aplite is of hydrothermal origin. Probably the hydrothermal

idea is the closest to being correct for it allows the possibility that the aplite is a hydrothermal derivative of a magma of unknown composition or that the constituents which make up quartz and feldspar were picked up by hydrothermal solutions during their ascent upwards through crystalline rocks.

From the geochemical point of view, pitchblende or uraninite vein deposits are distinctly different from uranium deposits in pegmatites. It is well known that in pegmatites, uranium is closely associated with thorium zirconium, niobium, tantalum, and the rare earths. Why is it then, that in vein deposits almost a clean separation of uranium from these elements takes place?

From the geochemical point of view the close association of carbon with uranium is also particularly noteworthy. It is recalled that this close association occurs throughout the complete cycle of uranium, from pegmatites, to hydrothermal veins, to sedimentary deposits. It is well known for instance that many sedimentary deposits such as phosphorites and bituminous shales contain uranium, presumably of syngenetic origin. Similarly, in the Morrison sandstone of the Colorado Plateau, plant remains commonly are partly replaced by the mineral carnotite which contains uranium and vanadium. In the Rand of South Africa, it is reported that the uranium in the gold-bearing reefs occurs as the uraniferous hydrocarbon thucholite. In the vein deposits at Shinkelobwe, Belgian

Congo, the uranium occurs in part, though not entirely, where the veins intersect carbonaceous dolomite. At Schneeberg, Germany, the most productive uranium veins occur where the veins intersect flat lying fault zones containing carbonaceous material. At Silver Islet, Ontario, a schistose "aplite" dyke containing abundant graphite occurs in the same fault structure as the veins. At Goldfields, Saskatchewan, the uraniferous hydrocarbon thucholite occurs in several of the veins and at one locality a wide breccia zone cemented almost wholly by carbonaceous material is anomalously radioactive. It should be pointed out that the mineral thucholite was first reported by Ellsworth from pegmatites in Ontario. It is of interest too that the carbon in the Ontario pegmatites and in at least some of the hydrothermal deposits, probably is not of organic origin. In the Goldfields area in particular the carbon, like the uranium, is probably of hydrothermal (hypogene) origin, for none of the sedimentary rocks (all are of Precambrian age) in the district contain recognizable amounts of carbonaceous material.

The genesis of pitchblende deposits, like the genesis of most hypogene deposits is of course highly speculative. As pointed out, little is known concerning the geochemistry of uranium under magmatic conditions. Furthermore, although most if not all pitchblende deposits are believed to be genetically derived from magmas, far more knowledge about the actual generation and behavior of magmas is necessary as a

preliminary step before the origin of hydrothermal vein deposits, as distinct from pegmatites, is well understood.

Although many economic geologists today hold that all pitchblende and uraninite deposits are derived from granite magma, such blanket statements do the science of geology no good. It is conceded that the genetic relationship between the pegmatitic uranium deposits and granite probably holds true; however, a critical review of the literature does not in any instance point to a clear-cut genetic relationship between vein deposits of pitchblende and granite. Furthermore, it cannot even be concluded that all pitchblende is derived from a magmatic source, and this applies in particular to the deposits of the Belgian Congo where a sedimentary (syngenetic) origin has to be recognized as possible.

In several districts, viz., Great Bear Lake, N.W.T., Theano Point, Cobalt, and Silver Islet, Ontario, the pitchblende followed, how closely is not known, intrusives of diabase. At Great Bear Lake still later intrusives of diabase cut the veins and at Theano Point, Ontario, basaltic extrusives occur which are younger than the diabase dykes with which uranium deposits are associated. At Goldfields, Saskatchewan, the youngest intrusive rocks are diabase and the pitchblende is younger than the diabase. However, the general consensus regarding the Goldfields deposits is that mineral deposition did not immediately follow the intrusion of the diabase dykes, but belongs to a later period of major faulting with which no exposed

intrusive rocks are associated. In all of these districts, all exposed granites can be effectively ruled out as possible sources of the pitchblende, for diabase or basalts are the youngest igneous rocks and the pitchblende deposits are younger than the diabase.

At all other places reviewed, the geological relationships are not clear-cut; but the case for a granitic source is weak. At both Cornwall, England, and the Erzgebirge of central Europe, although a granitic magma must be recognized as a possible source for the pitchblende, the deposits are later than exposed granitic rocks and there is certainly no obvious zonal arrangement around the granite bodies.

In deposits of the Western Cordillera of the United States and Canada, too little is known to state whether pitchblende or vein-deposited uraninite are associated with any particular igneous rock type. At Hazelton, B.C., mineral deposition in one vein followed the intrusion of an andesite dyke which in turn is younger than a large granodiorite mass; at Marysvale, Utah, the uranium minerals appear to have been introduced during an after-phase of volcanic activity in which rhyolites etc. were extruded. At other places in the Western Cordillera, the geological relationships are still less certain; about all that can be said is that the deposits are probably related to Mesozoic or Tertiary igneous activity.

Very little information is available concerning pitch-blende deposits in the Belgian Congo. At the single locality described (Shinkelobwe), it is particularly difficult

to show any relationship with igneous activity, as no intrusive rocks are reported within some 25 miles of the deposits.

In conclusion, the author feels that the problem of the genesis of pitchblende should be kept open until much more information is available. There is certainly little geological evidence for the commonly held belief that all pitchblende deposits are genetically related to granite. On the other hand, the author feels that as a working hypothesis in the search for new deposits of pitchblende, much more attention should be given to the possibility that pitchblende deposits (especially those containing cobalt-nickel arsenides and native silver) are genetically derived from basaltic (diabasic) magma from great depth.

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APPENDICES

SPECTROGRAPHIC TECHNIQUE

1. Determination of Na

0.1000 gram rock powder
 0.1000 gram pulverized spodumene
 0.4000 gram pure carbon powder

Mix rock powder, spodumene and carbon in agate
 mortar for 6 minutes

Pure carbon electrodes, 3/16" size
 Double exposure

Hilger quartz-glass prism spectrograph

Optics - glass

Right end plate 10,000 Angstroms

Focus 4.1

Inclined screw - 7 divisions

1st. 4 steps, slit height 6 mm.

Slit width 6 divisions (0.03 mm).

Type 1L Plate (Kodak)

Amperage - 6 amps

Rack down 7 or 8

Load - emulsion side down

Develop - emulsion side up

Kodak D19 developer diluted 1:1 with H₂O

Temperature 18°C

Time 4½ minutes

Fix - Leave 10 minutes after plate clear

Wash - At least 20 minutes

2. Determination of K, Rb and Li

same procedure as for sodium except

- (1) arc pure rock powder
- (2) 1/8" pure carbon electrodes
- (3) single exposure
- (4) 3 amps

3. Determination of Ca, Mg, Fe, Al and Mn

0.1000 gm. rock powder
 0.1000 gm. SrCO₃
 0.4000 gm. pure carbon powder

Mix in agate mortar for 6 minutes

Pure carbon electrodes - 1/8" size

Grating spectrograph - Wadsworth mounting

Plate holder - right hand edge 2850 Angstroms

Plate holder focus 24.5

Kodak plate 103-0, load emulsion side down

Slit width 0.02 mm

Slit height 1.9 mm

Amperage - 6 amps

Arc pure iron electrodes 15 seconds at 3 amps

Develop, fix and wash same as for sodium.

4. Determination of Cu, Ni and Co (in diabase)

Arc pure rock powder

Pure carbon electrodes, 3/16" size, small bore

Hilger quartz-glass prism spectrograph

Optics - quartz

Right end 5000 angstroms

Focus 4.0

Slit width - 5 divisions

Inclined screw 11.0

7 steps, slit height 10½ mm.

Kodak plate, type 1L.

Amperage - 3 amps

Rack down 11 divisions

Develop, wash and fix same as for sodium.

STANDARDS

Determination of Na, K, Rb, and Li

Standard granite G-1
Mixture of 2 parts G-1 plus 1 part W-1
Mixture of 2 parts W-1 plus 1 part G-1
Standard diabase W-1

Microcline, U.S. Bureau of Standards No. BS 70
Albite, U. S. Bureau of Standards No. BS 99

Determination of Ca, Mg, Fe, Al and Mn

Standard granite G-1
Mixture of 2 parts G-1 plus 1 part W-1
Mixture of 2 parts W-1 plus 1 part G-1
Standard diabase W-1

Pyroxene, chemically analyzed, M.I.T. No. R1096

Dried clay, U. S. Bureau of Standards No. BS. 98

Determination of Cu, Ni and Co.

Standard diabase W-1

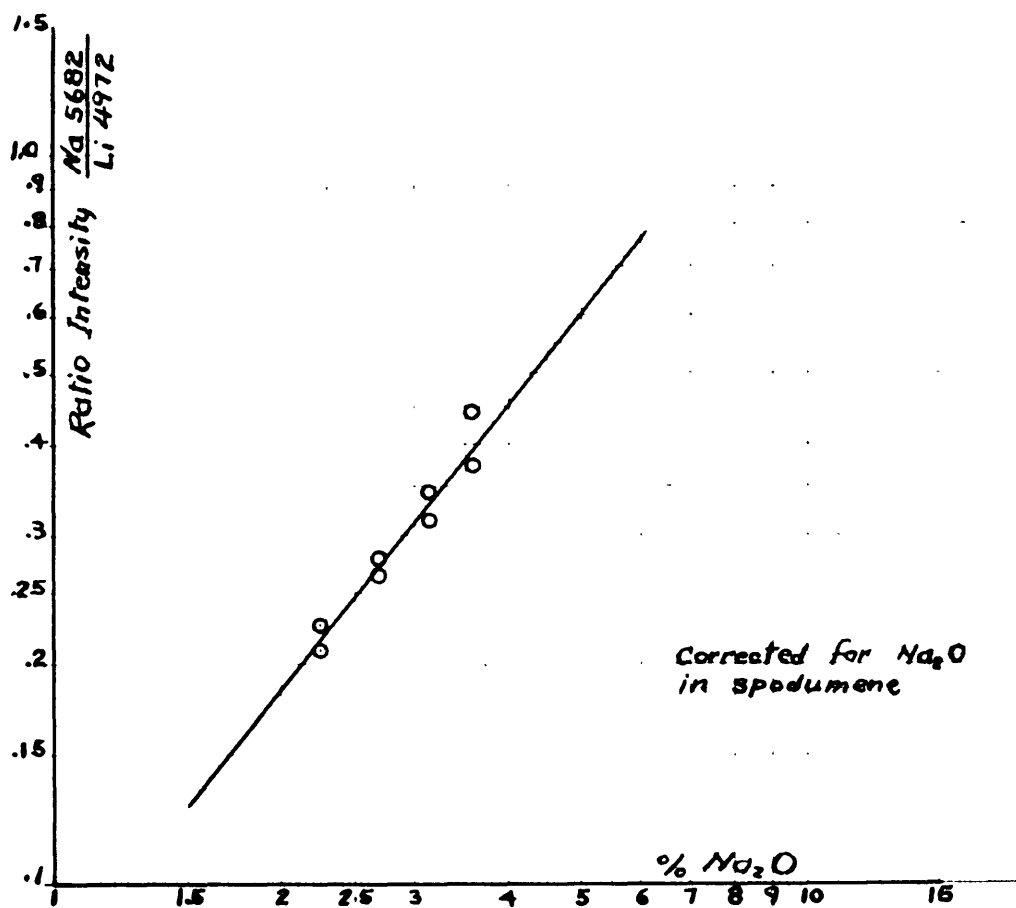


Plate XV. Typical working curve used in thesis.

Determined Chemically - University of
MinnesotaSiO₂

A8	53.14	<u>53.1</u>
A39	49.74	<u>49.8</u>
A44	73.51	<u>73.5</u>
A45	72.81	<u>72.8</u>
A53	45.16	
A54	57.69	
A55	77.81	<u>77.8</u>
A57	74.91*	<u>75.1</u>
A101	39.98	
D27	57.35	<u>57.3</u>
D83	68.48	<u>68.5</u>
D101	67.03	<u>67.0</u>
D113	52.70	<u>52.9</u>
E1	72.30	<u>72.2</u>
E102	73.33	<u>73.3</u>
E107	77.86	<u>78.0</u>
E164	72.25	<u>72.3</u>
E166	51.78	<u>51.7</u>
E171	71.81	
E172	73.68	
E179	45.26*	<u>45.2</u>
E200	61.55	
E203	42.88*	<u>42.8</u>
E211	76.45	
E216	80.85*	<u>80.8</u>

SiO₂ - Continued

E239	70.66	
E269	42.15	
E316	<u>67.4</u>	
E324	88.29*	<u>88.3</u>
E346	44.61	
E369	<u>64.8</u>	
E420	76.54*	<u>76.5</u>
E421	44.44*	<u>44.5</u>
G19	<u>66.4</u>	
G23	<u>47.6</u>	
GB1	<u>45.4</u>	
GB2	<u>54.1</u>	
GB3	<u>55.2</u>	
GB4	<u>51.5</u>	
MS -9-10	<u>49.9</u>	
M12-13	<u>53.7</u>	
M14-15	<u>49.4</u>	
M17	<u>52.6</u>	
R2	52.89	<u>52.9</u>
R130	66.64*	<u>66.4</u>
R164	<u>67.7</u>	
Th-1	<u>54.3</u>	
Th-2	<u>50.2</u>	
Th-3	<u>47.3</u>	
Th-4	<u>50.2</u>	

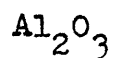
SiO₂ - Continued

Th-5	<u>49.3</u>	
U36	59.43	<u>59.5</u>
U37	74.04	<u>74.0</u>
U40	57.04	<u>57.0</u>
U50	89.14	
Z11	<u>51.3</u>	
Z12	<u>76.3</u>	
Z13	<u>67.7</u>	
Z14-a	<u>51.6</u>	
Z14-b	<u>55.1</u>	

* 3 evaporations, standard method

— so-called approximate chemical method

Note. All other analyses are single evaporations by standard methods +0.85 per cent correction to allow for silica lost by not carrying through additional evaporations.



Determined Spectrochemically - R. W. Edie, analyst

						<u>Average</u>
A8		14.3	13.6	13.5		13.8
A39	1.40	0.92				1.16
A44		13.7	15.0	14.8		14.5
A45		12.2	13.3	13.0		12.8
A53	17.5		16.0	16.7		16.7
A54	22.1	22.0				22.1
A55	11.7		11.0	11.3		11.3
A57		13.2	12.7	13.2		13.0
A101			23.5	21.5	19.3 20.4	21.1
D27	16.5		21.5	14.8		17.6
D83	18.0	21.2				19.6
D101	9.9		11.0	12.6		11.2
D113	17.2	17.5				17.3
E1	11.6	13.7				12.7
E102	13.0	13.3	13.0			13.1
E107	15.7	14.8	12.6	13.4		14.1
E164	16.0	19.0				17.5
E166		17.6	18.6	18.2		18.1
E171	15.1	15.0				15.1
E172	13.5	13.0				13.3
E179	13.7	13.8				13.8
E200			18.8	19.2		19.0
E203			24.2	21.2		22.7

Al₂O₃ - Continued

							<u>Average</u>
E211	12.7	12.4					12.6
E216	9.8	8.2					9.0
E239	12.0	14.1	13.5				13.2
E269	14.2	15.8	21.7	22.4	22.4	20.0	19.4
E316	14.8	14.5					14.7
E324	6.6	6.6					6.6
E346	16.0	16.3					16.2
E369	18.7	20.2					19.5
E420	13.3	14.0					13.7
E421	16.3	16.0					16.2
G19	13.1	12.9					13.0
G23	6.6	17.7	16.1	13.8			15.9
GB1	14.5	14.4					14.5
GB2			12.8	12.4			12.6
GB3	18.0	17.0	16.1	16.2			16.8
GB4	13.8	14.0					13.9
M8-9-10	13.3	13.0					13.2
M12-13	14.0	13.3					13.7
M14-15	13.9	14.6					14.3
M17	14.2	11.7					13.0
R2	14.1	16.3					15.2
R130	15.6	14.0					14.8
R164	12.0	14.2					13.1

Al₂O₃ - Continued

Th-1	13.6	12.2			12.9
Th-2	12.5	14.7			13.6
Th-3	12.2	14.5			13.3
Th-4	15.7	17.0			16.4
Th-5	14.1	13.5			13.8
U36	15.7		14.0	18.4	16.0
U37	11.8	13.6			12.7
U40	13.2	13.6			13.4
U50	6.6	6.8			6.7
Z11	14.2	15.6			14.9
Z12	8.0	7.3			7.7
Z13		18.6	20.4	18.8	19.3
Z14-a	11.8	10.5			11.2
Z14-b		13.0	13.7	17.3	14.7

Fe_2O_3

Determined by subtracting Ferrous Iron from Total Iron, analyzed spectrochemically - R. W. Edie, analyst

A8	3.33
A39	14.53
A44	0.86
A45	0.31
A53	6.55
A54	3.33
A55	0.59
A57	1.18
A101	6.55
D27	4.69
D83	2.74
D101	1.83
D113	4.59
E1	2.04
E102	1.44
E107	1.24
E164	1.70
E166	5.16
E171	2.89
E172	2.54
E179	4.10
E200	3.27
E203	5.50

Fe_2O_3 - Continued

E211	2.46	Th-2	1.97
E216	1.77	Th-3	12.49
E239	2.77	Th-4	7.07
E269	8.54	Th-5	5.99
E316	1.87	U36	3.64
E324	2.07	U37	3.71
E346	1.70	U40	1.24
E369	2.77	U50	2.09
E420	0.80	Z11	3.40
E421	1.90	Z12	1.83
G19	4.39	Z13	1.20
G23	3.31	Z14-a	3.16
GB1	5.70	Z14-b	1.96
GB2	2.03		
GB3	1.53		
GB4	4.66		
M8-9-10	9.46		
M12-13	8.11		
M14-15	9.01		
M17	2.90		
R2	1.38		
R130	1.99		
R164	0.71		
Th-1	6.00		

FeO

Determined chemically. - University of Minnesota

A8	4.81
A39	9.26
A44	0.60
A45	0.76
A53	8.25
A54	5.62
A55	2.07
A57	0.38
A101	11.47
D27	0.83
D83	3.58
D101	0.32
D113	4.68
E1	3.17
E102	2.58
E107	2.20
E164	3.40
E166	2.76
E171	3.80
E172	3.81
E179	11.60
E200	4.12
E203	14.53
E211	1.62

FeO - continued

E216	1.55	Th-5	9.08
E239	4.26	U36	3.05
E269	6.59	U37	0.71
E316	3.71	U40	7.63
E324	1.15	U50	1.40
E346	10.80	Z11	7.74
E369	3.81	Z12	n.d.
E420	0.72	Z13	0.12
E421	10.56	Z14-a	9.24
G19	1.55	Z14-b	6.69
G23	11.38		
GB1	9.01	n.d. - not determined	
GB2	7.01		
GB3	3.64		
GB4	6.48		
M8-9-10	2.54		
M12-13	2.79		
M14-15	2.62		
M17	7.94		
R2	6.73		
R130	3.35		
R164	4.31		
Th-1	8.42		
Th-2	11.40		
Th-3	5.60		
Th-4	6.94		

MnO

Determined Spectrochemically - R. W. Edie, Analyst

					<u>Average</u>
A8		0.107	0.096	0.099	0.10
A39	0.192	0.210	0.177	0.182	0.19
A44	0.0263	0.0258	0.0315	0.0280	0.03
A45	0.0263	0.037	0.037		0.03
A53	0.165		0.170	0.180	0.17
A54	0.126	0.123			0.12
A55	0.0425	0.0350			0.04
A57	0.0218	0.0243	0.0290		0.03
A101	0.37	0.30	0.275	0.315	0.32
D27	0.085	0.062	0.138	0.089	0.09
D83	0.060	0.083			0.07
D101	0.052	0.050	0.0360	0.042	0.05
D113	0.154	0.117			0.14
E1	0.089	0.096			0.09
E102	0.114	0.185	0.132	0.150	0.15
E107	0.089	0.091	0.069	0.067	0.08
E164	0.092	0.103			0.10
E166	0.076	0.086	0.094	0.082	0.08
E171	0.102	0.092			0.10
E172	0.098	0.096			0.10
E179	0.247	0.24			0.24
E200	0.130	0.125			0.13
E203	0.263	0.275			0.27
E211	0.059	0.064			0.06

MnO - Continued

					<u>Average</u>
E216	0.053	0.0565			0.05
E239	0.195	0.173	0.192	0.160	0.18
E269	0.247	0.260			0.25
E316	0.210	0.153			0.18
E324	0.086	0.084			0.09
E346	0.270	0.260			0.27
E369	0.109	0.117			0.11
E420	0.058	0.056			0.06
E421	0.237	0.258			0.25
G19	0.147	0.142			0.14
G23		0.250	0.270	0.275	0.27
GB1	0.395	0.430			0.41
GB2			0.270	0.252	0.26
GB3	0.043		0.050	0.050	0.05
GB4	0.213	0.204			0.21
M8-9-10	0.100	0.105			0.10
M12-13	0.123	0.108			0.12
M14-15	0.079	0.087			0.08
M17	0.180	0.145			0.16
R2	0.125	0.140			0.13
R130	0.205	0.196			0.20
R164	0.110	0.131			0.12

MnO - Continued

					<u>Average</u>
Th-1	0.160	0.155			0.16
Th-2	0.160	0.180			0.17
Th-3	0.145	0.173			0.16
Th-4	0.215	0.230			0.22
Th-5	0.200	0.185			0.19
U36	0.130		0.103	0.118	0.12
U37	0.079	0.081			0.08
U40	0.206	0.225			0.22
U50	0.080	0.086			0.08
Z11	0.120	0.130			0.13
Z12	0.028	0.027			0.03
Z13	0.0253	0.0253	0.0243	0.0240	0.02
Z14-a	0.157	0.148			0.15
Z14-b		0.114	0.126	0.153	0.13

MgO

Determined Spectrochemically - R. W. Edie, Analyst

							<u>Average</u>
A8	6.90	4.75	5.20	4.55			5.4
A39	7.8	11.6	9.05	8.90			9.4
A44	0.78	0.90	1.03	1.01			0.93
A45			0.60	0.55			0.58
A53	8.1		8.6	9.3			8.7
A54	4.6	4.65					4.6
A55	1.45	1.09					1.3
A57		0.42	0.435	0.515			0.46
A101			16.7	15.0	12.8	13.7	14.6
D27	1.90		2.55	1.74			2.1
D83	2.80	3.10					3.0
D101	0.70	0.75	0.63	0.70			0.69
D113	5.65	4.80					5.2
E1	2.12	2.55					2.3
E102	3.04	2.56	3.20	2.70			2.9
E107	2.30	2.26	2.70	2.60			2.5
E164	2.40	2.87					2.6
E166	3.6	4.2	5.25	4.90			4.5
E171	3.5	3.55					3.5
E172	2.9	2.85					2.9
E179	6.8	7.8					7.3
E200			4.15	4.35			4.3
E203			9.3	9.5			9.4

MgO - Continued

					<u>Average</u>
E211	1.75	1.80			1.8
E216	1.47	1.52			1.5
E239	5.4	5.2	6.55	5.75	5.7
E269	7.1	7.1			7.1
E316	4.00	3.55			3.8
E324	1.84	1.97			1.9
E346	6.6	7.4			7.0
E369	3.95	4.75			3.9
E420	0.95	0.90			0.93
E421	5.8	6.1			6.0
G19	3.35	3.60			3.5
G23		7.3	7.80	7.80	7.6
GB1	5.5	5.65			5.6
GB2			3.66	3.40	3.5
GB3	9.0	8.4	9.90	10.6	9.5
GB4	6.3	6.3			6.3
M8-9-10	4.6	4.5			4.6
M12-13	4.55	4.75			4.7
M14-15	4.0	3.95			4.0
M17	4.20	3.55			3.9
R2	6.0	7.0			6.5
R130	5.15	4.70			4.9
R164	2.5	2.75			2.6

Mgo - Continued

					<u>Average</u>
Th-1	4.40	3.95			4.2
Th-2	4.85	5.60			5.2
Th-3	5.00	5.9			5.5
Th-4	8.6	9.1			8.9
Th-5	7.05	6.7			6.9
U36	4.70		3.80	4.50	4.3
U37	1.70	1.90			1.8
U40	6.00	6.20			6.1
U50	1.92	2.15			2.0
Z11	7.4	7.7			7.6
Z12	1.06	0.96			1.0
Z13	0.66	0.80	0.89	0.86	0.80
Z14-a	4.85	4.80			4.8
Z14-b		5.2	6.7	8.3	6.7

CaO

Determined spectrochemically - R. W. Edie, analyst

								<u>Average</u>
AB		4.45	4.70	3.30				4.2
A39	7.0	7.5	7.6					7.4
A44	0.54	0.70	0.45	0.42				0.53
A45			0.410	0.425				0.42
A53	14.4		12.3	12.5	<u>14.0</u>	<u>13.3</u>	<u>13.3</u>	13.3
A54	0.83	0.70						0.77
A55	1.30	0.89						1.1
A57	1.18	1.18	1.25					1.2
A101	0.69	0.65	0.47	0.41				0.55
D27	2.80		3.43	2.43				2.9
D83	1.05	1.05						1.1
D101	1.03	0.95						1.0
D113	6.5	5.8	<u>4.15</u>	<u>4.20</u>				5.2
E1	0.44	0.465						0.45
E102		5.7	4.15	4.55	<u>4.00</u>	<u>3.90</u>		4.5
E107	0.485	0.40						0.44
E164	0.42	0.46						0.44
E166	1.60	1.82	1.67					1.7
E171	0.386	0.33						0.36
E172	0.315	0.33						0.32
E179	5.85	6.7	<u>5.5</u>	<u>5.4</u>				5.9
E200	0.84	0.80						0.82
E203	0.61	0.535						0.57

CaO - Continued

								<u>Average</u>
E211	0.52	0.53						0.53
E216	0.60	0.60						0.60
E239	0.85	0.78	0.80	0.68				0.78
E269	3.72	4.00	<u>3.85</u>	<u>3.63</u>	6.1	5.8	6.5	4.8
E316	2.46	2.52						2.5
E324	0.58	0.51						0.55
E346	5.70	5.50	<u>6.0</u>	<u>6.3</u>				5.9
E369	0.42	0.43						0.43
E420	0.58	0.57						0.58
E421	4.85	4.70	<u>5.9</u>	<u>5.3</u>				5.2
G19	1.84	1.97						1.9
G23		3.3	2.76	2.84				3.0
GB1	7.7	7.3	<u>6.0</u>	<u>5.8</u>				6.7
GB2	0.53	0.79	0.475	0.42	0.46			0.54
GB3	0.81		0.50	0.58				0.63
GB4	9.9	9.4	<u>10.5</u>	<u>11.0</u>				10.2
M8-9-10	3.85	3.95						3.9
M12-13	3.00	3.00						3.0
M14-15	2.90	3.25						3.1
M17	6.7	5.5	<u>5.6</u>	<u>6.0</u>				6.0
R2	3.95	4.23	<u>4.8</u>	<u>4.15</u>				4.3
R130	3.65	3.50	<u>3.35</u>	<u>3.4</u>				3.5
R164	0.96	0.99						0.98

	CaO - Continued					<u>Average</u>
Th-1	6.5	6.6	<u>5.8</u>	<u>5.0</u>		6.0
Th-2	8.7	8.4	<u>8.2</u>	<u>8.5</u>		8.5
Th-3	4.3	4.9	<u>4.1</u>	<u>4.0</u>		4.3
Th-4	8.7	9.2	<u>6.9</u>	<u>5.4</u>		7.6
Th-5	7.0	6.4	<u>4.9</u>	<u>4.75</u>		5.8
U36	0.91	0.50	0.62	0.72		0.69
U37	1.04	1.12				1.1
U40	6.8	7.2	<u>6.8</u>	<u>6.7</u>		6.9
U50	0.75	0.65				0.70
Z11	3.75	3.70				3.7
Z12	0.50	0.44				0.47
Z13		0.343	0.26	0.26		0.29
Z14-a	7.0	6.2				6.6
Z14-b	2.20	3.05	1.70	1.84	2.30	2.2

used Ca 3006 —

all others Ca 3158



Determined Spectrochemically - R. W. Edie, analyst

			<u>Average</u>
A8	2.60	2.43	2.52
A39	2.77	2.97	2.87
A44	5.36	5.42	5.39
A45	2.20	2.21	2.21
A53	1.95	1.80	1.88
A54	1.94	2.04	1.99
A55	3.65	3.60	3.63
A57	5.18	5.18	5.18
A101	3.58	4.03	3.81
D27	9.40	8.90	9.15
D83	1.55	1.43	1.49
D101	9.00	8.70	8.85
D113	3.93	3.70	3.82
E1	2.62	2.45	2.54
E102	2.10	2.03	2.07
E107	3.05	3.50	3.28
E164	4.10	3.84	3.97
E166	7.10	6.80	6.95
E171	2.28	2.15	2.22
E172	2.06	2.03	2.05
E179	2.47	2.60	2.54
E200	5.01	4.93	4.97

Na₂O - Continued

					<u>Average</u>
E203	3.78	4.04			3.91
E211	2.27	2.34			2.31
E216	3.22	3.02			3.12
E239	1.53	1.44			1.49
E269	4.25	4.60			4.43
E316	2.14	2.25			2.20
E324	2.24	2.24			2.24
E346	3.53	3.74			3.64
E369	1.27	1.20			1.24
E420	5.78	5.84			5.81
E421	2.98	2.92			2.95
G19	5.15	5.25			5.20
G23	3.35	3.22			3.29
GB1	2.85	2.63			2.74
GB2	0.37	0.39			0.38
GB3	0.38	0.365			0.37
GB4	2.00	1.88			1.94
M8-9-10	4.65	4.70			4.68
M12-13	4.32	4.34			4.33
M14-15	5.35	5.13			5.23
M17	3.12	3.00			3.06
R2	2.13	2.17	2.63	2.50	2.36
R130	1.98	1.97	1.68	1.62	1.81

Na₂O - Continued

					<u>Average</u>
R164	3.13	3.00			3.07
Th-1	3.63	3.42			3.53
Th-2	2.66	2.90			2.78
Th-3	3.34	3.17			3.26
Th-4	2.66	2.82			2.74
Th-5	2.92	2.75			2.84
U36	6.12	6.45			6.29
U37	5.80	5.30			5.55
U40	2.72	2.78	2.67	2.75	2.73
U50	0.44	0.42	0.505	0.501	0.47
Z11	2.20	2.10			2.15
Z12	0.275	0.25			0.26
Z13	0.43	0.40	0.39	0.36	0.40
Z14-a	3.00	3.02			3.01
Z14-b	4.10	4.52			4.31



Determined Spectrochemically - R. W. Edie, analyst

				<u>Average</u>
AB	6.17	6.35		6.26
A39	<u>0.30</u>			0.30
A44	1.01	1.02		1.02
A45	6.85	8.17		7.51
A53	1.05	0.94		1.00
A54	4.28	3.68		3.98
A55	0.58*	0.56*		0.57
A57	<u>0.17</u>	<u>0.35</u>		0.26
A101	<u>0.51</u>	<u>0.51</u>		0.51
D27	0.46*	0.52*		0.49
D83	2.58	2.94		2.76
D101	0.50*	0.52*		0.51
D113	5.65	5.62		5.64
E1	1.78	1.53		1.66
E102	0.62	0.85		0.74
E107	0.69*	0.73*		0.71
E164		1.29	1.47	1.35
E166	0.81	0.80		0.81
E171	1.75	1.42		1.59
E172	1.64	1.56		1.60
E179	<u>0.26</u>	<u>0.17</u>		0.21
E200	2.48	2.28		2.38
E203	0.74	0.76		0.75

K₂O - Continued

					<u>Average</u>
E211	1.45	1.34			1.40
E216	<u>0.71</u>	<u>0.67</u>			0.69
E239	2.52	2.59			2.56
E269	1.06	1.10			1.08
E316	4.95	5.02			4.99
E324	<u>0.08</u>	<u>0.07</u>			0.08
E346	1.62	1.60			1.61
E369	3.17	3.15			3.16
E420	0.35	0.26			0.31
E421	1.95	2.09			2.02
G19	<u>0.30</u>				0.30
G23	<u>0.35</u>				0.35
GB1	2.36	2.55			2.46
GB2	8.4*	9.7*			9.1
GB3	6.7*	5.9*			6.3
GB4	5.34	5.14			5.24
M8-9-10	2.10	1.79			1.95
M12-13	2.86	3.25			3.06
M14-15	2.30	1.52	1.83	1.31	1.74
M17	4.28	3.61			3.95
R2	1.49	1.40	1.51	1.82	1.56
R130	3.76	3.86	3.89	3.35	3.72
R164	2.15	1.96			2.06

K₂O - Continued

			<u>Average</u>
Th-1	0.99	1.02	1.01
Th-2	0.92	0.91	0.92
Th-3	0.80	0.90	0.85
Th-4	0.73	0.85	0.79
Th-5	0.62	0.51	0.57
U36	<u>0.35</u>	<u>0.51</u>	0.43
U37	<u>0.67</u>	<u>0.51</u>	0.59
U40	0.77	0.76	0.77
U50	<u>0.17</u>	<u>0.26</u>	0.22
Z11	1.96	2.11	2.04
Z12	<u>0.25</u>		0.25
Z13	4.6*	5.4*	5.0
Z14-a	1.25	1.20	1.23
Z14-b	0.49*	0.47*	0.51

— Interpolated visually

* Special working curve

Fluorine

Determined Spectrochemically - R. Seraphim, analyst

						<u>Average</u>
A45	0.0025	0.0025				0.0025
A53	0.08	0.11				0.09
A54	0.045	0.025				0.035
A57	trace	trace				trace
A101	0.17	0.17				0.17
E1	0.043	0.058	0.035			0.048
E171	0.03	0.04	0.025			0.032
E172	0.018	0.020	0.020			0.020
E179	0.12	0.12	0.017	0.15		0.13
E200	0.055	0.055	0.062	0.042	0.065	0.052
E203	0.025	0.045				0.035
E211	0.033	0.035	0.02	0.04	0.05	0.036
E216	0.054	0.06				0.057
E239	0.15					0.15
E269	0.09	0.09				0.09
E324	< 0.001	< 0.001				< 0.001
E346	0.11	0.14				0.13
E420	0.001	0.001				0.001
E421	0.11	0.20				0.15
M17	0.40	0.60	0.35			0.45
R2	0.11	0.11				0.11
R130	0.08	0.07				0.075
U36	0.22	0.26				0.24
U37	0.02	0.02	0.03			0.02
U40	0.11	0.07				0.09
U50	0.006	0.008				0.007

Gallium (Ga_2O_3)

Determined Spectrochemically - C. K. Bell, Analyst

				<u>Average</u>	<u>$\frac{\text{Ga}_2\text{O}_3}{\text{Al}_2\text{O}_3}$</u>
A54	0.00412	0.0044		0.0043	0.00019
E1	0.00277	0.00278		0.0028	0.00022
E211	0.002257	0.002195		0.0022	0.00017
R164	0.00259	0.00262		0.0026	0.00020
U50	0.000685	0.000778	0.000778	0.00075	0.00011
Z13	0.00416	0.00393		0.0040	0.00021

Carbon (non-carbonate)

Determined chemically - R. W. Edie, analyst

Average

Z12	9.58	8.84	9.07	7.20	7.67	8.5
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Rubidium (Rb_2O)

Part I

Determined Spectrochemically - R. W. Edie, analyst

			Average % Rb_2O	%K O	Ratio $\frac{\text{K}_2\text{O}}{\text{Rb}_2\text{O}}$
A8	0.061	0.059	0.060	6.26	104
D113	0.061	0.063	0.062	5.64	91
E316	0.0429	0.0440	0.0435	4.99	115
GB-1	0.0134	0.0164	0.0149	2.46	165
GB-2	0.067	0.070	0.069	9.1	132
GB-3	0.052	0.052	0.052	6.3	121
GB-4	0.045	0.039	0.042	5.24	125
M8-9-10	0.0133	0.0098	0.0116	1.95	168
M12-13	0.0182	0.0229	0.0206	3.06	149
M14-15	0.0082	0.0103	0.0093	1.74	187
M17	0.031	0.029	0.030	3.95	132
R2	0.0080	0.0093	0.0087	1.56	179
R130	0.0368	0.0390	0.0379	3.72	98
Th-1	0.0088	0.0078	0.0083	1.01	122
Th-2	0.0078	0.0070	0.0074	0.92	124
Th-3	0.0059	0.0088	0.0073	0.85	116
Th-4	0.0064	0.0070	0.0067	0.79	118
Th-5	0.0084	0.0064	0.0074	0.57	77
Z-11	0.0114	0.0123	0.0118	2.04	173
Z14- 6	0.0034	0.0035	0.0035	0.51	146

Rubidium (Rb_2O)

Part II

Determined Spectrochemically - R. W. Edie, analyst

	<u>Wt. % K_2O</u>	<u>Wt. % Rb_2O</u>	<u>$\text{K}_2\text{O}/\text{Rb}_2\text{O}$</u>
A45	7.51	0.019	395
A53	0.99	0.010	99
A54	3.98	0.061	65
A57	0.26	0.0015	174
A101	0.51	0.007	73
E1	1.66	0.019	87
E171	1.59	0.020	80
E172	1.60	0.022	73
E179	0.22	0.0012	183
E200	2.38	0.014	170
E203	0.75	0.006	125
E211	1.40	0.019	74
E216	0.69	0.005	138
E239	2.56	0.020	128
E269	1.08	0.012	90
E324	0.08	< 0.001	--
E346	1.61	0.012	134
E420	0.30	0.0013	230
E421	2.02	0.019	106
R2	1.45	0.012	121
R130	3.81	0.030	127
U36	0.43	0.0026	165
U37	0.59	0.0012	490
U40	0.77	0.007	110
U50	0.22	0.0026	85

Lithium (Li_2O)

Determined Spectrochemically - R. W. Edie, analyst

					<u>Average % Li_2O</u>
A8	0.0063	0.0044			0.0054
D113	0.0050	0.0047			0.0049
E316	0.0051	0.0060			0.0056
GB-1	0.0098	0.0086			0.0092
GB-2	0.0033	0.0034			0.0034
GB-3	0.0047	0.0031			0.0039
GB-4	0.00295	0.00235			0.0027
M8-9-10	0.00400	0.00235	0.00325	0.00335	0.0032
M12-13	0.0036	0.0029			0.0033
M14-15	0.0036	0.0040			0.0038
M17	0.00245	0.00255			0.0025
R2	0.0066	0.0041	0.0048	0.0058	0.0053
R130	0.0026	0.0024	0.0030	0.0032	0.0028
Th-1	0.00190	0.00215			0.0020
Th-2	0.00195	0.00200			0.0020
Th-3	0.0022	0.0023			0.0023
Th-4	0.00195	0.00245			0.0022
Th-5	0.0024	0.0024			0.0024
Z11	0.0052	0.0045			0.0049
Z14-b	0.0030	0.0034*			0.0032

*Interpolated visually

Copper

Determined Spectrochemically - R. W. Edie, analyst

			<u>Average</u>
A8	0.00147	0.00147	0.0015
Co1	0.0123	0.0113	0.012
Co2	0.0102	0.0115	0.011
Co3	0.0142	0.0135	0.014
D113	0.0026		0.0026
E316	0.00043	0.00053	0.0005
E420	0.00332	0.00320	0.0033
GB-1	0.0103	0.0098	0.010
GB-3	0.0130	0.0162	0.015
GB-4	0.0068	0.0076	0.0072
M17	0.00380	0.0049	0.0044
R2	0.0103	0.0096	0.010
R130	0.0046	0.0044	0.0045
S-1	0.0056	0.0063	0.0060
S-2	0.0048	0.0052	0.0050
S-3	0.0066	0.0060	0.0063
Th-1	0.0140	0.0137	0.014
Th-2	0.0045	0.0056	0.0051
Th-4	0.0138	0.0157	0.015
Th-5	0.0143	0.0143	0.014
US-1	0.0103	0.0108	0.011
US-2	0.0106	0.0130	0.012
US-3	0.0117	0.0133	0.013
Z11	0.0050	0.0065	0.0058
Z14b	0.0053	0.0039	0.0046

Cobalt

Determined Spectrochemically - R. W. Edie, analyst				<u>Average</u>	<u>Ratio Co/Ni</u>	
A8	0.00125	0.00090		0.0011	0.30	
Co1	0.0029	0.0031		0.0030	0.23	
Co2	0.0157	0.0163		0.0160	0.67	
Co3	0.0047	0.0040		0.0044	0.24	
D113	0.00090	0.00098		0.0010	0.31	
E316	0.00100	0.00113		0.0011	0.18	
E420	0.00090	0.00070		0.0008		
GB-1	0.00320	0.00175		0.0025	0.53	
GB-3	0.00031	0.00050	0.00044	0.00039	0.00041	0.09
GB-4	0.0022	0.0022		0.0022	0.23	
M17	0.00115	0.00140		0.0013	0.30	
R2	0.00275	0.00204	0.0021	0.0023	0.0023	0.28
R130	0.00150	0.00110	0.00130	0.00113	0.0013	0.26
S-1	0.00210	0.00243		0.0023		
S-2	0.0037	0.0038		0.0038		
S-3	0.00265	0.00250		0.0026	0.35	
Th-1	0.00185	0.00197		0.0019	0.49	
Th-2	0.00280	0.00255		0.0027	0.60	
Th-4	0.00242	0.00330	0.0031	0.0021	0.0027	0.32
Th-5	0.00324	0.00300	0.00360		0.0033	0.36
US-1	0.00280	0.00232		0.0026	0.33	
US-2	0.00310	0.00290		0.0030	0.32	
US-3	0.0038	0.00310		0.0035	0.35	
Z11	0.00265	0.00207		0.0024	0.33	
Z14b	0.00280	0.00245		0.0026	0.30	

Determined Spectrochemically - R. W. Edie, analyst

			<u>Average</u>
A8	0.00400	0.00343	0.0037
Co-1	0.0130	0.0132	0.013
Co 2	0.0225	0.0250	0.024
Co 3	0.0183	0.0168	0.018
D113	0.00295	0.00350	0.0032
E316	0.0060	0.0061	0.0061
E420	not detectable probably less than 0.0005		
GB-1	0.0051	0.0043	0.0047
GB-3	0.0040	0.0048	0.0046
GB-4	0.0094	0.0099	0.0097
M17	0.0039	0.0046	0.0043
R2	0.0089	0.0073	0.0081
R130	0.0055	0.0045	0.0050
S-1	* Trace	* Trace	Trace
S-2	"	"	Trace
S-3	0.0076	0.0073	0.0075
Th-1	0.0039	0.0039	0.0039
Th-2	0.0045	0.0045	0.0045
Th-4	0.0078	0.0092	0.0085
Th-5	0.0089	0.0086	0.0091
		0.0097	
US-1	0.0080	0.0077	0.0079
US-2	0.0095	0.0095	0.0095
US-3	0.010	0.010	0.010
Z11	0.0070	0.0076	0.0073
Z14b	0.0095	0.0080	0.0088

*Trace = <0.001%

Radioactivity Measurements, Thick Source Alpha Count

Ra equiv. $\times 10^{12}$ gm/gm

Determined by R. W. Edie

							<u>Average</u>
A8	1.79	1.99					1.89
A44	2.41	2.52					2.47
A45	9.10	8.47	9.18				8.92
D113	1.76	1.98	2.06				1.93
E200	2.81	3.09					2.95
E239	2.98	2.98					2.98
E316	2.76	4.23	4.27				3.75
E346	0.59	0.42	0.47	0.46	0.51		0.47
E420	6.60	6.92					6.76
E421	0.28	0.27	0.25				0.27
GB-1	1.01	0.99	0.69				0.90
GB-2	1.02	1.07					1.05
GB-3	0.86	0.87					0.87
GB-4	0.45	0.38	0.41	0.39	0.42		0.41
M8-9-10	2.81	3.90	4.17				3.63
M12-13	1.00	1.13					1.07
M14-15	3.03	3.20					3.12
M17	1.83	1.95	2.14	1.98			1.93
R2	1.14	1.06	0.98	1.08	0.98	1.02	1.04

Radioactivity Measurements - Continued

					<u>Average</u>
R130	4.04	4.12	4.24	2.32	3.68
Th-1	0.66	0.71			0.69
Th-2	0.66	0.66	0.71		0.68
Th-3	0.72	0.54			0.63
Th-4	0.38	0.39			0.39
Th-5	1.18	1.08			1.13
Z11	0.47	0.48	0.46	0.46	0.47
Z14-b	1.60	1.38	1.42		1.47

NAME AND LOCATION OF SPECIMENS

- A8 Diabase dyke, Ace Mine-area, Goldfields, Saskatchewan
(see Fig. 3).
- A39 Blue chlorite-schist, Ace mine-area, Goldfields,
Saskatchewan (see Fig. 3).
- A44 Albite-alaskite, Ace mine-area, Goldfields, Saskatchewan
(see Fig. 3).
- A45 Microcline-alaskite, Ace Creek, Goldfields, Saskatchewan
(see Fig. 3).
- A53 Chlorite-epidote rock with veinlets of epidote, Ace
mine-area, Goldfields, Saskatchewan.
- A54 Chlorite-sericite schist (metasediment), Ace mine,
Goldfields, Saskatchewan.
- A55 Brown "cherty" band in chlorite-sericite schist, Ace
mine, Goldfields, Saskatchewan.
- A57 Albite-alaskite mylonite, Ace mine, Goldfields,
Saskatchewan.
- Al01 Chlorite-schist inclusion in alaskite, Ace mine-area,
Goldfields, Saskatchewan.
- Co1 Nipissing diabase, Beaver mine, Cobalt, Ontario
- Co2 Nipissing diabase, Keely mine, Cobalt, Ontario
- Co3 Nipissing diabase, King Edward mine, Cobalt, Ontario
- D27 Albitite, Emar claims, Goldfields, Saskatchewan,
(see Fig. 3).
- D83 Gneissic granodiorite, Emar claims, Goldfields,
Saskatchewan, (see Fig. 3).
- Dl01 Albite-alaskite mylonite with introduced carbonate and
specularite, Emar claims, Goldfields, Saskatchewan
(see Fig. 3).
- Dl13 Diabase dyke, Emar claims, Goldfields, Saskatchewan
(see Fig. 3).

E1	(G-1) (C-1)	Chloritized and sericitized albite-alaskite mylonite, Eagle mine-area, Goldfields, Saskatchewan (see Sheet 3).
E102	(C102)	Same as E1
E107	(C107)	Same as E1
E164	(C164)	Same as E1
E166	(C166)	Same as E1 but red-altered
E171	(C171)	Same as E1
E172	(C172)	Same as E1
E179	(C179)	Propylite, Eagle mine-area, Goldfields, Saskatchewan (see Sheet 3).
E200	(C200)	Black trap-like mylonite, Eagle mine-area, Goldfields, Saskatchewan.
E203	(C203)	Chlorite-schist inclusion in alaskite, Eagle mine-area, Goldfields, Saskatchewan
E211	(C211)	Same as E1
E216	(C216)	Same as E1
E239	(C239)	Same as E200, see sheet 3.
E269	(C269)	Propylite, same as E179.
E316	(S316)	Same as E200.
E324	(S324)	Same as E200.
E346	(S346)	Coarse-grained plagioclase-amphibolite, Eagle mine-area, Goldfields, Saskatchewan.
E369	(S369)	Same as E1.
E420	(S420)	Albite-alaskite, Eagle mine-area, Goldfields, Saskatchewan (see sheet 3).
E421	(S421)	Same as E346.

- G19 (S19) Same as E200 but red-altered.
- G23 (S23) Psuedo conglomerate, Eagle mine-area, Goldfields, Saskatchewan (see sheet 3).
- GB1 Early diabase, Eldorado mine, Great Bear Lake, N.W.T.
- GB2 Same as GB1 but red-altered
- GB3 Narrow post-ore diabase dyke, Eldorado mine, Great Bear Lake, N.W.T.
- GB4 Younger diabase, near Eldorado mine, Great Bear Lake, N.W.T.
- M8-9-10 (M1) Flow 1, RA claims, Goldfields, Saskatchewan (See Fig. 3).
- M12-13 (M2) Flow 2, RA claims, Goldfields, Saskatchewan (See Fig. 3).
- M14-15 (M3) Flow 3, RA claims, Goldfields, Saskatchewan (See Fig. 3).
- M17 Diabase sill or coarse grained flow, Martin Lake, Goldfields, Saskatchewan.
- R2 Diabase dyke, Mic claims, Goldfields, Saskatchewan (see Fig. 3).
- R130 Black trap-like mylonite, Eagle claims, Goldfields, Saskatchewan (see sheet 2).
- R164 Slate, Ato claims, Goldfields, Saskatchewan, (see sheet 2).
- S1 Norite, Sudbury, Ontario, collected by H. W. Fairbairn
- S2 Norite, at the basic border, Wendy Lake, Sudbury, Ontario.
- S3 Norite, near Blezard mine, Sudbury, Ontario.
- Th-1 Ranwyk dyke, coarse grained diabase, Theano Point district, Ontario.
- Th-2 Jalore dyke, coarse grained diabase, Theano Point district, Ontario.
- Th-3 Damascus dyke, slightly red-altered coarse grained diabase, Theano Point district, Ontario.

- Th-4 Camray dyke, coarse grained diabase, Theano Point district, Ontario.
- Th-5 "No name" dyke, coarse grained diabase, Theano Point district, Ontario.
- U36 Same as E200
- U37 Red-altered albite-alaskite mylonite, Eagle mine, Goldfields, Saskatchewan (see sheet 3).
- U40 Propylite same as E179.
- U50 "Quartzite", Eagle mine, Goldfields, Saskatchewan, (see sheet 3).
- US1 Triassic trap, Cornwall, Pennsylvania
- US2 Same as US1 but farther from contact
- US3 Same as US1 but near ore-body
- Z11 Diabase, Pitche claims, Goldfields, Saskatchewan (see Fig. 3).
- Z12 Breccia cemented by carbonaceous material, Pitche claims, Goldfields, Saskatchewan.
- Z13 Quartz-muscovite schist, Pitche claims, Goldfields, Saskatchewan, see (Fig. 3).
- Z14-a Plagioclase-amphibolite, south of Beaverlodge Lake, Goldfields, Saskatchewan.
- Z14-b Diabase dyke, strike claims, Goldfields, Saskatchewan (see Fig. 3).

BIOGRAPHICAL NOTE

RALPH WILLIAM EDIE

Born: 2 October 1921
Smoky Lake, Alberta

Education: B.Sc. Mining Engineering University of Alberta, 1945
M.Sc. Geology, University of Alberta, 1949
Graduate Student, Massachusetts Institute of
Technology, 1949-51

Teaching Experience:

Laboratory Instructor, University of Alberta, 1947-
1949

Professional Experience:

Underground mining, International Nickel Co.,
Sudbury, Ontario, summer 1941

Rodman and Instrumentman, U.S.P.R.A.
Alaska highway, summer 1942 and 1943

Geological assistant, Frobisher Exploration Co.,
Yellowknife N.W.T., season 1944

Field Geologist, Hudson Bay Mining and Smelting Co.
Flin Flon, Manitoba, season 1945

Field Geologist, Prospect Street Syndicate,
Yellowknife N.W.T., September 1945 -
August 1947

Field Geologist, Eldorado Mining and Refining
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seasons 1948, 1949 and 1950

Affiliations:

Junior member, Canadian Institute of Mining and
Metallurgy

Engineer in training, Professional Engineers of
Alberta

**GEOLOGY OF THE EAGLE-ATO-MIC CLAIMS
GOLDFIELDS AREA SASKATCHEWAN
NORTH SHEET**

SCALE
0 200 400 600
FEET

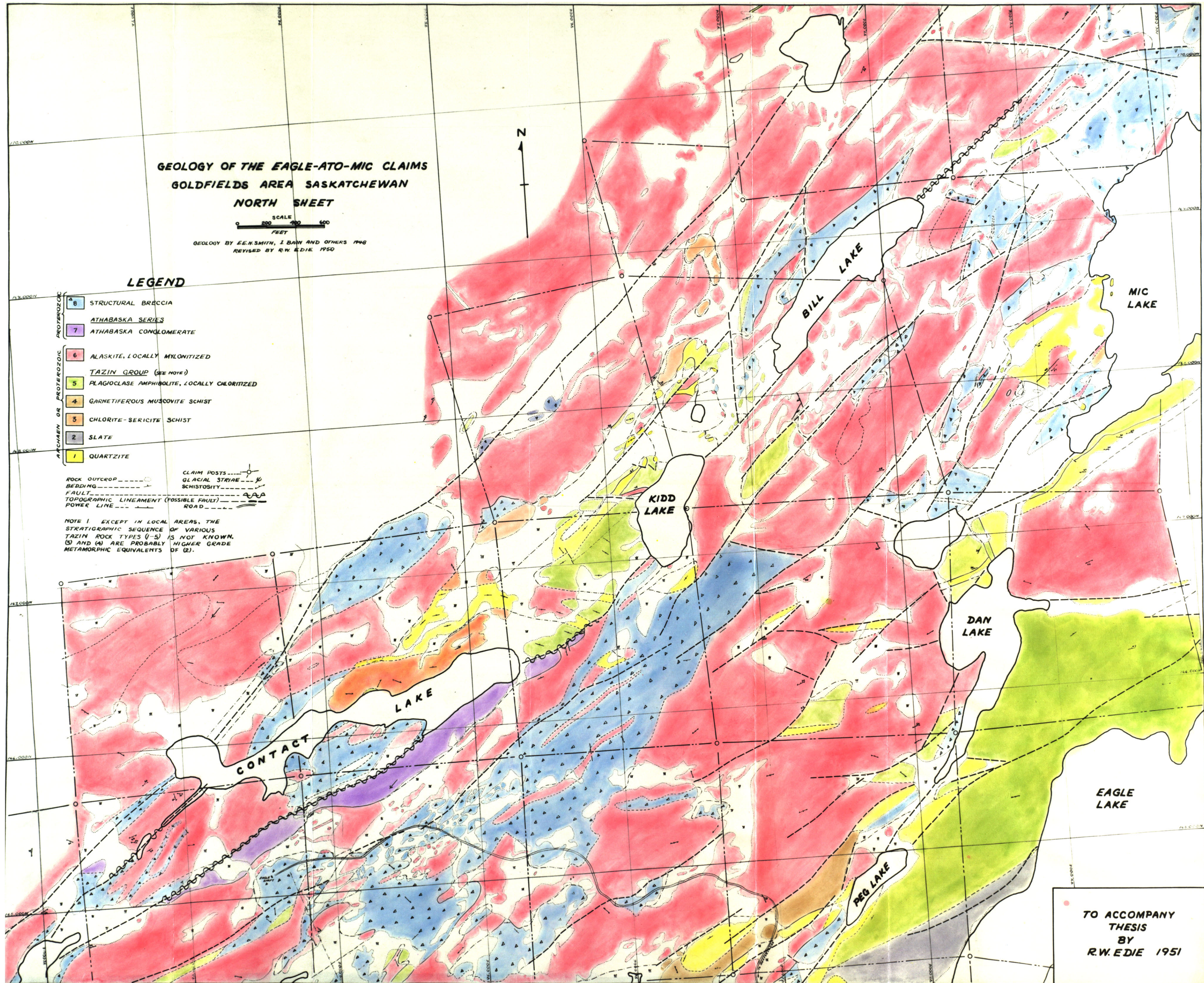
GEOLOGY BY E.E. SMITH, J. BARN AND OTHERS 1948
REVISED BY R.W. EDIE 1950

LEGEND

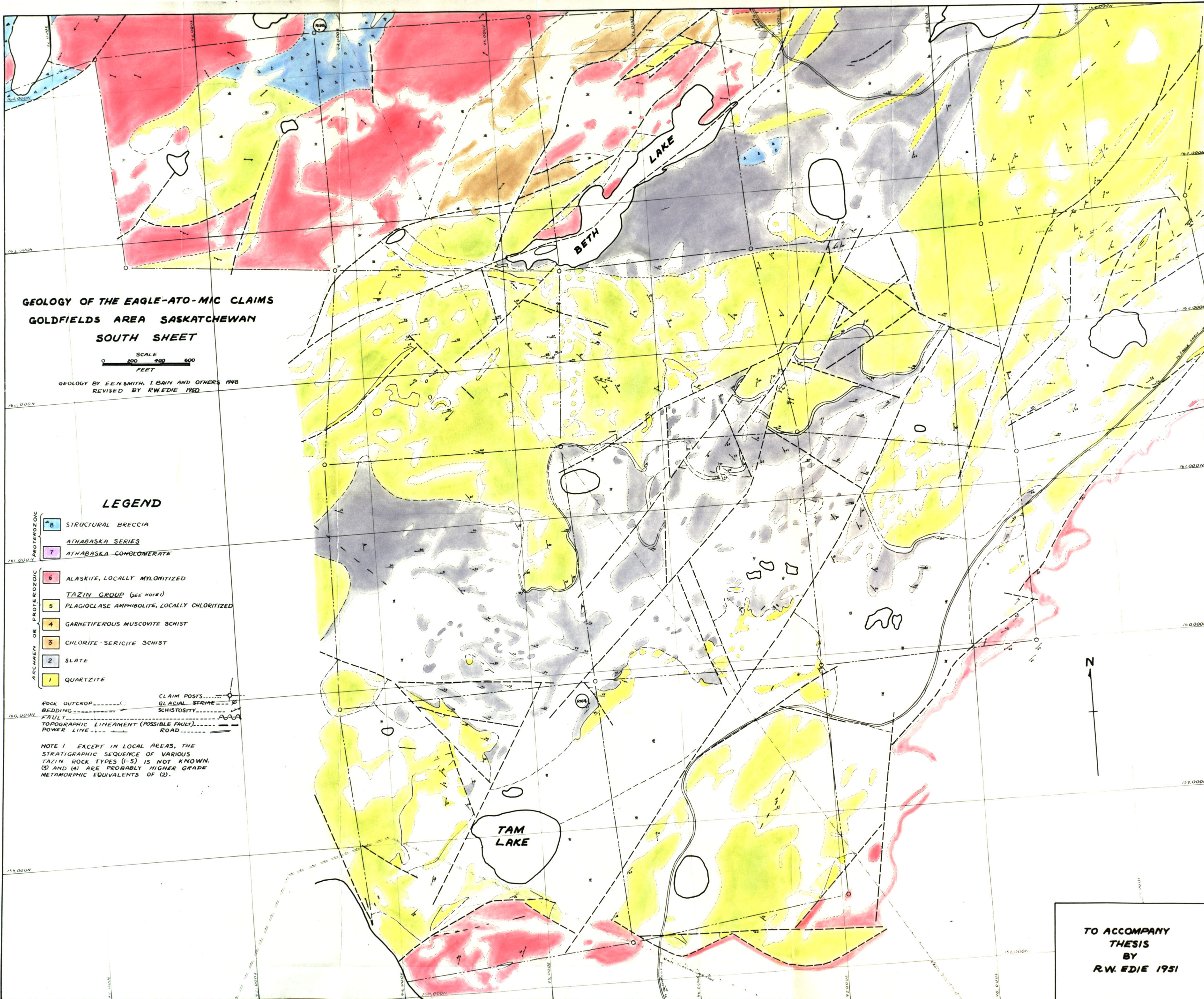
- | | | |
|------------------------|-------------------------------|--|
| ARCHAEO-OR-PROTEROZOIC | | 8 STRUCTURAL BRECCIA |
| | ATHABASKA SERIES | |
| | | 7 ATHABASKA CONGLOMERATE |
| | ALASKITE, LOCALLY MYLONITIZED | |
| | TAZIN GROUP (SEE NOTE 1) | |
| | | 5 PLAGIOCLASE AMPHIBOLITE, LOCALLY CHLORITIZED |
| | | 4 GARNETIFEROUS MUSCOVITE SCHIST |
| | | 3 CHLORITE-SERICITE SCHIST |
| ARCHAEO-OR-PROTEROZOIC | | 2 SLATE |
| | | 1 QUARTZITE |

- | | |
|--|----------------|
| ROCK OUTCROP | CLAIM POSTS |
| BEDDING | GLACIAL STRIAE |
| FAULT | SCHISTOSITY |
| TOPOGRAPHIC LINEAMENT (POSSIBLE FAULT) | ROAD |
| POWER LINE | |

NOTE 1 EXCEPT IN LOCAL AREAS, THE STRATIGRAPHIC SEQUENCE OF VARIOUS TAZIN ROCK TYPES (1-5) IS NOT KNOWN. (3) AND (4) ARE PROBABLY HIGHER GRADE METAMORPHIC EQUIVALENTS OF (2).



TO ACCOMPANY
THESIS
BY
R.W. EDIE 1951



**GEOLOGY OF THE EAGLE-ATO-MIC CLAIMS
GOLDFIELDS AREA SASKATCHEWAN
SOUTH SHEET**

SCALE
0 200 400 600
FEET

GEOLOGY BY E.E. SMITH, I. BAIN AND OTHERS 1948
REVISED BY R.W. EDIE 1950

LEGEND

- | | | |
|------------------------|--------------------------|--|
| PROTEROZOIC | 8 | STRUCTURAL BRECCIA |
| | ATHABASKA SERIES | |
| | 7 | ATHABASKA CONGLOMERATE |
| ARCHAEN DE PROTEROZOIC | 6 | ALASKITE, LOCALLY MYLONITIZED |
| | TAZIN GROUP (SEE NOTE 1) | |
| | 5 | PLAGIOCLASE AMPHIBOLITE, LOCALLY CHLORITIZED |
| | 4 | GARNETIFEROUS MUSCOVITE SCHIST |
| | 3 | CHLORITE-SERICITE SCHIST |
| | 2 | SLATE |
| | 1 | QUARTZITE |

- | | |
|--|----------------|
| ROCK OUTCROP | CLAIM POSTS |
| BEDDING | GLACIAL STRIAE |
| FAULT | SCHISTOSITY |
| TOPOGRAPHIC LINEAMENT (POSSIBLE FAULT) | ROAD |
| POWER LINE | |

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TO ACCOMPANY
THESIS
BY
R.W. EDIE 1951

**GEOLOGY IN VICINITY OF EAGLE MINE
 ELDORADO MINING AND REFINING (1944) LIMITED
 GOLDFIELDS SASKATCHEWAN**

0 100 200 300 400 500
 SCALE FEET
 GEOLOGY BY R.W. EDIE 1948 AND 1950



SYMBOLS

- ✓ DIAMOND DRILL HOLE, PLAN VIEW
- LOCATION OF SPECIMENS FOR MAJOR ELEMENT ANALYSES
- C - SPECIMEN OF DRILL CORE
- S - SPECIMEN FROM SURFACE
- U - SPECIMEN FROM UNDERGROUND FIRST LEVEL

LEGEND

PROTEROZOIC

- ▲ STRUCTURAL BRECCIA
- ATHABASKA SERIES
- ATHABASKA CONGLOMERATE

ARCHAEN OR PROTEROZOIC

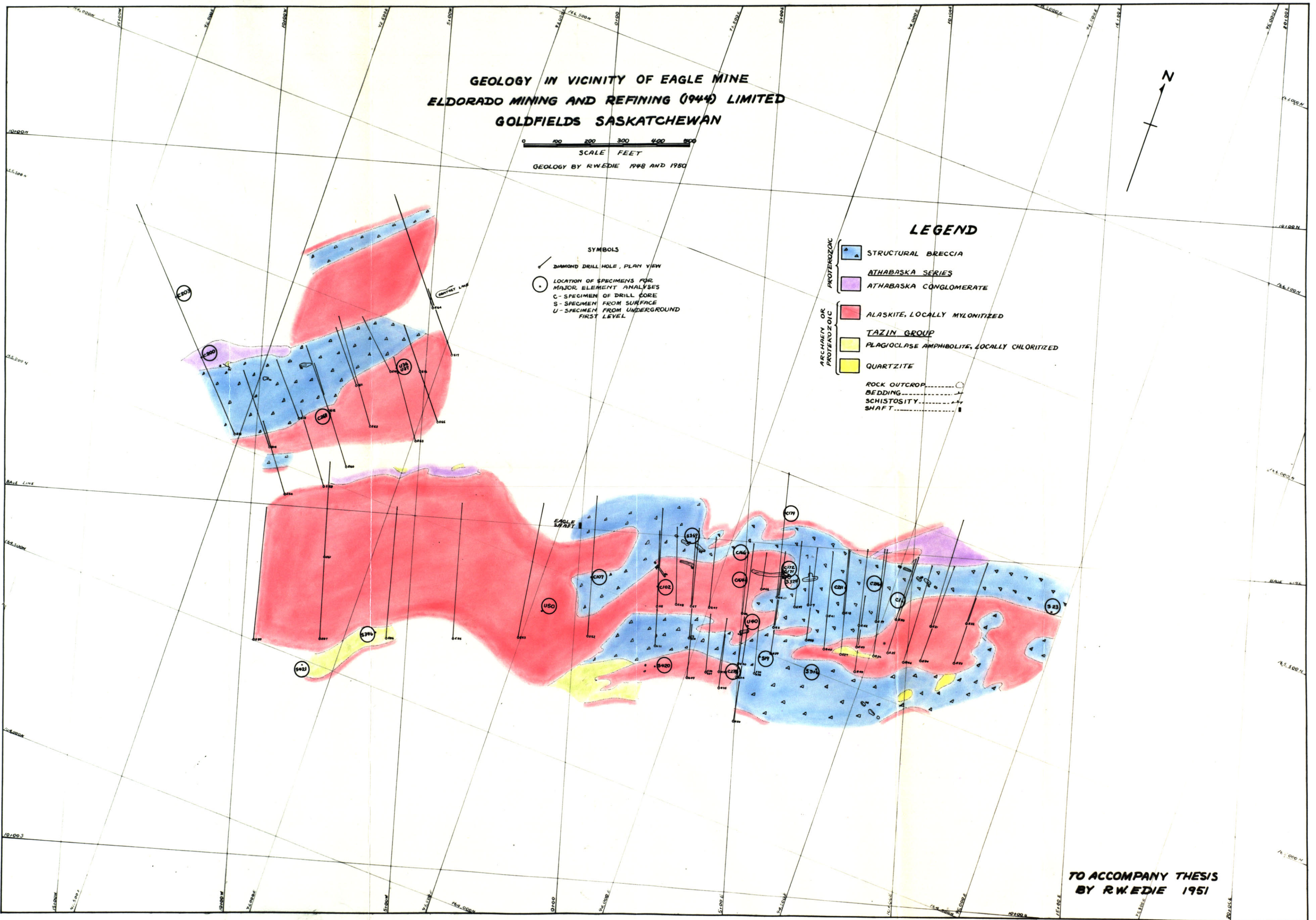
- ALASKITE, LOCALLY MYLONITIZED
- TAZIN GROUP
- PLAGIOCLASE AMPHIBOLITE, LOCALLY CHLORITIZED
- QUARTZITE

○ ROCK OUTCROP

— BEDDING

- - - SCHISTOSITY

▬ SHAFT



**TO ACCOMPANY THESIS
 BY R.W. EDIE 1951**