BRITISH
COLUMBIA
Ministry of Employment and Investment
Energy and Minerals Division
Geological Survey Branch

PHOSPHATE DEPOSITS IN BRITISH COLUMBIA

By S. Butrenchuk, P.Geo

BULLETIN 98

Canadian Cataloguing in Publication Data
Butrenchuk, S.B.
Phosphate deposits in British Columbia

(Bulletin ; 98)

Issued by Geological Survey Branch.
Includes bibliographical references : p.
ISBN 0-7726-2895-5

1. Phosphate rock - British Columbia. 2. Geology, Economic - British Columbia. I. British Columbia. Ministry of Employment and Investment. II. British *Columbia. Geological Survey Branch. III. Title. IV. Series:* Bulletin (British Columbia. Ministry of Employment and Investment) ; 98.

TN914.C32B74 1996 553.6'4'09711 C96-960152-2

VICTORIA
BRITISH COLUMBIA
CANADA

AUGUST 1996

Field research for this publication was carried out during the period 1986 to 1987.

ABSTRACT

Phosphate is an abundant commodity worldwide and is produced in over 29 countries. While there is currently an oversupply analysts believe that international trade patterns will change. Canada's traditional sources of imported phosphate rock are predicted to decline and new sources may have to be found. This study assesses the resource potential of phosphate deposits in British Columbia and comments on their economic viability.

Sedimentary phosphate deposits occur in 14 stratigraphic units in rocks ranging in age from Cambrian to Lower Jurassic. Deposits of Triassic and Jurassic age offer the best potential for future development. Beneficiation problems and high cost mining must be overcome before these deposits are considered economic. A large resource is present at the Aley carbonatite where phosphate could conceivably be produced as a byproduct from its niobium production.

This study discusses in detail the petrographical and chemical makeup of the sedimentary phosphate deposits, especially how they relate to beneficiation. A comprehensive classification based on chemical and mineralogical parameters is proposed for British Columbia phosphate deposits. The trace element content of these deposits is also described. Uranium, fluorine, yttrium and rare-earth metals may be recoverable.

Sedimentary phosphate was deposited in a shelf to basinal environment. Nodular phosphates are common and characterize deposition in shallow waters while the pelletal varieties were deposited in a deeper water, more reducing environment. Many of the deposits occur above unconformities; better grade deposits are associated, transgressive events where upwelling currents allowed phosphate deposition to take place.

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

APPENDICES

TABLES

FIGURES

PHOTOS

CHAPTER 1 INTRODUCTION

Phosphorus is essential to all forms of animal life and together with niotrogen and potassium is necessary for plant growth. Plants derive these elements from the soil, a process that leads to the impoverishment of such vital components. While some of this loss may be replenished by natural processes the use of chemical fertilizers is the most effective means of restoring these nutrients to the soil. Phosphate rock is the most suitable source of raw material in the manufacture of phosphate fertilizers.

The average phosphorus content in the earth's crust is estimated to be 0.23% P_2O_5. Igneous rocks contain an average of 0.16 to 0.43% P_2O_5 while sedimentary rocks contain between 0.03 and 0.17% P_2O_5. Shales generally have the highest phosphate content. Most phosphorus occurs in minerals of the apatite group. The structure of apatite is such that carbonate, vanadate, arsenate and sulphate may substitute for phosphate and sodium, strontium, uranium, thorium and rare earth elements may substitute for calcium. Because of this capacity for substitution, phosphate deposits very often represent a significant resource for these metals, in particular, uranium, yttrium and the rare earth elements. Marine phosphate deposits generally contain 50 to 200 parts per million uranium while igneous deposits usually have a lower uranium content. Concentrations of rare earths vary considerably. Values range from a few parts per million for deposits in Florida to 1% for the Maikop and Mangyshlak deposits in the Soviet Union (Slansky, 1986).

Phosphate reserves worldwide are sufficient to last well into the next century. The estimated resource is believed to be in the range 128 billion tonnes of which 69 billion tonnes can be classified as reserves (Cathcart, 1983). While worldwide resources may be substantial, approximately two-thirds of known resources are contained in carbonate rich deposits for which satisfactory beneficiation technology is not yet available on a commercial scale (Notholt and Highley, 1986).

Phosphate is presently produced in 29 countries with the major producing centres and those with potential for production shown in Figure 1. The United States, Morocco and the Soviet Union account for 70% of this production. World production figures for the period 1970 to 1987 are shown in Figure 2. Production of phosphate in 1987 was 145.1 million

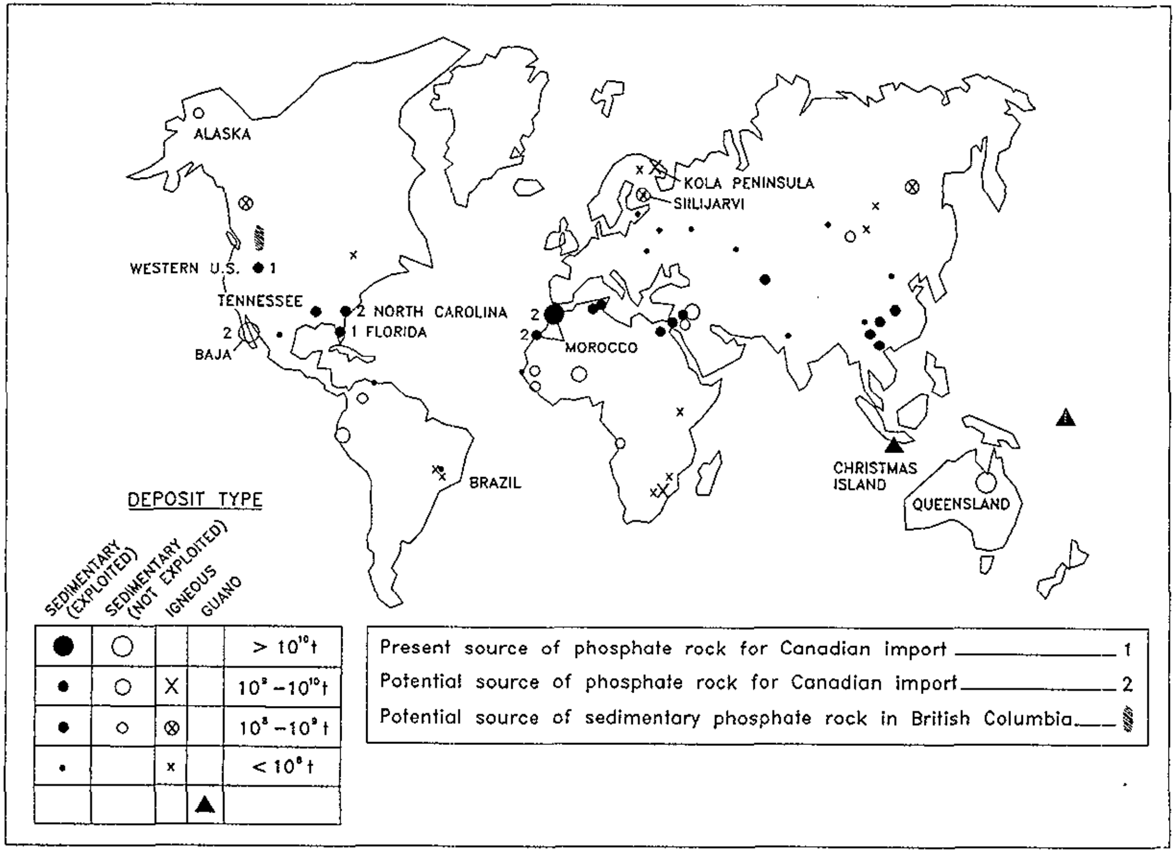


Figure 1. World distribution of identified phosphate resources expressed in terms of commercial product (modified from Slansky, 1986).

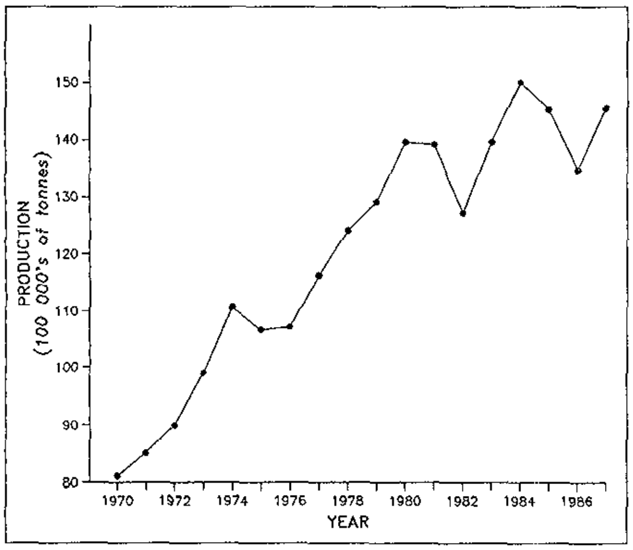


Figure 2. World production of phosphate rock, 1970-1987.

tonnes, a decline of approximately 5% from the previous year. World production figures for the period 1970 to 1987 are shown in Figure 2.

OVERVIEW OF PHOSPHATE SUPPLY AND DEMAND

During the 1970s and early 1980s there was a substantial increase in the production and consumption of phosphate. However, since 1980 world supply capability has exceeded demand. As a result the phosphate fertilizer industry is currently in oversupply, a situation that is expected to continue until at least 1990. Future annual growth rates of phosphate consumed worldwide will be 3% in the fertilizer industry and 2% in the non-fertilizer sector. The long term outlook is for continued growth, if for no other reason than an increasing world population. By 1995 world consumption of phosphate rock is estimated to be 180 million tonnes and by the year 2000 it is estimated to be 198 million tonnes per year (Lavers, 1986). Demand will be greatest in developing countries, especially in southeast Asia. The present oversupply to the fertilizer industry is expected to end by 1990 when markets for phosphate rock should move to a more balanced position.

Present trends are toward the mining of lower grade material and for exporting countries to treat their own rock and to export products with higher added value. Imports of phosphate rock will be increasingly limited to those countries that have an adequate supply of sulphuric acid at competitive prices (Lavers, 1986) as large quantities of this acid are used to treat phosphate rock to produce phosphoric acid. Canada has a plentiful supply of both sulphuric acid and sulphur and therefore is in a good position with respect to the importation of unprocessed phosphate rock.

Phosphate is produced from three sources: marine sedimentary rocks, igneous apatite (carbonatites and related alkaline intrusions) and guano-derived deposits. Approximately 80% of phosphate production is from bedded sedimentary rocks and most of the balance is from alkaline igneous rocks or carbonatites. The fertilizer industry consumes approximately 95% of phosphate rock production while chemicals, refractories, pharmaceuticals and food processing account for the remaining 5% (Emigh, 1983).

Although Canada has substantial phosphate deposits, none are economical at the present time and therefore imports all of the phosphate rock. The United States is the major source with Florida supplying 70% of Canada's imports and the western United States supplying the remaining 30%. Florida supplies 45% of western Canada's fertilizer needs while the remaining 55% is imported from Utah, Idaho and Montana (Figure 3). In recent years Canada has begun importing phosphate rock from Morocco. Fertilizer plants in British Columbia presently import all of their feedstock from Montana. In 1986 the annual capacity of fertilizer plants in western Canada was 724 000 tonnes (Table 1), of which, the greatest capacity was in Alberta. At present there is only a single fertilizer plant in the province. It is located at Trail and operated by Cominco Limited.

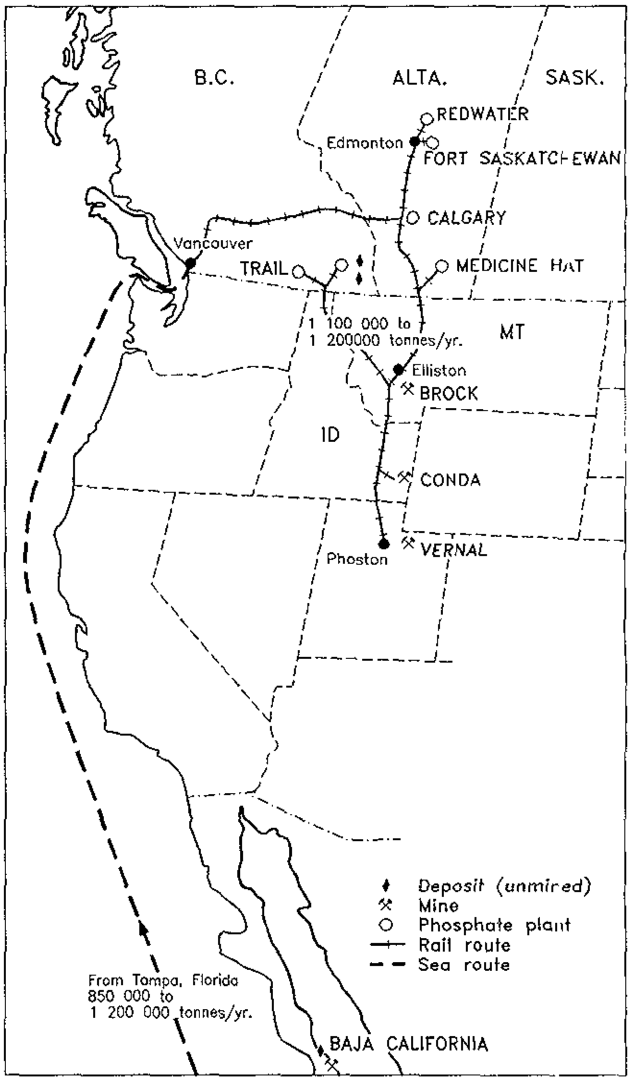


Figure 3. Sources of imported phosphate rock for western Canada, early 1980s (from Werner, 1982).

The upward trend of Canadian imports of phosphate rock for the period 1965 to 1986 (the last year for which data is available) is illustrated by Figure 4. In 1985 Canada imported 2.64 million tonnes of phosphate rock (Barry, 1986). Imports declined again in 1986 to 2.35 million tonnes. This downward trend is not expected to continue. Energy, Mines and Resources, Canada predicts that there will be an increase in demand but prices will not rise substantially until at least 1990-92 (Barry, 1987). Imports from Florida, Canada's traditional supplier, are expected to decrease because of decreased production resulting from higher mining costs related to lower grade deposits and environmental concerns. While there are sufficient reserves in the Phosphoria Formation in the western United States to take up the slack, many deposits are folded and faulted and not amenable to conventional mining methods (Cathcart, 1983). Increased production from the western United States will be required to offset increased consumption in the United States and a decrease in production from Florida. In mid 1988 Idaho's phosphate production was operating at capacity. If Canada is unable to obtain its phosphate requirements from current sources, it will have to look for new suppliers or produce phosphate rock from within its own borders. In response to this anticipated need to locate its own phosphate deposits studies were initiated by Energy, Mines and Resources, Canada and by the provincial government of Alberta (MacDonald, 1987) to assess the resource potential of phosphate in Canada and Alberta respectively. Similarly, in 1986, British Columbia also began an assessment of its phosphate potential, the results of which are presented in this report.

In 1983 the average price paid by Canadian fertilizer plants for phosphate rocks imported to Canada was C$75 (Prud'homme and Francis, 1987). Since that time prices have decreased dramatically. Current prices for phosphate rock are approximately US$27.50 f.o.b. vessel Tampa. The cost to Canadian fertilizer plants is actually higher once freight costs are included. These prices are expected to remain stable until the end of the 1980s and then rise to US$45.00 per tonne in 1995 (basis 70% bone phosphate of lime). A potential source of phosphate rock is from Baja California. Christie (1981) suggested that it would cost Canadian $73 per tonne to deliver this material to Calgary. Prices approaching the C$70 to C$80 range could make deposits in Canada economic (Barry 1987).

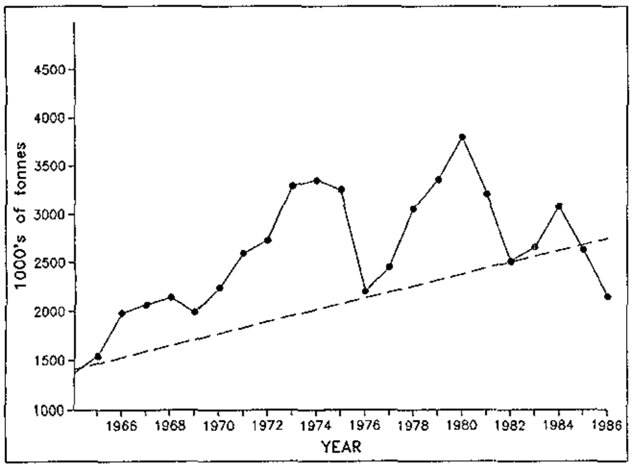


Figure 4. Canadian imports of phosphate rock, 1965-1986.

Byproducts that may be recovered from the processing of phosphate rock include uranium, vanadium, fluorine and rare earth elements. Uranium has the best potential for byproduct recovery but is generally only recovered at a very few plants. In Canada it is only recovered in a single plant in Alberta. World production of uranium is forcasted to meet demand until 1995 when production capability from known sources (including phosphate) will begin to decline and be overtaken by world demand (MacDonald, 1987).

Vanadium is used in the iron and steel industry but little is produced in Canada. This is the only metal that is currently being recovered as a byproduct of phosphate extraction in the United States. Presently world production exceeds demand, a situation which is expected to continue. Future market potential is predicted to increase by approximatley 2.9% until the year 2000 (Kuck, 1983).

Fluorine is used in the chemical, ceramics and steel industries and in the refining of uranium ores. Much of Canada's fluorspar requirements are imported from Mexico. Fluorine which can be recovered from phosphate as fluosilic acid is present in all of British Columbia's sedimentary phosphate deposits. Only modest growth is forcast for this commodity.

A variety of rare earth metals and yttrium occur in sedimentary phosphate deposits. Those in British Columbia are no exception. Rare-earth growth in the United States is forcast to be less than 3% while in Japan demand for yttrium, lanthanum, cerium and europium is expected to increase at the rate of 13 % compounded annually until the year 2000. The actual growth rate for yttrium in Japan in the past few years has been 35 % (King, 1986). At the present time world consumption for yttrium is growing at a rate of 10 to 17 % per annum. In 1986 the price of yttrium (99.99% purity) was U.S. $52.50 per kilogram. At the end of 1986 prices for cerium were between US$21.00 and 27.00 and for lanthanum they were between US$27.50 and 45.00 (King, 1986). Yttrium, lanthanum and cerium are used as dilutents in nuclear reactors. Rare earth elements are also used in magnetic materials, phosphors, neutron capture applications, glass, ceramics and other uses (King, 1986).

SCOPE OF WORK

Sedimentary phosphate was first discovered in Canada in 1915 near Banff in rocks of Permian age. In 1925 W.D. Burgess and L. Telfer discovered phosphate in Jurassic rocks in the Crowsnest Pass area. Since the early work of Telfer (1933) several companies that include Cominco Limited, Esso Resources, Crowsnest Industries Limited and First Nuclear Corporation have conducted exploration in southeastern British Columbia. Cominco Limited constructed adits at the Crow, Lizard and Marten properties and completed beneficiation tests but none went into production. Metallurgical studies were also done on phosphate from the Line Creek area. With the decline of phosphate prices in the early 1980's exploration activity declined. At

TABLE 1
CANADA, PHOSPHATE FERTILIZER PLANTS
(From Barry, 1987)

Company	Plant Location	Annual Capacity (tonnes P_2O_5 equivalent)	Principal End Products	Source of Phosphate Rock	Basis for H_2SO_4 Supply for Fertilizer Plants
EASTERN CANADA					
Belledune Fertilizer Div. of Noranda Inc.	Belledune, N.B.	150 000	am ph	Florida	SO_2 smelter gas
C.I.L. Inc.	Courtright, Ont,	90 000[1]	am ph	Florida	SO_2 smelter gas, pyrrhotite roast and waste acid
		240 000			
WESTERN CANADA					
Cominco Ltd.	Kimberley, B.C.	86 700[2]	am ph	Montana and Utah	SO_2 pyrite roast
	Trail, B.C.	77 300	am ph	Utah[3]	SO_2 smelter gas
Esso Chemical Canada	Redwater, Alta.	370 000	am ph	Florida	Sulphur
Sherritt Gordon Mines Limited	Fort Saskatchewan, Alta.	50 000	am ph	Florida	Sulphur
Western Co-operative Fertilizers Limited	Calgary, Alta.	140 000	am ph	Idaho Florida	Sulphur
		724 000			
Canada: installed capacity: mid 1986		964 000			
historical capacity:					
	end of 1983	1 031 000			
	end of 1984	913 000			
	end of 1985	788 000			
	end of 1986	698 000			

P_2O_5 equivalent - Phosphorus pentoxide equivalent; am ph Ammonium phosphates.

[1] Shutdown as of the end of June 1986.

[2] Shutdown in 1987.

[3] Phosphate now imported from Montana.

the beginning of this study in 1986,Cominco still retained a few phosphate leases north of Fernie, and in the Crowsnest Pass and Line Creek areas. In late 1988 and early 1989 there has been renewed staking activity for phosphate, specifically in the Cabin Creek area and along Alexander Creek north of the Crow deposit. In northeastern British Columbia exploration has concentrated on phosphate of Triassic age and recently on exploration for carbonatite deposits. Exploration work in conjunction with regional mapping programs and stratigraphic studies by the Geological Survey of Canada has delineated the stratigraphic setting of phosphate horizons and identified several significant phosphate occurrences. Although the carbonatite exploration was orientated towards niobium and rare-earth metals it did locate significant phosphate potential on the Aley property.

In this study, which began in 1986, all available data were collected and compiled in a province wide inventory with the objective of identifying potentially economic deposits. The compilation stage preceeded fieldwork in southeastern (1986) and northeastern (1987) British Columbia (Figure 5). This report summarizes the results of a two year program. Interim reports have been published previously in the 1986 and 1987 editions of Geological Fieldwork and as an open file (Butrenchuk 1987a,b; 1988).

During the compilation stage favourable stratigraphic horizons were identified and known phosphate occurrences

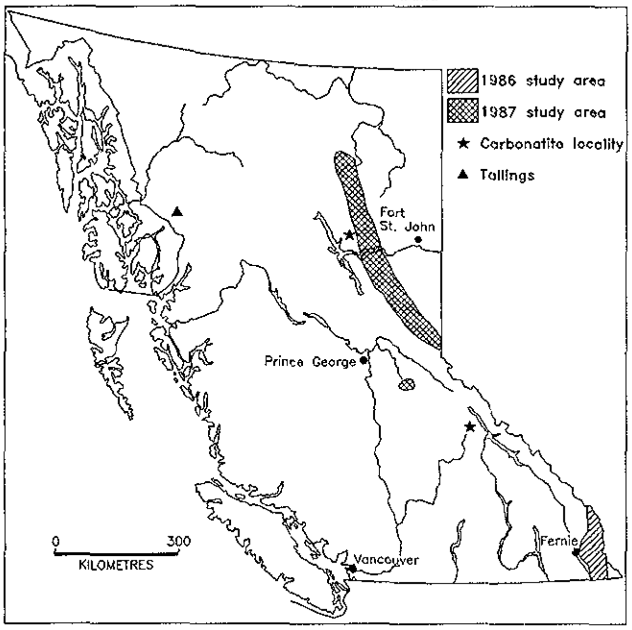


Figure 5. Location of study area.

were recorded for follow-up field examination. Fieldwork consisted of an evaluation of reported occurrences and examination of stratigraphic horizons known to contain phosphate. Phosphate localities were routinely sampled and, where possible, stratigraphic sections were measured. Samples were analyzed for phosphate using both x-ray fluoresence and wet chemical, volumetric techniques and for uranium, vanadium, yttrium, lanthanum, cerium and zinc using x-ray fluoresence only. In addition, samples collected from phosphate occurrences in southeastern British Columbia were analyzed for copper, lead, and arsenic. Specimens were also collected for petrogrpahic and x-ray diffraction studies and whole-rock and trace element analyses. Analyses were done by the Analytical Laboratory of the British Columbia Ministry of Energy, Mines and Petroleum Resources in Victoria and by Bondar-Clegg Company Limited in Vancouver. Analytical and petrographic data were used to identify possible beneficiation problems and potential byproducts. A cursory evaluation of the subsurface phosphate potential was also completed. This portion of the study concentrated on an area paralleling the outcrop of Triassic sedimentary rocks eastward to the Alberta border south of the Peace River. Northerly from the Peace River the eastern limit was delineated by the Alaska Highway.

In addition to investigating bedded phosphate deposits the resource potential of carbonatites was also evaluated. The Aley deposit north of MacKenzie and the Verity carbonatite north of Blue River were the only carbonatites investigated.

Other aspects of this study involved the sampling of tailings from the former producing Granduc Mine for phosphate and titanium and the investigation of Paleozoic strata in the Wells area east of Quesnel where phosphate and base metal mineralization has been reported (A.B. Mawer, oral communication, 1987). Samples from this locality were analyzed for phosphate, vanadium, barium, uranium, yttrium, lanthanum, cerium, copper and zinc.

ACKNOWLEDGMENTS

Funding for this program was provided by the Canada/British Columbia Mineral Development Agreement (1985-1990). The author gratefully acknowledges Cominco Ltd., Crows Nest Resources Ltd., and Esso Minerals Canada for providing pertinent phosphate data. Special gratitude is expressed to A. Legun who provided analytical and petrographic data from his 1985 fieldwork in the Wapiti Lake area; to David Grieve for his logistical support throughout the 1986 field season and to Shaun Pattenden and David Carmichael who provided able assistance in the field. Z.D. Hora is thanked for giving the author the opportunity to do this study and for providing many useful suggestions during its course. Drafting of the final figures was done by J. Armitage and input of the manuscript was done by D. Butrenchuk. The manuscript was critically reviewed by J. Newell who provided many useful improvements. Janet Holland and Doreen Fehr are acknowledged for the extensive and tedious work required to prepare this material for printing and I thank them for their many hours of hard labor.

CHAPTER 2

PHOSPHATE DEPOSITS OF THE NORTH AMERICAN CORDILLERA

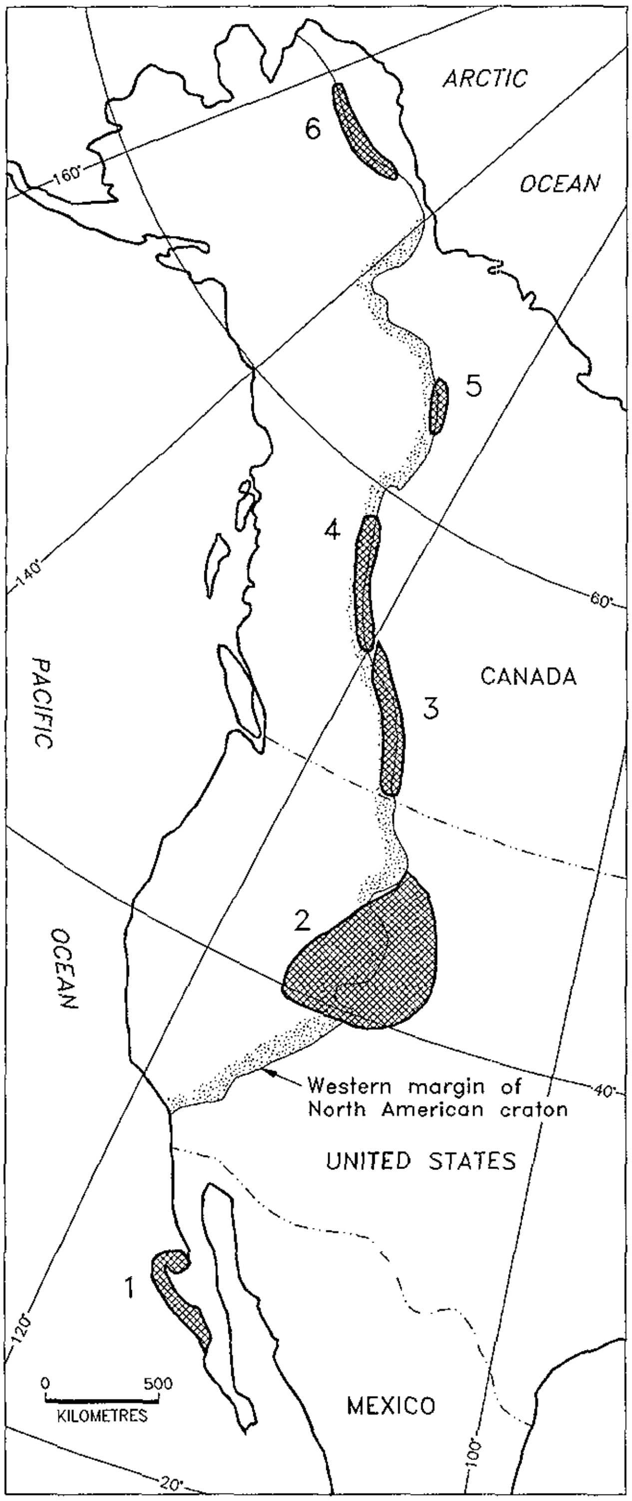


Figure 6. Distribution of phosphate deposits in the North American Cordillera: 1 - Baja, California: Miocene - Monterrey and San Isidro Fms.; 2 - Montana, Idaho, Wyoming and Nevada: Permian - Phosphoria Fm.; 3 - Southeastern British Columbia: Mississippian - Exshaw Fm.; Permian - Ishbel Group and Jurassic - Fernie Fm.; 4 - Northeastern British Columbia: Triassic - Sulphur Mountain and Toad Fms.; 5 - Yukon and Northwest Territories (Mackenzie Mountains): Silurian Whittaker fm.; 6 - Alaska (Brooks Range): Mississippian - Lisburne Group and Triassic - Shublik Fm.

Extensive bedded sedimentary phosphate deposits occur along the western margin of the craton in the North American Cordillera (Figure 6). The best studied of these deposits are those of the Permian Phosphoria Formation. The Phosphoria Formation covers an area of approximately 340 000 square kilometres and underlies parts of Montana, Idaho, Utah, Wyoming and Nevada. Phosphate deposits also occur at the base of the Mississippian in the Brazer limestone and Deseret limestone. The Phosphoria Formation is the source of much of the phosphate rock imported into western Canada.

In Alaska phosphate occurs extensively along the northern slope of the Brooks Range in the Mississippian Lisburne Group and the Triassic Shublik Formation. Their resource potential is estimated to be tens of billions of tonnes at greater than 10% P_2O_5 (Patton and Matzko, 1959). Phosphate deposits are associated with limestone, shale and chert.

In the MacKenzie Mountains, immediately east of the Yukon - Northwest Territories boundary, phosphate occurs associated with calcareous shales and argillaceous limestones in the Upper Ordovician to Lower Silurian Whittaker Formation. A phosphatic chert, in strata possibly equivalent in age, is associated with the Howards Pass lead-zinc deposit (Goodfellow and Jonasson, 1983).

Throughout geological time there have been distinct stratigraphic intervals in which phosphate deposition was more prevalent. Cretaceous and younger strata contain most of the world's phosphate reserves. The Permian was another important period of phosphate deposition. Most of the Permian reserves are contained in the Phosphoria Formation of the northwestern United States. In British Columbia phosphate occurs in formations that range in age from Cambrian to Jurassic. These correlate well with phosphogenic episodes worldwide. Although none of British Columbia's extensive marine sedimentary deposits are presently economic, significant deposits are present in the Permian Ishbel Group and its equivalents in the Middle Triassic Sulphur Mountain and Toad formations and in the Lower Jurassic Fernie Formation. These deposits, which are continuous throughout the Rocky Mountains of British Columbia and parts of western Alberta, are described in detail in the following chapter. Minor phosphate occurrences are present in Cambro-Ordovician, Devonian and Mississippian strata.

Carbonatites and related alkaline intrusions are the second most important source of phosphate worldwide. In British Columbia phosphate bearing carbonatites, most notably the Aley and Verity intrusions, are known at a number of localities. In addition to phosphate these carbonatites represent potential sources of niobium, tantalum and rare-earth elements (Pell, 1987; Aaquist, 1981).

FORMATION OF PHOSPHATE DEPOSITS

How sedimentary deposits develop has been the subject of much research and discussion over the years. Kazakov (1937) first postulated that they formed by direct chemical precipitation due to supersaturation when cold water enriched in phosphorus rises and meets warmer upper waters that are more alkaline and contain less dissolved carbon dioxide. He concluded that deposition took place in the photosynthesis zone at depths between 50 and 200 metres. Kazakov also observed that many of the phosphorites formed in the border zone between shallow-water platform sediments and deep water geosynclinal basins. Although Kazakov's theory of upwelling is still accepted, other factors appear to be important in the deposition and concentration of phosphate. His theory did not account for the suppression of calcium carbonate which normally precipitates under similar conditions to those favouring phosphate precipitation. In areas where there is high organic activity, it is possible for calcium carbonate to be suppressed as phosphate ion activity is increased.

Specific conditions are essential for the formation of phosphate deposits. An adequate source of phosphate is required as are areas where phosphorus can be accumulated. Some form of trap is required. Upwelling waters and the right chemical conditions for apatite precipitation are also needed (Sheldon, 1981). A sedimentation rate which is very slow or inhibited is also important. The formation of rich phosphate deposits is closely associated with restricted sedimentation and a high degree of stability in the basin and its supply of organic matter (Slansky, 1986). He postulates that it requires 200 000 to 1 000 000 years for a phosphate bed 1 metre thick to be deposited. Some authors have related phosphate deposition to diastemic conditions.

The best areas for phosphate deposition are basin margins or near shoal areas. This is most evident in the Phosphoria Formation where the best deposits occur at the structural hinge line between the stable shelf and the Cordilleran miogeosyncline. Once the phosphate has been deposited some reworking is required to concentrate it to economic grades. One process of upgrading is the winnowing out of organic matter, clays and fine clastic particles.

An adequate source of phosphorus is available in most seawater. It is estimated that the total phosphorus entering oceans from all sources is 1.6 million tonnes per year. The key factor is a concentrating mechanism. In areas of upwelling currents there is a proliferation of plankton and other organisms that utilize phosphorus in their life processes. These biota settle to the sea floor where some phosphorus is dissolved and returns to the sea and the remainder is concentrated interstitially in the sediments. Phosphate deposits can then form.

Phosphate deposits can form by primary precipitation at the seawater interface, by deposition of phosphate bearing organisms or by diagenetic precipitation in ocean floor sediments (Sheldon, 1981). One or all of these processes may be active at any given locality.

The type of phosphate deposit that may form is dependent upon the environment of deposition. Platformal phosphate deposits are nodular in habit and very often associated with glauconite. Miogeosynclinal deposits are bedded, most often pelletal and generally associated with black shales, chert, and occasionally limestone.

In British Columbia the majority of nodular deposits are interpreted to have formed diagenetically. Most of the nodules contain nucleii of varying descriptions, commonly one or more quartz grains, ammonite shells or other bioclastic material. Rapson-McGugan (1970) observed that compaction of the sediment surrounding the nodule took place as the nodule grew and displaced the sediment. Studies by Burnett *et al.* (1982) of nodules of Holocene to Late Pleistocene age along the Peru-Chile continental margin show that phosphate nodules grow slowly, at rates of less than 1 to 10 millimetres per 1000 years. They observed that these nodules occur at the sediment-water interface and form preferentially near the upper and lower boundaries of the oxygen minimum zone where it intersects the continental margin. They also noted that the nodules grow downward into the sediment. Deposition during the time of formation of these nodules is not necessarily slow. The source of the phosphorus and other elements contained in the nodules is believed to be sedimentary interstitial water. Christie (1978) states that the phosphate content of interstitial waters of marine sediments can be ten to a hundred times greater than that of sea water. Phosphate rich water will phosphatize clay, oozes, calcareous sediments and biogenic debris to form fluorapatite just below the sediment surface.

For some of the pelletal phosphorites it appears that the pellets formed by the precipitation of phosphate from seawater. In some of the Fernie phosphorites moulding of the pellets around others suggests that they were probably deposited in a gel-like state at or below the water/sediment interface. A few of these pellets also have quartz or carbonate nucleii. Elsewhere, especially in pelletal varieties of Triassic age, there are textures suggesting that phosphate formed as a replacement of calcium carbonate. The original sediment is thought to have been a limestone or calcareous siltstone that has been wholly or in part replaced by phosphate.

Most phosphate deposits appear to have formed within 30° of the equator (Christie, 1980). Many of British Columbia's phosphate deposits do not meet this criterium. Paleogeographic reconstruction indicates that the Whistler member was deposited within 30° of the paleoequator (Irving, 1979; MacDonald, 1985) while Triassic strata north of

Lemoray were deposited further to the north. Theoretically these more northerly exposures should not be expected to contain extensive phosphorite deposits. However, although not abundant, phosphorite has developed in more temperate climates as in the Jurassic Fernie Formation. There are extensive nodular phosphate beds in the Toad Formation and occasional thin phosphorite beds north of the Tetsa River, all of which are interpreted to have formed in a temperate climate.

Many phosphate deposits in British Columbia are spatially related to transgressive unconformities. MacDonald (1985) suggests that deep ocean circulation is speeded up during periods of transgression or regression. This increased circulation should then be able to supply more phosphate to areas where all other factors required for the formation of phosphate are favourable. The best deposits are those located immediately above unconformities, an example of which is the phosphorite at the base of the Fernie Formation.

CLASSIFICATION OF SEDIMENTARY PHOSPHATE DEPOSITS

Phosphate rock occurs in a variety of forms many of which are present in the British Columbia Cordillera. Variations in petrology are a reflection of the genesis of the deposits. Oolitic varieties are generally associated with a near shore, moderately agitated environment whereas structureless pellets are formed in deeper water. Petrological variations are also an important factor with respect to the beneficiation of phosphate rock.

Slansky (1986) proposed a classification of phosphate rocks based on their physical characteristics, using the parameters of grain size of the main phosphate fraction and the nature of the non-phosphatic fraction. This is mainly a qualitative classification.

Mabie and Hess (1964) while studying the Phosphoria Formation developed a more rigorous classification primarily orientated towards pelletal phosphorites. Their classification used a three component system consisting of fluorapatite or collophane, quartz and chert and muscovite-sericite-clay as the three end members. The terms "calcareous" and "ferruginous" were used to describe phosphate rock containing more than 10% carbonate and 1 to 2% iron respectively.

A more comprehensive classification is proposed for British Columbia phosphate deposits based on Pettijohn's (1957) tetrahedral classification of sedimentary rocks while retaining the compositional parameters established by Mabie and Hess. A complete classification using the end-members phosphate, quartz, carbonate and muscovite and clay is given in Figure 7. This classification is more quantitative while still retaining some petrological aspects of these deposits. It can be used to compare phosphorite deposits throughout North America. For deposits in British Columbia this classification can be simplified to a three component system by using either carbonate or muscovite-sericite-clay as the third end member. The derivation of mineralogical components in the Mabie and Hess classification and the classification proposed in this study is detailed in Appendix 1. Deposits in the phosphorite fields could represent potentially economical deposits; deposits plotting near the carbonate or muscovite-clay end members may be difficult to beneficiate.

Figures 8, 9, 10 and 11 are diagrammatic representations for phosphorites from the Permian, Toad and Sulphur Mountain Formations and the Fernie Formation respectively. A number of samples from the Phosphoria Formation are included for comparison.

Most of the phosphate-bearing rocks in the Permian are classified as phosphatic sandstones or siltstones (Figure 8). Samples from Weigert Creek (57) are calcareous. Also, samples from both Weigert Creek and Nordstrum Creek can be classified as the only true phosphorites. They are slightly more siliceous than phosphorite from the Phosphoria Formation.

Samples from the Toad Formation (Figure 9) can be classified as siliceous while samples from the Whistler member of the Sulphur Mountain Formation (Figure 10) are distinctly calcareous and plot towards the carbonate end member.

For the Fernie Formation (Figure 11) there is a wide variation in phosphate deposits ranging from very siliceous to calcareous. Western localities (Liz, 6 and 11) are carbonate rich whereas eastern localities are quartz rich. The Crow deposit (4) is the only exception as it contains some carbonate. A sample from Fording River (6) plots in the phosphatic limestone-siltstone field corresponding to what is observed in the field.

Phosphate deposits can also be classified according to their iron and organic matter content (Figure 12). The majority of British Columbia phosphates are slightly to moderately carbonaceous or bituminous and generally non-ferruginous. A single sample from the Permian (84) is both highly carbonaceous and slightly ferruginous. Interestingly this sample is also anomalous in gold.

WEATHERING OF PHOSPHATE DEPOSITS

Weathering is an important consideration in the evalutaion of both sedimentary and carbonatite phosphate deposits as it may cause enrichment in the phosphate by leaching of the more soluble constituents. In some localities within the Phosphoria Formation the P_2O_5 content may decrease by as much as 5% below the outcrop surface (Cheney, 1957). *A deposit mineable at surface may not be economic at depth.*

Several factors affect the degree to which phosphate deposits are weathered. Weathering is more intense close to old erosion surfaces or faults that facilitate the movement of groundwater and hence weathering. Weathered phosphate rocks generally have a very low carbonate and organic content.

The effects of weathering appear to be most prevalent in the Fernie Basin. Here, differential weathering has been superimposed on carbonate rich strata along its western margin and weakly calcareous shales along its eastern margin. Along the western margin calcite dominates the gangue mineralogy while along the eastern and southeastern mar-

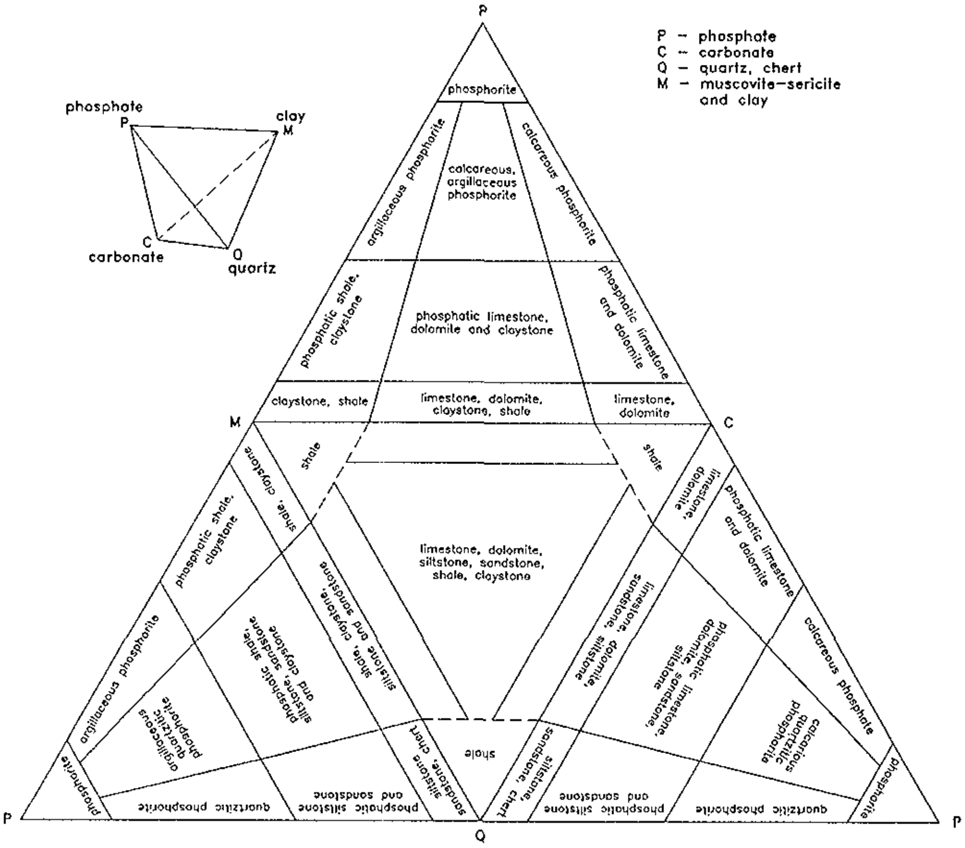


Figure 7. Proposed classification for phosphate deposits in British Columbia.

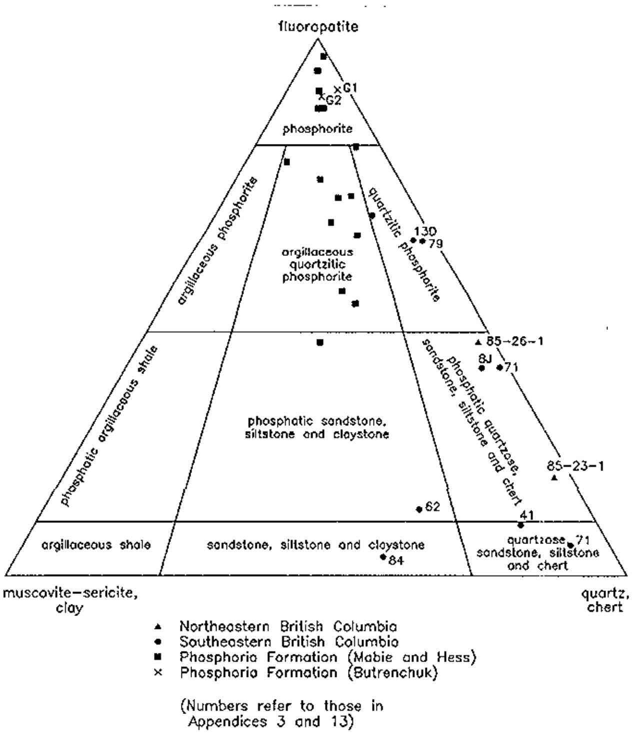


Figure 8. Compositional classification of phosphate-bearing strata of the Permian (after Mabie and Hess, 1964).

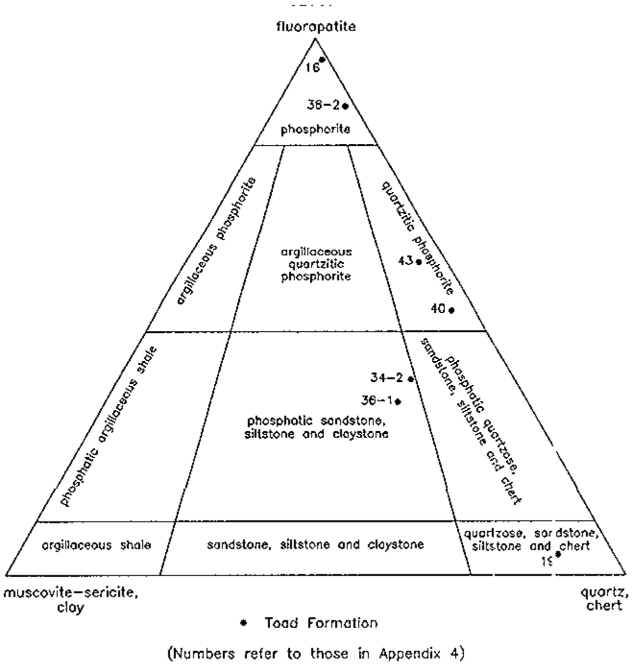
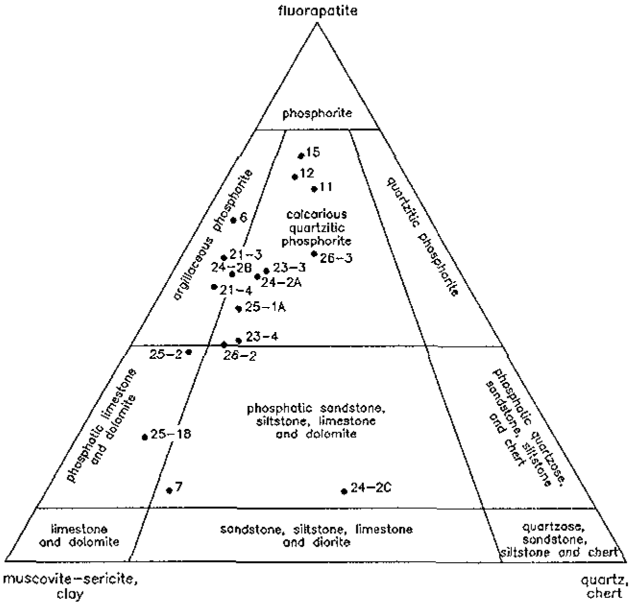
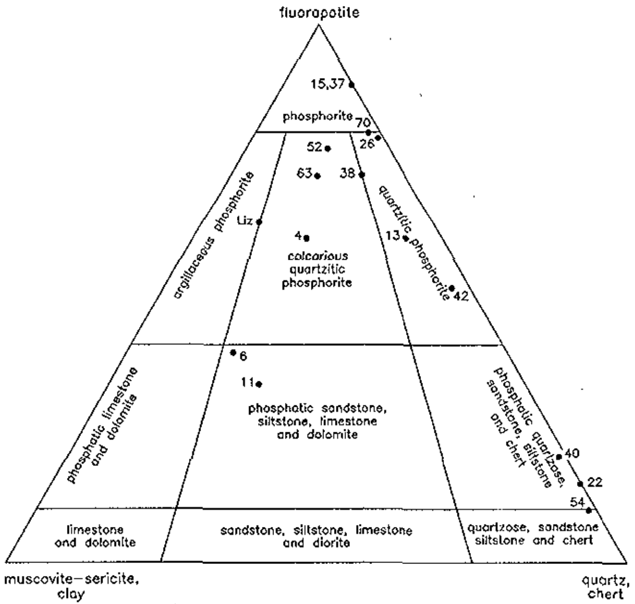


Figure 9. Compositional classification of phosphate-bearing strata for the Toad Formation (after Mabie and Hess, 1964).



(Numbers refer to those in Appendices 4 and 13)

Figure 10. Compositional classification of the Whistler member phosphate based on the three-component system: fluorapatite-quartz-carbonate.



(Numbers refer to those in Appendix 5)

Figure 11. Compositional classification of the basal Fernie phosphate based on the three-component system: fluorapatite-quartz-carbonate.

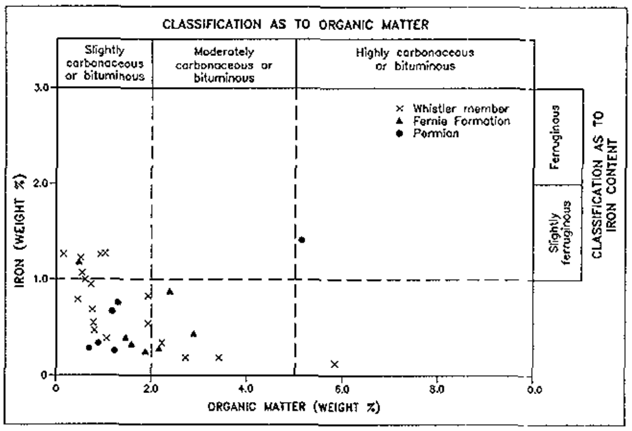


Figure 12. Classification of phosphate deposits according to their organic and iron content (after Mabie and Hess, 1964).

gins of the Fernie Basin quartz is dominant and calcite is only a minor constituent, locally becoming virtually absent. Dolomite is rare or absent throughout the Fernie Basin. The presence of yellow-orange weathering beds above the phosphorite is another indication of weathering. In the western United States strongly weathered phosphatic strata contain a thin residuum of pale or dark yellowish orange mudstone (Cheney, 1957). Similar beds were only observed in more easterly exposures of the Fernie phosphate. These same exposures very often have a basal phosphatic conglomerate that is interpreted to have formed on an erosion surface. Thrust faulting is also much in evidence. Both of these features would promote weathering of the phosphate deposits.

Weathering of surface phosphate has been cited as the reason for differences in grade between surface and drill-core samples in the Line Creek (Hannah, 1980) and Barnes Lake areas (Dales, 1978). The presence of blebs of limonite replacing pyrite grains indicates that some weathering has taken place. It is most pronounced in the Barnes Lake area and at the Lodge phosphate occurrence. In thin section there is no indication that weathering has affected the phosphate pellets.

Only minor weathering appears to have occurred in phosphorite of the Whistler member of the Sulphur Mountain Formation. Carbonate is abundant in the most southerly exposures becoming rare at the northernmost locality. Locally many of the pellets have a lighter coloured rim suggesting that some organic matter may have been removed. The degree to which weathering has affected the phosphorite appears to increase northwards.

Permian phosphate deposits in British Columbia appear have been less affected by weathering processes.

Only surface exposures were sampled in this study and the depth to which the phosphate may have been weathered, or how much the grade may have been affected were not determined.

CHAPTER 3

STRATIGRAPHY OF SEDIMENTARY PHOSPHATE DEPOSITS IN BRITISH COLUMBIA

REGIONAL STRATIGRAPHY

Bedded phosphate deposits in British Columbia occur in a sequence of Helikian to Lower Jurassic marine strata (Tables 2 and 3) deposited in a miogeosyncline along the western edge of the stable craton (Douglas and Price, 1972). Depositional environments varied from platformal to basinal with phosphate occurring most often in platformal or shelf-edge facies.

Cambrian to Mississippian strata consist of shallow-water carbonate assemblages that pass westward into deeper water, more basinal limestone, shale and siltstone facies (Cecile and Norford, 1979; McMechan, 1987). During the Cambrian there were a number of marine transgressions with each successive transgression progressing further eastward (McCrossan and Glaister, 1964). Deposition of fine clastic sediments predominated through Ordovician and Silurian time. The Devonian is characterized by the development of widespread evaporitic conditions and the deposition of platform carbonates. Phosphate deposition was restricted to the Upper Cambrian and Lower Ordovician in northeastern British Columbia. In southeastern British Columbia deposition of the first phosphate took place in the Upper Devonian to Lower Mississippian Exshaw Formation. The remainder of the Mississippian is represented by crinoidal limestone, argillaceous and cherty limestone and shale of the Rundle Group. These rocks were deposited in a shallow shelf environment.

During the Pennsylvanian, deposition of shallow-marine fine clastic and carbonate strata took place under quiescent conditions (Douglas *et al.*, 1970). Quartzitic sandstone and chert-bearing dolomite and limestone were deposited in a neritic to littoral environment.

An unconformity marks the transition from Pennsylvanian to Permian deposition. The Permian was characterized by low hinterland relief and low-energy, shoreline conditions (MacRae and McGugan, 1977) in which fine-grained sandstone, siltstone, chert and minor shale and phosphate were deposited. Numerous marine transgressions and regressions resulted in a number of unconformities. In the waning stages of the Permian, sabkha conditions appear to have been present locally, resulting in the deposition of evaporites. Phosphate deposition occurred at several stratigraphic intervals and is frequently associated with the unconformities.

Mesozoic strata consisting dominantly of fine clastic sediments, unconformably overlie the Paleozoic sequence. During the Early Triassic there was a rapid marine transgression. Deposition was continuous through the early and middle Triassic except in the Wapiti Lake area where there is a disconformity of short duration between the Vega-Phroso and Whistler members of the Sulphur Mountain Formation. Phosphorite approaching economic grade occurs above this disconformity.

Early Triassic deposition took place in a stable shelf environment. The eastern limits of the shelf are marked by bar and deltaic deposits (McCrossan and Glaister, 1964; Douglas *et al.*, 1970). During the Middle Triassic deposition took place under partially restricted stagnant conditions. Lower and Middle Triassic sediments are characterized by their uniformity and widespread continuity of stratigraphic units.

Following the Late Triassic regression sediments of the Whitehorse Formation (northeast British Columbia) and Charlie Lake Formation (Pine Pass area) were deposited in a more restricted shallow-marine, intertidal and/or lagoonal environment with an arid to semi-arid climate (Douglas *et al.*, 1970; Gibson, 1974, 1975). At the same time sediments of the Ludington Formation were deposited in slightly deeper water in an environment that probably represents the western margin of a tidal flat or intertidal shelf (Gibson, 1975). A major unconformity marks the end of the Triassic.

Another marine transgression occurred in the Early Jurassic. Widespread deposition of phosphorite and phosphatic shales began in Sinemurian time with phosphatic shales persisting into the Toarcian. Sedimentation gradually became non-marine at the end of the Jurassic in southeastern British Columbia but marine deposition continued into the Cretaceous in the northeastern corner of the province.

The Rocky Mountains in which these bedded phosphate deposits and marine strata occur are characterized by thrust faults and concentric folds. Thrust faults are generally southwest dipping, concave upward and imbricate; northeastward displacements of up to 165 kilometres are envisaged in southeastern British Columbia (Benvenuto and Price, 1979; MacDonald, 1985). Notable examples of these faults are the Lewis thrust with a displacement of 72 kilometres (Christie and Kenny, in preparation), the Hosmer thrust west of Fernie and the Bourgeau thrust along the west side of the Elk River. While closely spaced thrust faults predominate in the southern Rocky Mountains, widely spaced thrusts and more numerous concentric folds prevail in the north.

A second important structural feature in the southeast is the Fernie synclinorium. This double-plunging synclinal fold, which is outlined by the outcrop of the Jurassic Fernie Formation, has been the focus of phosphate exploration for many years. Several west-side-down normal faults cut

TABLE 2
STRATIGRAPHY OF PHOSPHATE-BEARING FORMATIONS IN SOUTHEASTERN BRITISH COLUMBIA

Age	Group/Formation (Thickness, Metres)	Lithology	Phosphate	Thickness (metres)	Grade (% P_2O_5)
Cretaceous	Kootenay Fm.	— grey to black carbonaceous siltstone and sandstone; nonmarine; coal			
Jurassic	Fernie Fm. (±244)	— black, shale, siltstone, limestone; marine to nonmarine at top — glauconitic shale in upper section — belemnites; common fossil — *rare calcareous sandstone* — thin conglomerate may be present at base	— approximately 60 metres above base low-grade phosphate-bearing calcareous sandstone horizon or phosphatic shale		
			— basal phosphate in Sinemurian strata; generally pelletal/oolitic; rarely nodular; 1-2 metres thick; locally two phosphate horizons; top of phosphate may be marked by a yellowish orange weathering marker bed	1-2	11-29
		regional unconformity			
Triassic	Spray River Group Whitehorse Fm.	— dolomite, limestone, siltstone			
	Sulphur Mtn. Fm. (100-496)	— grey to rusty brown weathering **sequence of siltstone, calcareous** siltstone and sandstone, shale, silty dolomite and limestone	— nonphosphatic in southeastern British Columbia		
		regional unconformity			
Permian	Ishbel Group Ranger Canyon Fm. (1-60)	— sequence of chert, sandstone and siltstone; minor dolomite and gypsum; conglomerate at base — shallow marine deposition	— upper portion — brown, nodular phosphatic sandstone; also rare pelletal phosphatic sandstone (few centimetres to >4 metres)	0.6	9.5
			— basal conglomerate-chert with phosphate pebbles present (≤1 metre)	0.5-1.0	13-18
	Ross Creek Fm. (90-150)	— sequence of siltstone, shale, chert, carbonate and phosphatic horizons areally restricted to Telford thrust sheet — west of Elk River, shallow marine deposition	— phosphate in a number of horizons as nodules and finely disseminated granules within the matrix — phosphatic coquinoid horizons present	0.4-1.0	1.7-6.0
		unconformity			
	Telford Fm. (210-225)	— sequence of sandy carbonate containing abundant brachiopod fauna; minor sandstone — shallow marine deposition	— rare, very thin beds or laminae of phosphate; rare phosphatized coquinoid horizon	0.3	11.4
	Johnston Canyon *Fm. (1-60)*	— thinly bedded, rhythmic sequence of siltstone, chert, shale, sandstone and minor carbonate; basal conglomerate — shallow marine deposition	— phosphate generally present as *black ovoid nodules* in light-coloured siltstone; phosphatic interval ranges in thickness from 1-22 metres	1-22	0.1-11.0
			— locally present as a black phosphatic siltstone or pelletal phosphate	0.2-0.3	3.0-4.0
			— basal conglomerate (maximum 30 centimetres thick) contains chert and phosphate pebbles	1-2	14.2-21.2
		regional unconformity			
Pennsylvanian	Kananaskis Fm. (±55)	— dolomite, silty, commonly contains chert nodules or beds	— locally, minor phosphatic siltstone in uppermost part of section	1.0	tr-1.3
	Tunnel Mountain Fm. (±500)	— dolomitic sandstone and siltstone			
Mississippian	Rundle Group (±700)	— limestone, dolomite, minor shale, sandstone and cherty limestone			
Mississippian	Banff Fm. (280-430)	— shale, dolomite, limestone			
Devonian-Mississippian	Exshaw Fm. (6-30)	— black shale, limestone — areally restricted in southeastern British Columbia	— an upper nodular horizon	0.1	15
			— basal phosphate less than 1 metre thick; pelletal	1	6-10
			— phosphatic shale and pelletal phosphate 2-3 metres above base	0.1-0.3	1-9
Devonian	Palliser Fm.	— limestone			

TABLE 3
STRATIGRAPHY OF PHOSPHATE-BEARING FORMTIONS IN NORTHEASTERN BRITISH COLUMBIA

Age	Formation (Thickness) (Metres)	Lithology	Phosphate	Thickness (Metres)	Grade (P_2O_5)
Cretaceous	Monteith (700)	– sandstone, minor; marine			
Jurassic	Fernie Fm. 250 - 900	– shale; siltstone, minor limestone and sandstone; marine Regional Unconformity	– as phosphatic limestone of the Nordegg member of Sinemurian age – reported as far north as Wapiti River (Irish, 1970)		
Upper Triassic	Baldonnel Fm. (155)	– limestone, dolomite, siltstone, sandstone; marine marine			
	Charlie Lake Fm. (290) Whitehorse 400	– silty dolomite, dolomitic siltstone, sandstone; marine			
Middle and Upper Triassic	Ludington Fm. 400 Liard Fm. (450)	– dolomitic to calcareous siltstone, limestone; marine – dolomitic to calcareous sandstone and siltstone, dolomite, limestone; marine			
Lower and Middle Triassic	Toad Fm. (300) Sulphur Mountain Fm. (500) Llama Member (60-350)	– calcareous siltstone, silty limestone, silty shale, siltstone, minor sandstone; carbonaceous siltstone and shale; marine	– thick pelletal and nodular phosphorite bed at base of Whistler; also phosphatic limestone and siltstone	1–1.5 metres	
	Whistler member (30)	– local disconformity at base of Whistler Disconformity	– phosphate nodules in carbonaceous and calcareous siltstones and shale; also phosphatic siltstone and shale; minor pelletal phosphate north of Richards Creek	beds 1–3 metres thick; stratigraphic intervals 20–290 metres	11–24
	Grayling Fm. (75) Vega-Phroso member (50–250)	Regional Unconformity	– minor phosphate in the upper part of the Vega-Phroso member and lower part of the Llama member; minor phosphate in upper part of Grayling Fm.	0.2–0.6 metres	0.31–1.92
Permian	Mowitch (5-22) Fantasque Fm. (10–40)	– siltstone, phosphatic siltstone	– phosphatic nodules in siltstone (1 metre thick) near top of formation	0.34–0.60	6.8–16.2
	Ranger Canyon (3)	– chert Unconformity	– cherts are weakly phosphatic		
Pennsylvanian	Kindle Fm. (70)	– argillaceous limestone, shale, clcareous siltstone. Regional unconformity	– phosphatic lenses in shale along the Alaska Highway		
Mississippian Devonian	Flume Fm. (55-75)	– limestone, calcareous shale, sandstone	– 30 centimetres thick phosphate bed reported near Kakwa Lake		
Lower Ordovician	Road River Fm. (165–200)	– black shale, siltstone limestone, minor dolomite; marine	– phosphatic siltstone in basal part of formation; also thin phosphatic shale beds higher in section		
Lower Ordovician –UpperCambrian	Kechika Fm. (1500)	– argillaceous, nodular limestone, minor shale; banded limestone; marine	– thin beds containing phosphate fossil debris, pellets and microcrystalline phosphate (phosphate pavements) – parts of the nodular limestone are phosphatic – thin veneer of phosphatic shale or limestone around nodules		
Upper Cambrian		–shale, siltstone, argillaceous limestone	– thin beds containing phosphate lenses or nodules		

though the centre of the synclinorium, including the Erickson and Flathead faults.

Another important feature throughout the Rocky Mountains is a general thinning of stratigraphic units eastward. Thicker, more basinal deposits in the west give way to thinner shelf or platformal deposits in the east.

An important factor in the evaluation of phosphate deposits is the structural style of the host rocks. In southeastern British Columbia beds of Triassic or older age generally have gentle to moderate dips. The Jurassic Fernie Formation, being less competent, has absorbed much of the structural deformation and beds may have gentle to vertical dips. In many places beds of all ages are overturned and truncated by thrust faults. Elsewhere, especially in the Fernie Formation, thrusting has caused a repetition of beds, as at the Crow property (Telfer, 1933), resulting in a thickening of the phosphate section. Areas where phosphate beds have been thickened by repetitive thrust faulting are of particular economic significance, as are areas of overturning where competent strata of the Triassic Sulphur Mountain Formation overlie the basal phosphate and incompetent shale beds of the Jurassic Fernie Formation. Imbricate thrust faults and overturned folds are uncommon in Mesozoic rocks in the northeast and are not an important consideration. To the west in Paleozoic rocks the structure is more complex where locally thrust faulting is a signficant structural feature.

PHOSPHATE DEPOSITION

British Columbia phosphate deposits are of the miogeosynclinal type as defined by Christie (1978). The majority of the pelletal deposits are believed to have formed in a reducing but non-toxic environment near the outer edge of the continental shelf. Host lithologies are very often carbonaceous and the phosphorites are dark coloured as are the surrounding sediments. Pyrite often occurs in trace to minor amounts.

Nodular phosphate deposits are interpreted to have formed in a platformal environment at or near wave base. In some of the Triassic deposits crossbedding is present in the adjacent rocks. Host rocks for Permian nodular phosphates are generally quartzose sandstones and siltstones. The Triassic Toad Formation nodular phosphates occur in carbonaceous shales, quartzose siltstones and fine sandstones. These sediments are locally calcareous and limestone beds are occasionally present.

Phosphate deposition in British Columbia occurred principally in the Cambro-Ordovician Kechika Formation, the Devono Mississippian Exshaw Formation, the Permian Ishbel Group, the Triassic Toad Formation and Whistler member of the Sulphur Mountain Formation, and the Jurassic Fernie Formation (Tables 2 and 3). There are minor occurrences in the Ordovician Road River Formation, the Devonian Flume Formation, the Mississippian Black Stuart Formation and the Late Pennsylvanian Kananaskis Formation. The Jurassic Fernie Formation and the Permian Ishbel Group in southeastern British Columbia and the Sulphur Mountain Formation in the northeast contain phosphate deposits of some economic significance while the remaining phosphatic units are of interest only as marker horizons or as mineralogical curiosities.

CAMBRO-ORDOVICIAN PHOSPHATE

UPPER CAMBRIAN

Investigation of Upper Cambrian strata was restricted to the Mount Sheffield area in the headwaters of the Muskwa River at latitude 57°46′ north, longitude 124°35′ west (Figure 13). Lithologies consist of fine-grained sandstone, shale and siltstone. These rocks are thin to medium bedded and weakly calcareous. A grey calcareous siltstone that contains lenses of phosphatic material outcrops at this locality (Cecile and Norford, 1979). Beds are 5 to 20 centimetres thick and bedding planes are frequently marked by pyrite bands 1 to 2 millimetres thick. The stratigraphic position of this unit may be in the uppermost section of the Upper Cambrian sequence in strata equivalent to the Atan Group or in the lower part of the Kechika Formation.

Cecile and Norford describe the occurrence of phosphate as black nodules in sporadic shale beds 120 to 220 metres below the bottom of the Kechika Formation. These phosphate occurrences were not seen in outcrop during this study but similar material was found in talus. In addition some thin, poorly developed pelletal phosphorite beds in fine siltstone were identified.

KECHIKA FORMATION

Investigation of the Kechika Formation was restricted to a single locality in the vicinity of Grey Peak within Kwadacha Provincial Park (Figure 13). Previous work by Cecile and Norford (1979) had documented the presence of phosphate at various intervals in the upper part of the formation. This study focused on the uppermost unit of the

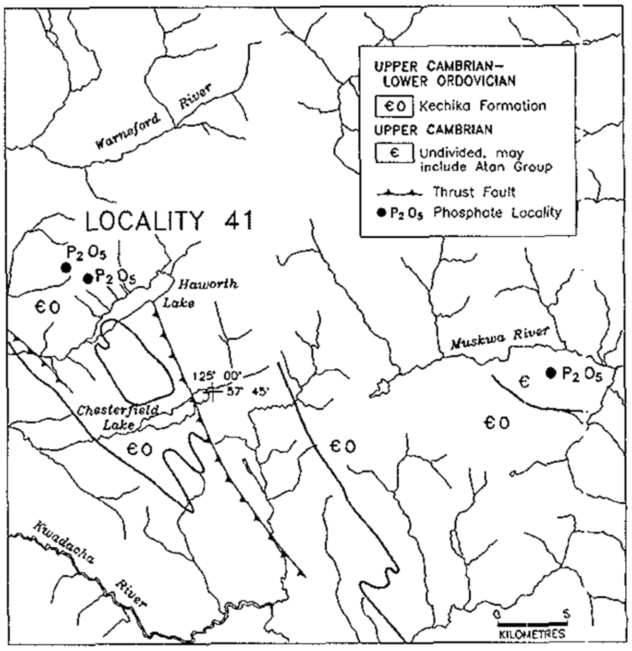


Figure 13. Distribution of Kechika Formation and phosphate deposits in the Grey Peak - Mount Sheffield area.

Kechika Formation (Unit OK4 of Cecile and Norford) and lower units of the Road River Formation (Photo 1); the presence of the phosphate beds was confirmed.

Cecile and Norford divided the Kechika Formation into five units. The lower two units consist of platy and arenaceous limestones and a putty-grey weathering, nodular, argillaceous limestone. A banded limestone overlies these units and is overlain in turn by a thick sequence of argillaceous, nodular calcilutite which is in excess of 500 metres thick in the Grey Peak area. This nodular unit can be traced southward into the Mount Selwyn area (MacIntyre, 1981, 1982; McMechan, 1987). Thin phosphate beds are present in the upper 100 metres of this unit. The uppermost unit of the Kechika Formation consists of yellowish orange weathering limestones, not observed at Grey Peak.

Thin phosphate beds occur at five horizons in the upper 100 metres of the nodular limestone unit. Phosphate is present as microcrystalline coatings, 1 to 10 millimetres thick, around limestone nodules, and as phosphatized fossil debris in beds 5 to 50 centimetres thick. Some pelletal and oolitic phosphate is also present. The phosphatic beds are recognized by their blue weathering surfaces and black colour contrasting with the pale grey of the host limestone. Also present, but not obvious, are thin phosphatic coatings, 1 millimetre or less in thickness, surrounding limestone nodules in beds two or more metres thick. Phosphate also occurs at several horizons in the lower banded limestone unit. Cecile and Norford describe these lower phosphate occurrences as "sea floor pavements or lag deposits".

The Kechika Formation can be traced southeastward through the Ware map area into the headwaters of the Ospika River (MacIntyre, 1980) but no phosphate has been observed outside the Grey Peak area.

Cecile and Norford postulate that the Kechika Formation was deposited in a shelf-margin environment. Deposition took place at the edge of a subtidal carbonate platform to the east, and in progressively deeper water to the west, towards Grey Peak. There is a corresponding westerly thickening of this formation towards the basin.

ROAD RIVER FORMATION

The Ordovician Road River Formation consists primarily of black siltstone and shale, calcareous shale and minor limestone. In the Grey Peak area (Figure 13 fine siltstone and graptolitic shale conformably overlie nodular limestone of the Kechika Formation. The lowermost unit is approximately 60 metres thick and very weakly phosphatic throughout, containing very fine-grained phosphate clasts, sometimes associated with glauconite. The phosphatic unit is overlain by a non-phosphatic carbonate sequence which in turn is overlain by siltstone and shale. Phosphate occurs in thin (1 centimetre) beds throughout the basal portion of this upper clastic unit (Unit OR3 of Cecile and Norford, 1979). In 1989, a low grade phosphatic black shale was observed in Road River Formation in the area of Cassiar asbestos mine (Hora and Nelson, personal communication, 1990).

The Road River Formation was deposited in a shallow basinal environment. The basal Road River records a period of slow sedimentation as evidenced by the presence of phosphate and glauconite.

DEVON-MISSISSIPPIAN PHOSPHATE

EXSHAW FORMATION

In southeastern British Columbia the earliest recorded deposition of phosphate took place in the Upper Devonian to Lower Mississippian Exshaw Formation. This is a distinctive, recessive black shale unit that forms an excellent marker. Exposures of Exshaw Formation are restricted to a narrow band in the High Rock Range, locally in the Flathead River area, and in the Morrissey Range south of Fernie. The

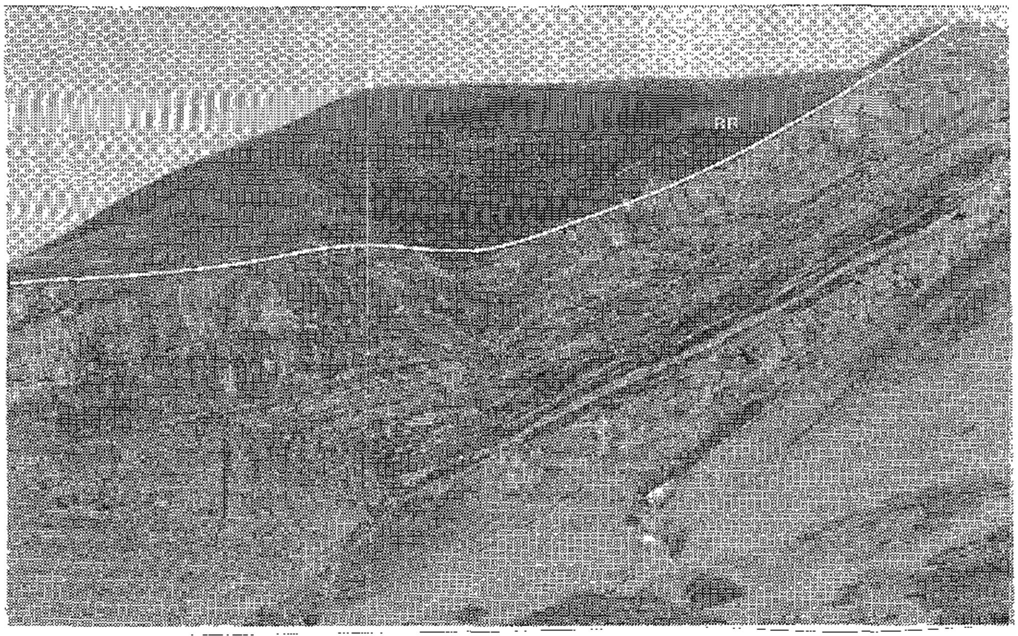


Photo 1. Section through Upper Kechika Formation (K) and Lower Road River Formation (RR) near Grey Peak.

best occurrences of phosphate occur north and south of Crowsnest Pass (MacDonald, 1985).

Investigation of the Exshaw Formation was limited to a single outcrop on the south side of Highway 3, at the southwest end of Crowsnest Lake. Here, the formation is in fault contact with the underlying Palliser Formation and is comprised of shale, fine siltstone, phosphatic shale and minor phosphate. A limestone band present within the unit may belong to the Banff Formation. The overlying shale may be a repetition of the Exshaw as there is a fault at the top of the limestone. Phosphate at this locality is low grade (less than 4% P_2O_5) with the highest grade (3.60% P_2O_5) occurring above the central limestone band.

Phosphate occurs at four horizons within the Exshaw Formation (MacDonald, 1985). A basal phosphate, sometimes present in sandstone overlying the top of the Palliser Formation, is absent at the locality on Highway 3. Three other phosphate horizons occur in the middle and upper parts of the formation.

The Exshaw Formation is conformably overlain by the Lower Mississippian Banff Formation, a sequence of interbedded limestone, dolomite and shale 280 to 430 metres thick, in turn overlain by the Rundle Group, a resistant carbonate unit also of Mississippian age, approximately 700 metres thick (*see* Table 2). Neither of these units are known to be phosphatic.

PENNSYLVANIAN PHOSPHATE

TUNNEL MOUNTAIN FORMATION

The Lower Pennsylvanian Tunnel Mountain Formation of the southern Rocky Mountains is described as a uniform, monotonous sequence of reddish brown weathering dolomitic sandstone and siltstone (MacDonald, 1985). It is exposed as far west as the Elk River (Figure 14, in pocket) where it attains thicknesses in excess of 500 metres and thins eastward to a thickness of 18 metres in the High Rock Range. Minor phosphate is associated with intraformational conglomerate (1.22% P_2O_5 across 10 centimetres) within this formation in Alberta (MacDonald, 1985).

KANANASKIS FORMATION

The Middle Pennsylvanian Kananaskis Formation conformably overlies the Tunnel Mountain Formation. It consists of a sequence of light grey, silty dolomite and dolomitic siltstone. Chert nodules and intraformational chert breccias are found in the upper part of the section. This unit attains its greatest thickness (approximately 70 metres) near Fernie and gradually thins eastward. Its contact with the overlying Permian Ishbel Group is unconformable and is generally marked by a phosphatic chert-pebble conglomerate 30 centimetres thick. Locally, as in the vicinity of the Fernie skihill, this conglomerate bed is only 1 centimetre thick.

Phosphate is rare in the Kananaskis Formation, recorded at only one locality adjacent to the MacDonald thrust fault, where disseminated phosphate grains and rare nodules or intraclasts are present in a calcareous siltstone. Some phosphate also replaces shell fragments or sponge spicules. A grab sample of typical material from this locality contained 1.3% P_2O_5.

PERMIAN PHOSPHATE: THE ISHBEL GROUP AND CORRELATIVE ROCKS IN NORTHEASTERN BRITISH COLUMBIA

Permian rocks extend throughout the Rocky Mountains of British Columbia. They unconformably overlie Pennsylvanian and Mississippian strata and are unconformably overlain by Triassic rocks. Regional correlations are shown in Figure 15. Phosphate deposits occur at several stratigraphic horizons within the Permian.

In southeastern British Columbia Permian strata are represented by the Ishbel Group which is comprised of four formations containing a number of phosphatic horizons. Phosphate is present in the Johnston Canyon, Ross Creek and Ranger Canyon formations. The Telford Formation is non-phosphatic except for phosphate laminae and rarely, a very thin phosphate bed. In northeastern British Columbia the Permian is comprised of the Kindle, Belcourt, Fanto, Ranger Canyon, Fantasque and Mowitch formations (McGugan and Rapson, 1964b) of which the latter two contain phosphate horizons.

The term Ishbel Group is not applied to strata in northeastern British Columbia although stratigraphically equivalent rocks are present. The Kindle and Belcourt formations can be correlated with the upper part of the Johnston Canyon Formation; the Fantasque Formation can be correlated with the Ranger Canyon Formation. The Mowitch Formation is younger that the Ishbel Group.

Phosphate deposits within the Ishbel Group have been known since 1916 (de Schmid, 1917). These strata occur extensively throughout southeastern British Columbia (Figure 17, with their maximum development in the Telford thrust plate west of the Elk River and north of Sparwood (MacRae and McGugan, 1977). The Ishbel Group has been correlated with the Phosphoria Formation of the western United States where extensive phosphate deposits are mined.

The Phosphoria Formation which is comprised of a sequence of shale, carbonate, chert, phosphorite and phosphatic shale is representative of miogeosynclinal deposits. Facies variations indicate deposition in a basin that was deepest in central Idaho and shallower to the north, east and west. It is estimated to have a resource potential of 22.5 billion tonnes of which 1.5 billion tonnes are considered economic reserves. The phosphate content varies between 18 and 36% P_2O_5 averaging approximately 25%. Phosphate is typically pelletal and consists of fluorapatite, quartz, minor muscovite and illite, and lesser organic material, carbonate and iron oxide.

Permian phosphate deposits in southeastern British Columbia and southwestern Alberta occur at several stratigraphic intervals. The Johnston Canyon and Ranger Canyon formations are the most significant phosphate resource potential, because of their widespread distribution (MacDonald, 1985, 1987). Phosphate is also present in the Ross Creek Formation but its distribution is restricted and good expo-

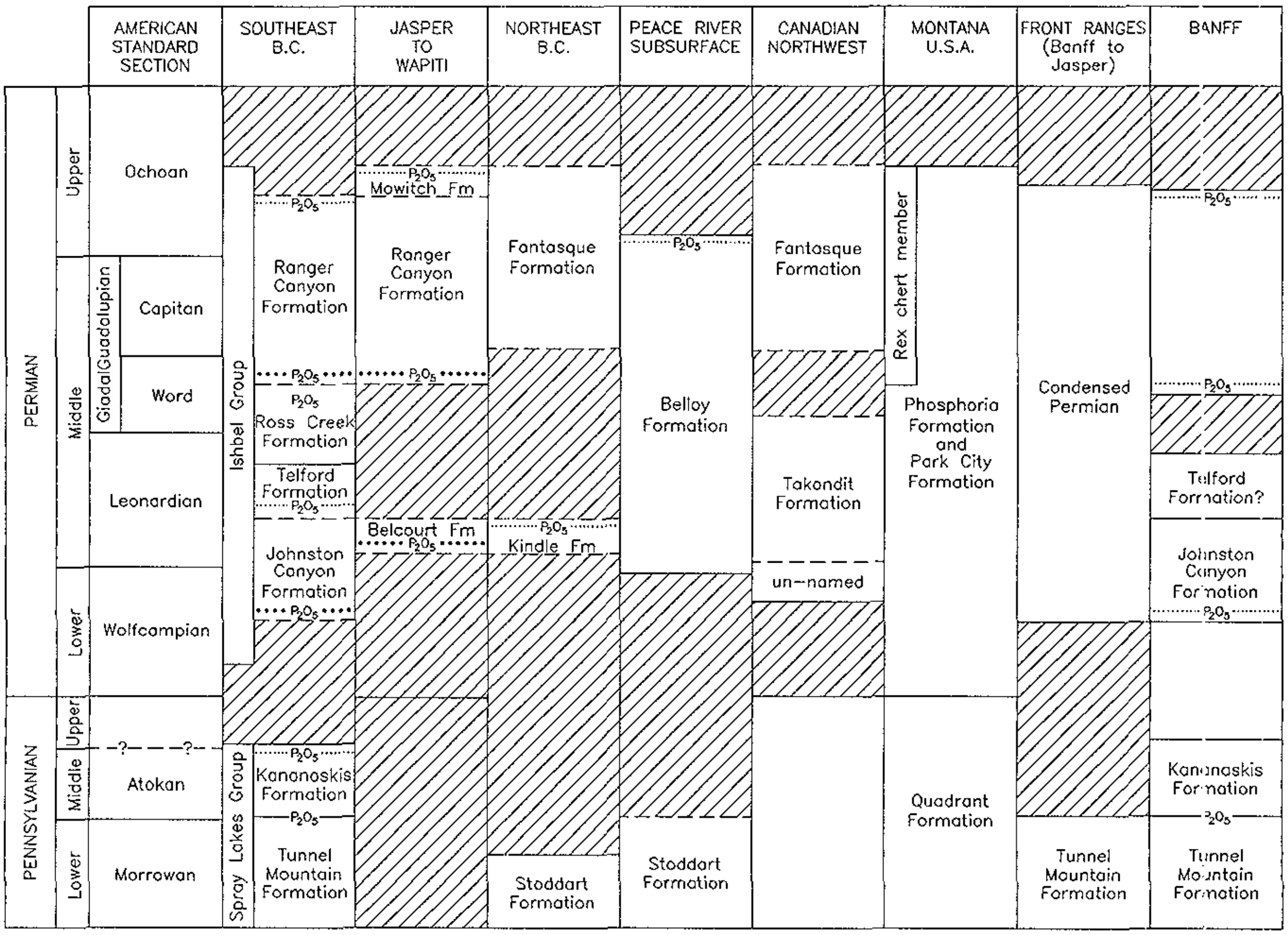


Figure 15. Stratigraphic correlation of Pennsylvanian-Permian strata and phosphate horizons in the North American Cordillera (modified from McCrossan and Glaister, 1964; Bamber *et al.*, 1968; MacDonald, 1985).

sures are rare. Deposition was in a shallow shelf environment, with the eastern sequence being deposited close to a hinge line parallel to a shoreline trend (MacRae and McGugan, 1977). Host lithologies vary from conglomerate to fine-grained sandstone, siltstone and shale. Phosphatic intervals vary considerably in thickness and grade.

Phosphate occurs in a number of forms but nodular varieties are the most common. Phosphate nodules may comprise anywhere from 5% of the rock by volume to almost the entire rock (Telfer, 1933). Although the nodules themselves may contain 25 to 32% P_2O_5, the rock as a whole rarely exceeds 2% P_2O_5. The best exposures of nodular phosphate lie along the MacDonald thrust fault, particularly near Mount Broadwood and in the Connor Lakes area, north of Forsyth Creek. Pelletal varieties are relatively uncommon, but where present, grades are generally in excess of 12% P_2O_5.

JOHNSTON CANYON FORMATION

The Johnston Canyon Formation, which unconformably overlies Kananaskis or Tunnel Mountain strata, consists of a series of thin to medium-bedded siltstones and sandstones with minor shale and chert. Locally these rocks are calcareous. A phosphatic chert-pebble conglomerate, a few centimetres thick, marks the base of the formation (MacRae and McGugan, 1977). Phosphate is present as black nodules in distinct horizons within sandstone, siltstone or calcareous siltstone beds at or near the base of the formation. It is also present as phosphate-cemented siltstone or as pelletal phosphorite. Phosphatic intervals range in thickness from less than 1 metre to a maximum of 22 metres near Mount Broadwood.

The nodular phosphatic horizons may contain true nodules formed *in situ* or intraclasts that have been transported a short distance. Intraclasts are distinguished from nodules by the fact that contained nuclei differ in size from that of the surrounding matrix; they may also be comprised of several pellets or of bioclastic debris.

Pelletal phosphorite crops out north of Weigert Creek. Phosphate pellets 0.1 to 0.5 millimetre in size comprise 50 to 60% of the rock. The pellets are subrounded, ovoid, structureless and chestnut-brown to dark brown in colour, set in a matrix consisting mainly of quartz and calcite.

Phosphate, probably fluorapatite, cements quartz grains in sedimentary rocks near the headwaters of Nordstrum Creek. Pelletal phosphorite is also present in a bed 1 metre thick and containing 21.2% P_2O_5.

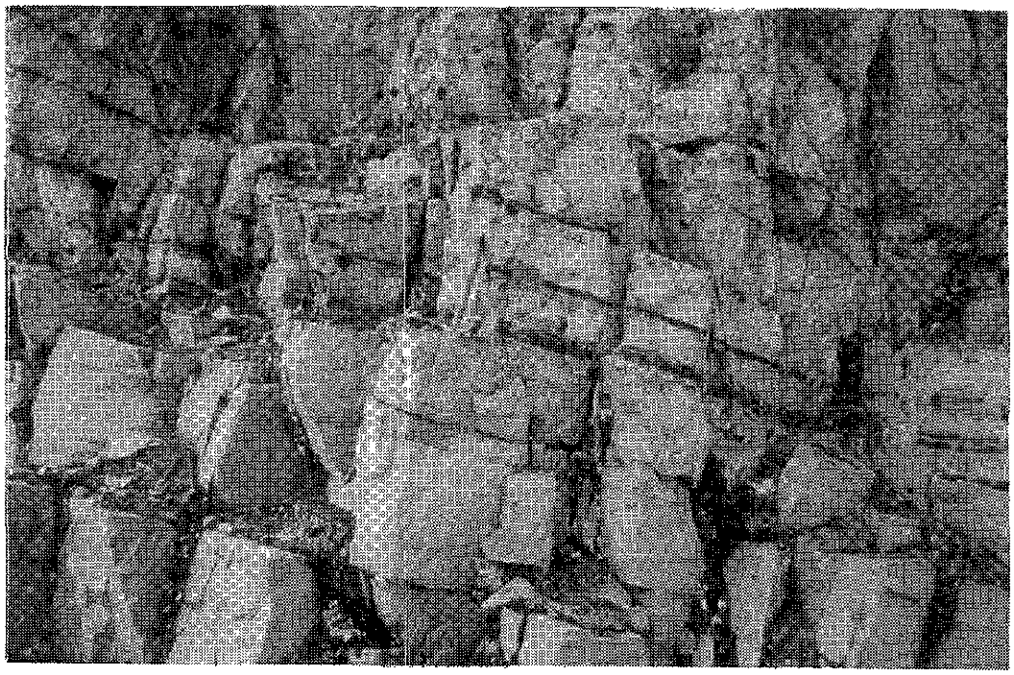


Photo 2. Phosphate laminae (blue-Black) in a sandstone bed, Telford Formation, Telford Creek.

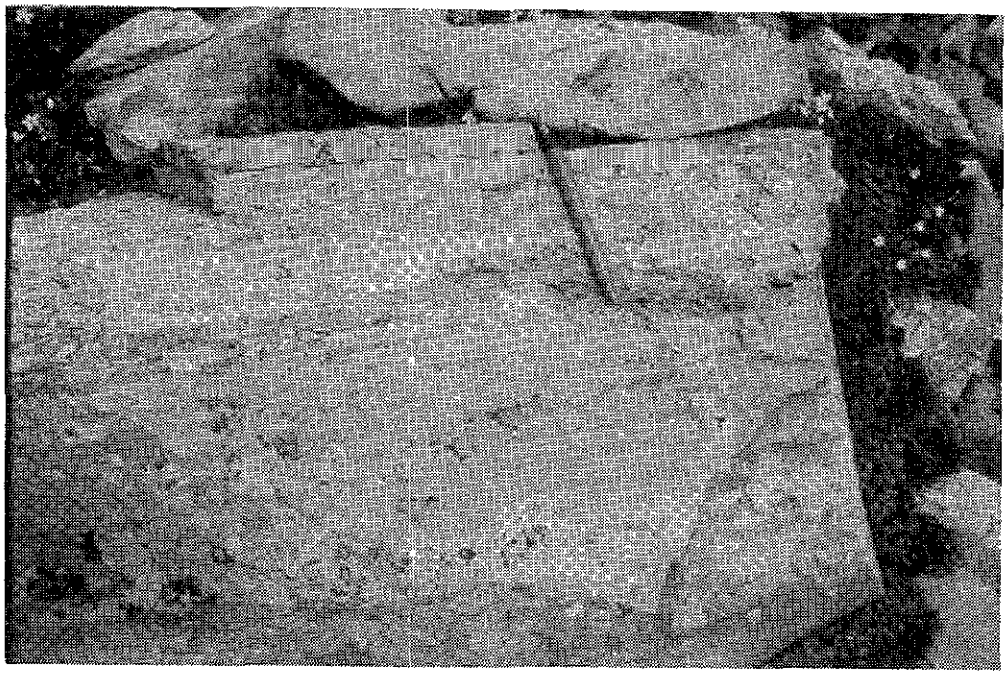


Photo 3. Phosphatic coquinoid bed (blue) in Telford Formation, Telford Creek.

TELFORD FORMATION

The Telford Formation comprises a thick sequence of cliff-forming carbonates and sandy carbonates, generally thick bedded and fossiliferous, that are preserved only in the Telford thrust plate (MacRae and McGugan, 1977).

Phosphate is present in the middle part of the section as a single nodular phosphate bed, 30 centimetres thick; a sandstone bed containing fine phosphate laminae (Photo 2); and a phosphatic coquinoid bed, 5 centimetres thick (Photo 3). These occurrences were not documented prior to this study. Although thin, these beds appear to have been deposited over a wide area under conditions of very quiescent sedimentation.

ROSS CREEK FORMATION

The Ross Creek Formation, preserved only in the Telford thrust plate, consists of a sequence of recessive, thin-bedded siltstone, argillaceous siltstone, minor carbonate and chert (MacRae and McGugan, 1977). Nodular phosphate occurs high in the section, associated with relatively thin coquinoid beds (Photo 4). The matrix in the coquinoid beds contains some phosphatic material. Pelletal phosphate is also present locally, as at the Elkford ski-hill. Unlike the other occurrences in the Ross Creek Formation, the phosphate at this locality occurs at the base of the formation, in an overturned sequence.

RANGER CANYON FORMATION

The Ranger Canyon Formation has been studied in detail and much of the information presented is summarized from Rapson-McGugan (1970) and MacRae and McGugan (1977).

In southeastern British Columbia this formation, which unconformably overlies the Ross Creek Formation, is a cliff-forming sequence of chert, cherty sandstone, siltstone, fine sandstone and conglomerate. Minor gypsum, as a primary cement in sandstone, and dolomite are also present. These strata are postulated to have been deposited in two environments: a shallow marine shelf starved of terrigenous material but able to produce clastic and authigenic phosphate; or a shoreline constructed of quartzose and phosphatic detritus. The depositional environment of the Ranger Canyon Formation is compared to that of Baja, California, where shelf phosphate, with associated lag gravels, is forming offshore at the present time.

The base of the Ranger Canyon Formation is marked by a phosphate-cemented chert-pebble conglomerate containing massive phosphate intraclasts (Photo 5). This conglomerate was only seen beneath the MacDonald thrust fault in the Cabin Creek area.

Phosphate also occurs in sandstone beds in the upper part of the formation where it is most commonly present as nodules (Photo 6) but also as detrital apatite, amorphous and crystallized fragments of bone material, pellets, rods, spheres and oolites. Rapson-McGugan also noted that phosphate is the second most abundant clastic component after quartz, generally comprising 5 to 6% of the rock. Phosphate is also present as phosphatic chert. Rapson-McGugan suggests that much of the chert is a replacement of pelletal phosphorite resulting from solution of phosphate under acidic conditions. If the solution becomes slightly alkaline, some relict phosphate will remain in the chert. Cherts in the Ranger Canyon Formation were not studied in detail. No petrographic or analytical work was done on them in the course of this study.

Phosphate beds in the upper part of the Ranger Canyon Formation range in thickness from a few centimetres at Mutz Creek to 4 metres at Fairy Creek, north of Fernie. With the exception of a phosphate bed in the vicinity of the Fernie ski-hill, most are low grade.

Between Kakwa Lake and Wapiti Lake in northeastern British Columbia the Ranger Canyon Formation consists predominantly of chert averaging 3 metres thick. Its base is marked by a phosphatic, chert conglomerate.

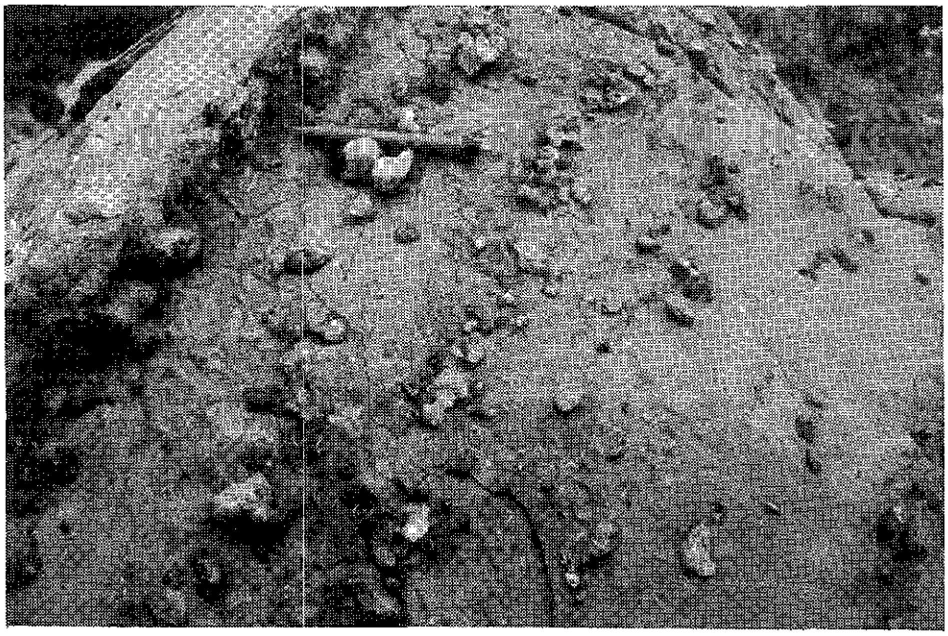


Photo 4. Phosphate nodules in a calcareous siltstone-coquinoid sequence of the Ross Creek Formation north of Sulphur Creek.

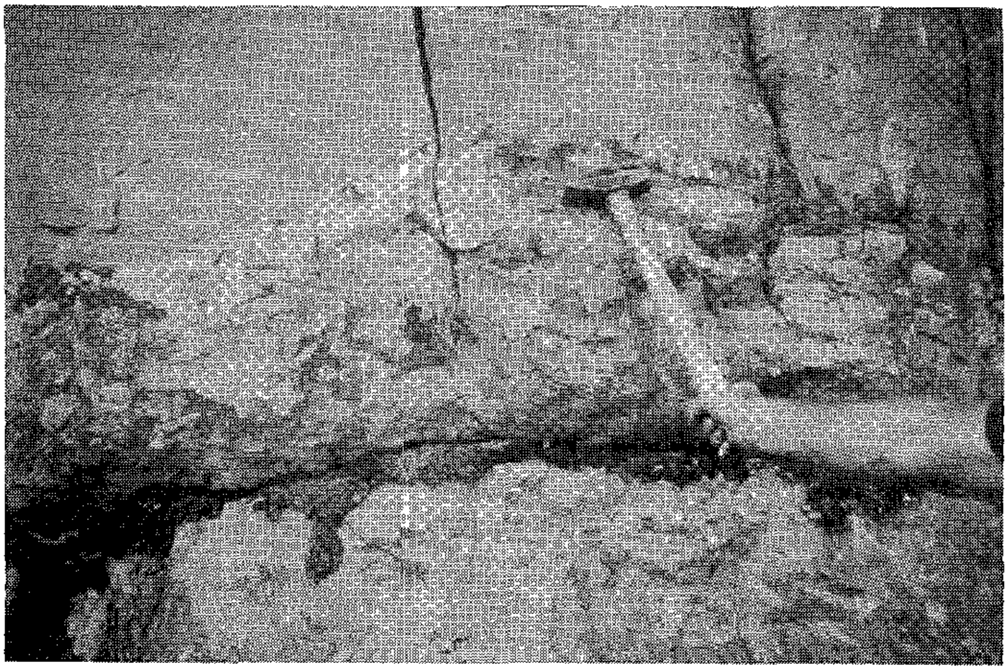


Photo 5. Basal conglomerate with phosphate cement (PC) and phosphate pebbles (P) in the Ranger Creek Formation, Cabin Creek area.

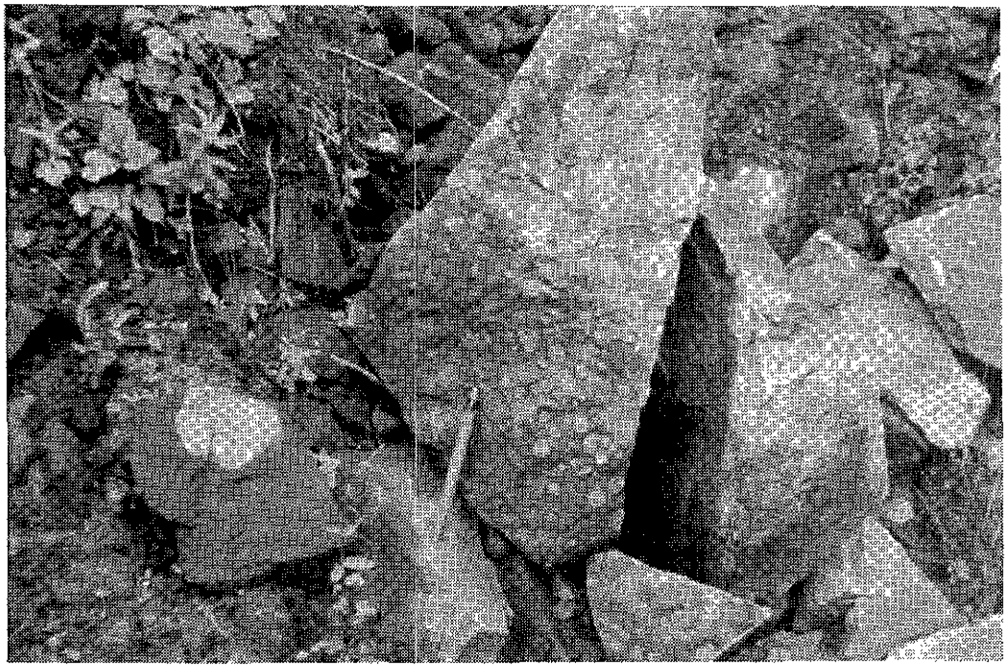


Photo 6. White-weathering phosphate nodules in a siltstone from the Ranger Canyon Formation, Cabin Creek area.

BELCOURT FORMATION

The Belcourt Formation is restricted to a narrow belt extending from Jarvis Creek north to Wapiti Lake (Figure 16) in northeastern British Columbia. It is approximately 30 metres thick and consists of thick and thin-bedded silty dolomite and limestone (McGugan and Rapson, 1964b). Chert nodules occur throughout the formation. The thickness of this unit is variable; no phosphate is known within it. It is assigned a Lower to Middle Permian age and may, in part, be stratigraphically equivalent to the Johnston Canyon Formation.

MOWITCH FORMATION

The Mowitch Formation is also restricted to a narrow belt in the front ranges of the Rocky Mountains between Jarvis Creek and Lemoray in northeastern British Columbia (Figures 16 and 17). It conformably overlies chert of the Ranger Canyon Formation and consists of thin, brown, phosphatic, siltstone to fine sandstone. The uppermost bed, which is approximatley 1 metre thick, is characterized by the presence of black, ovoid phosphate nodules. This nodular phosphate-bearing siltstone bed which is exposed at Wapiti Lake and Meosin Mountain is similar to a nodular unit seen in the Connor Lakes area, except that the nodules are smaller and more abundant.

The Mowitch Formation is unconformably overlain by shale and siltstone of the Vega-Phroso member of the Triassic Sulphur Mountain Formation. The depositional environment is considered to be shallow water in close proximity to the eastern shoreline of the basin (McGugan and Rapson, 1964b).

KINDLE FORMATION

The Kindle Formation outcrops in a belt along the western Rocky Mountains from the Halfway River northwards to the Toad River, with the best exposures between the Racing and Toad rivers (Taylor and Stott, 1973) (Figures 18, in pocket, to 20).

This formation, comprising a sequence of siltstone, shale, siliceous limestone and chert, unconformably overlies older strata and is unconformably overlain by the Fantasque Formation. It is 90 to 205 metres thick with the variation in thickness being due to erosion prior to deposition of the overlying rocks. Phosphate-bearing strata are locally present near the top of this formation, in exposures along the Alaska Highway immediately east of Summit Lake. The phosphate is present as black, wispy lenses and laminations in a dark grey siliceous shale associated with phosphatic chert.

At Mount Greene, north of the Peace River, phosphatic horizons were noted in strata underlying the Ranger Canyon Formation (McGugan, 1967). These rocks are tentatively correlated with the Kindle Formation (Bamber *et al.*, 1968) and are lithologically similar to the Johnston Canyon Formation in southeastern British Columbia.

FANTASQUE FORMATION

The Fantasque Formation of Permian age outcrops in a semi-continuous band from north of Lemoray, into the Yukon. It overlies younger Permian and Mississippian strata unconformably and is unconformably overlain by Triassic rocks. Lithologies consist primarily of chert with minor interbedded siliceous mudstone and siltstone. The chert is medium to dark grey in colour, locally pyritic, contains sponge spicules and very often traces of phosphate.

Phosphate nodules occur in a siltstone bed at the top of the Fantasque Formation in the Burnt River area. The siltstone bed is approximately 1 metre thick and contains 10 to 40% nodules by volume. It is believed to be stratigraphically equivalent to a siltstone bed in the Wapiti Lake area where two samples returned assays of 6.8 and 16.2% P_2O_5 across thicknesses of 63 and 34 centimetres respectively (A. Legun, personal communication, 1987). The author interprets this horizon to be correlative with a similar bed occurring at the top of the Ranger Canyon Formation near Connor Lakes in southeastern British Columbia (Butrenchuk, 1987), and to the bed at the top of the Mowitch Formation at Meosin Mountain and Wapiti Lake.

BELLOY FORMATION

Subsurface strata in the Peace River district, equivalent in age to the Fantasque and Ranger Canyon formations are assigned to the Belloy Formation, consisting of a lower carbonate member, a sand member and an upper carbonate member. Phosphate may be present in all three members. Phosphatic fish remains are present in the Sand member and glauconite is a major component of the sand.

The upper carbonate member consists of limy to dolomitic, fine-grained quartzose sandstones that grade into dolomitized limestones and bedded cherts (Halbertsma, 1959). Phosphatic fish remains are common and a phosphate-rich horizon, varying from a few centimetres to in excess of 2 metres, is reported near the top of the formation (J. MacRae, oral communication, 1988).

TRIASSIC PHOSPHATE

Triassic strata in northeastern British Columbia are exposed in a north-northwest trending belt from the Alberta - British Columbia boundary at 54° north latitude into the Yukon (Figure 21). This study focused on Lower and Middle Triassic strata in which phosphate has been reported by Gibson (1971, 1972, 1975) and Pelletier (1961, 1963, 1964). The Sulphur Mountain Formation south of Pine Pass and the Toad and Grayling formations north of Pine Pass are of particular interest. Correlation of the various stratigraphic units is shown in Figure 22.

Triassic sedimentation took place on a stable shelf characterized by a pattern of embayments and platforms. A minor embayment, flanked to the south by the Wapiti platform and to the north by the Nig Creek platform, developed south of Fort St. John during the Early Triassic (McCrossan and Glaister, 1964) (Figure 23). These conditions prevailed into the early Middle Triassic and probably exerted some control on phosphate deposition.

The majority of the known phosphate occurrences, and phosphatic sediments occur in the Whistler member of the Sulphur Mountain Formation and in correlative rocks of the Toad Formation (Figure 24) both of Anisian age. Phosphate

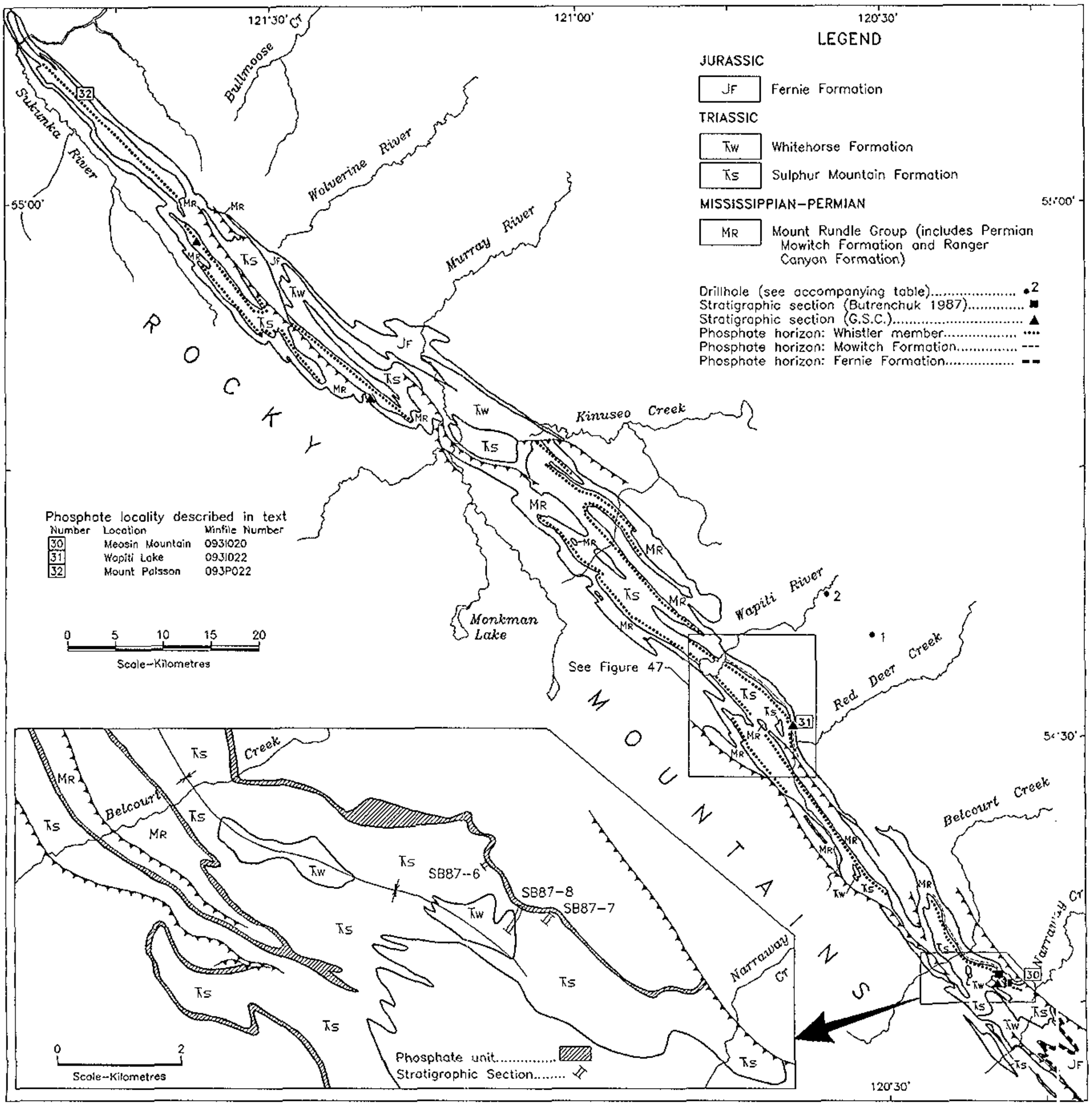


Figure 16. Distribution of phosphate bearing strata in the Monkman Pass - Sukunka River area (93I and 93P).

SUMMARY OF SUBSURFACE WELL DATA

Map No.	Drillhole	Latitude	Longitude	Phosphatic Interval (metres)	Comments
1	Triad Prairie a-24-H	54°36'08	120°32'37''	1112 - 1125 3024 - 3030	Trace phosphate pellets in shale - Toad Fm. Phosphate pellets in shale - Toad Fm.
2	Quasar Union Onion c-69-H	54°38'30''	120°36'36''	869 - 872 984 - 987 1000 - 1003	Phosphate pellets in sandstone - Toad Fm. Coarse phosphate pellets in shale - Toad Fm. Phosphate pellets in shale Toad Fm.

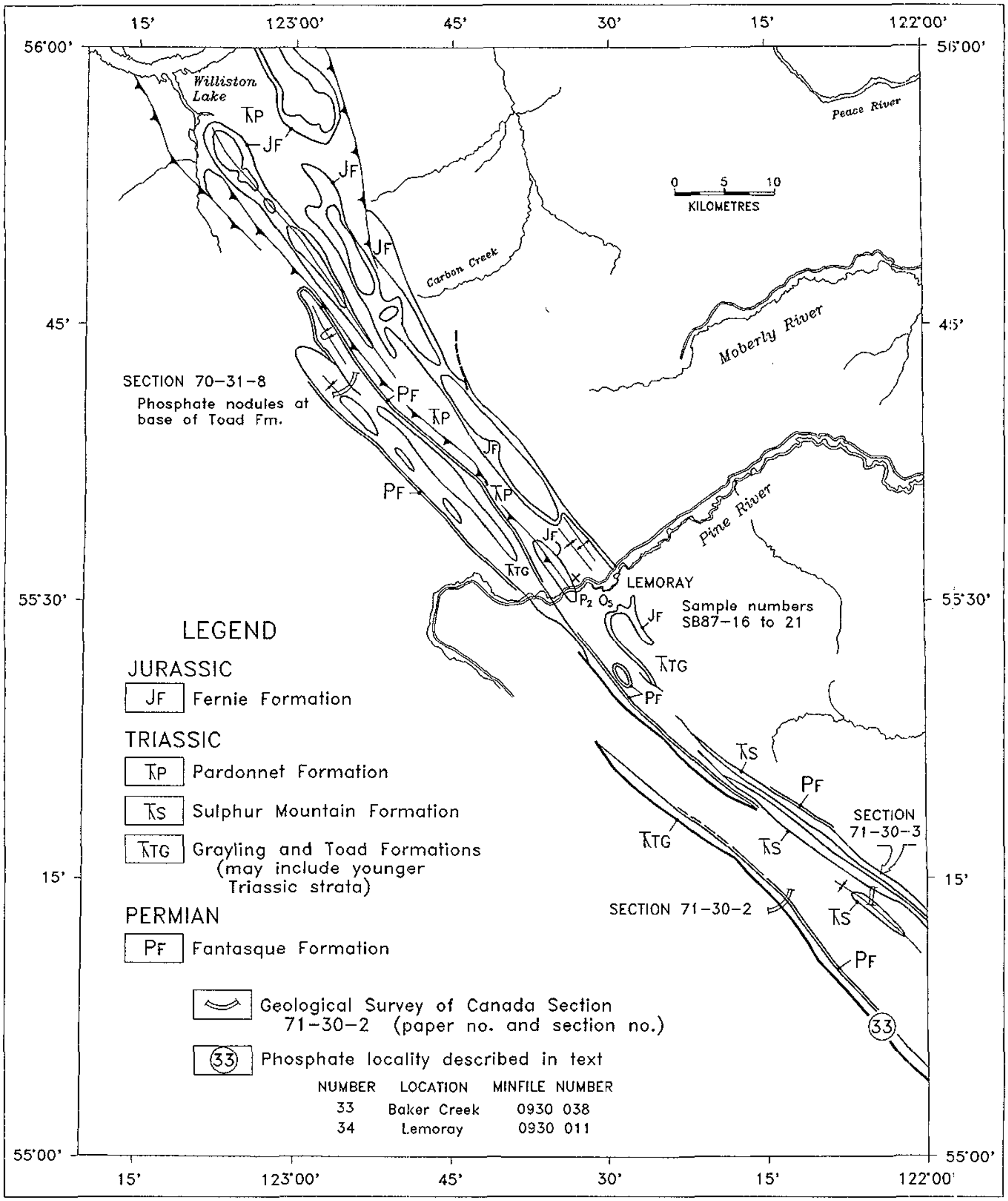


Figure 17. Phosphate deposits in the Mackenzie map area (93O).

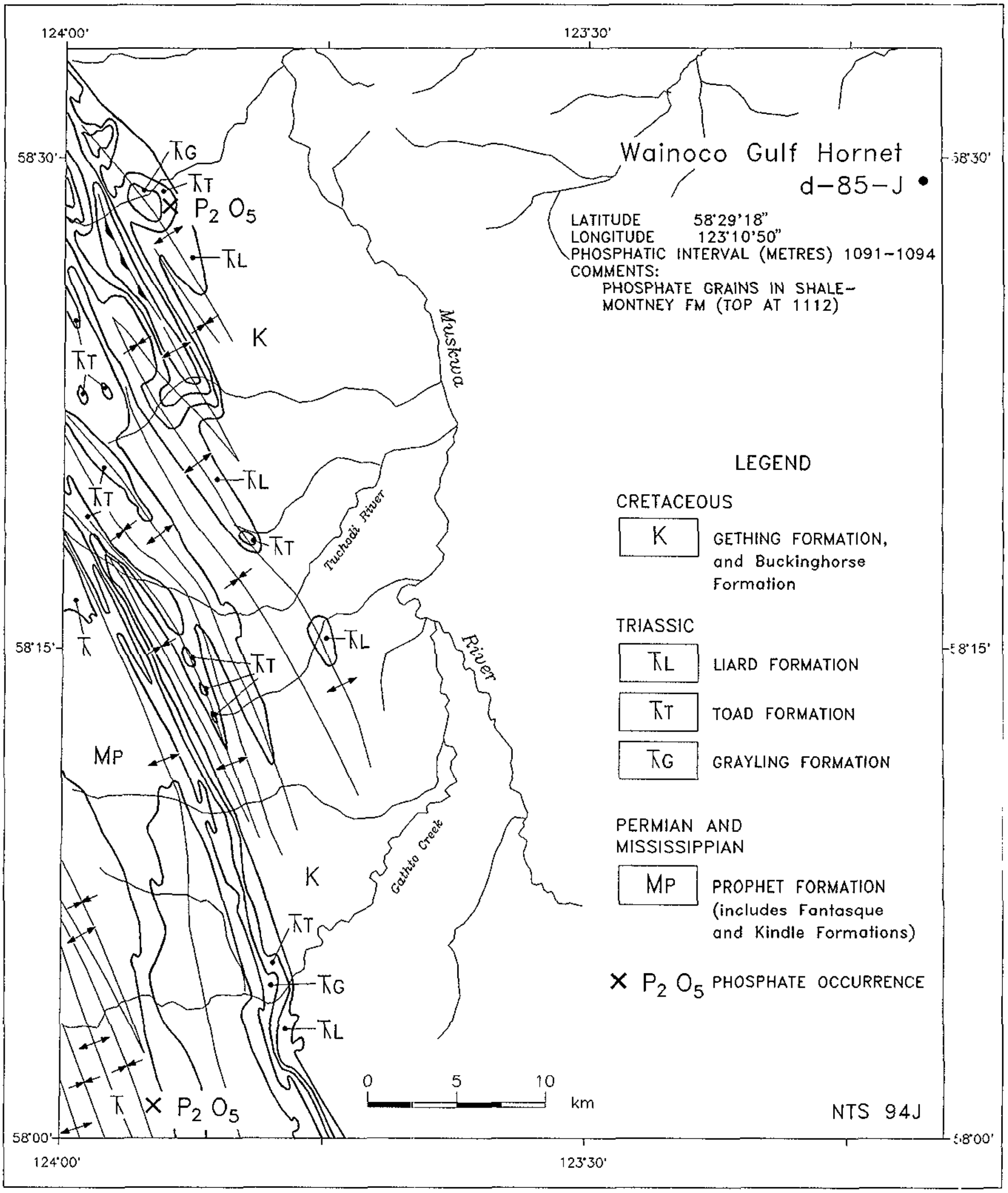


Figure 19. Phosphate deposits in the southwest corner of the Fort Nelson map area (94J).

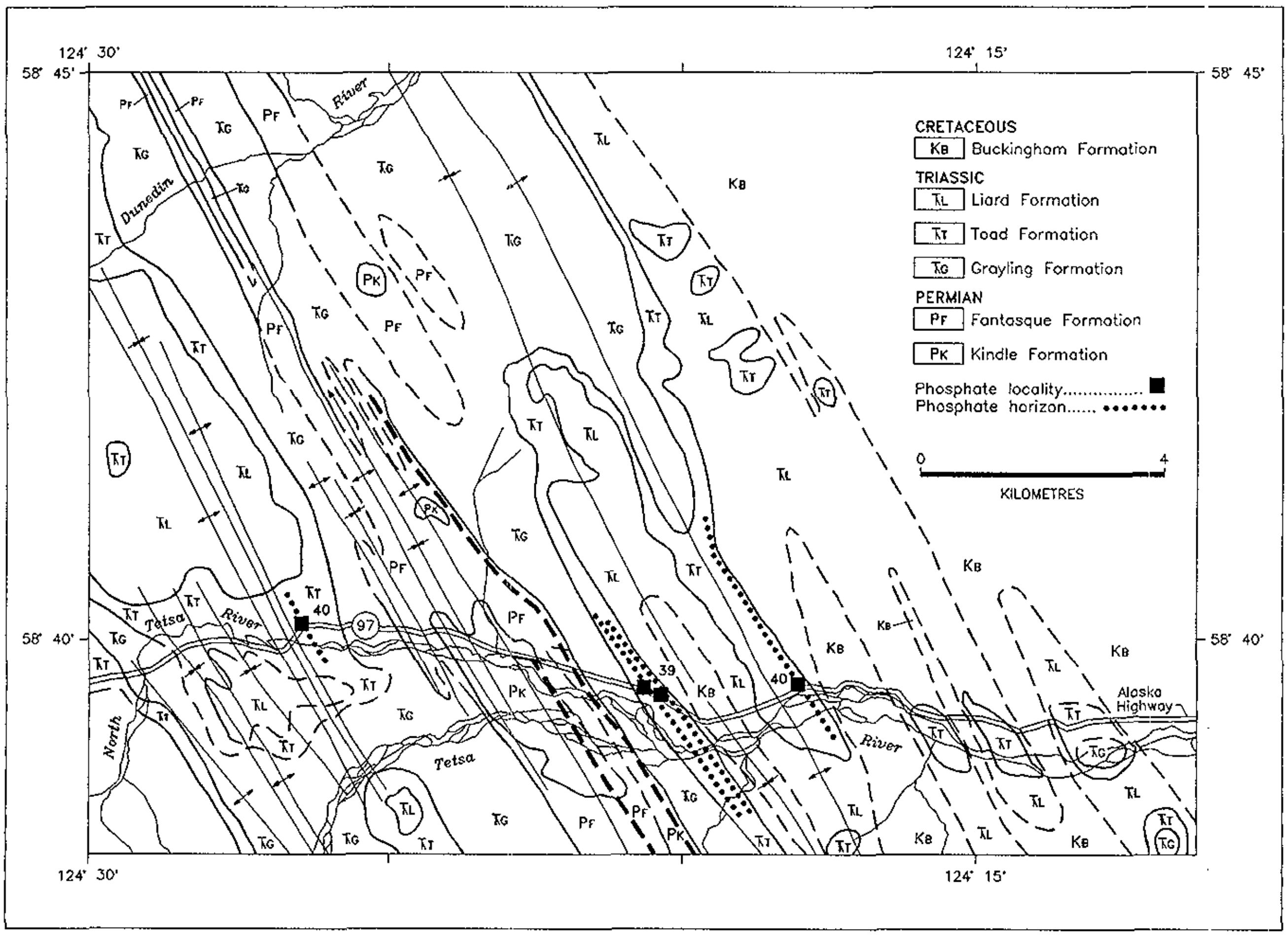


Figure 20. Geology and phosphate deposits in the Tetsa River area (94K/9).

is present in a variety of forms including pelletal phosphorite, nodules, phosphate cement, phosphatic fragments or clasts and phosphatized fossil debris. Minor phosphate is also present at a few localities in the Vega-Phroso and Llama members.

SULPHUR MOUNTAIN FORMATION

The Sulphur Mountain Formation unconformably overlies the Ishbel Group south of Pine Pass. It typically consists of a rusty brown-weathering sequence of medium-bedded siltstones, calcareous and dolomitic siltstones, silty dolomite and limestone, and minor shale. It attains thicknesses of 100 to 496 metres, thickening northward, and was deposited in a shallow-water, deltaic environment (Gibson, 1974). It is nonphosphatic in southeastern British Columbia.

In northeastern British Columbia the Sulphur Mountain Formation is subdivided into the Vega-Phroso, Whistler and Llama members. The formation consists of shale, siltstone and limestone and exhibits a general thickening westward. Phosphate occurs in the Whistler member (Heffernan, 1980; Legun and Elkins, 1986) extending from the British Columbia - Alberta boundary to northwest of the Sukunka River. Further to the north phosphate is present in the Toad Formation which is stratigraphically correlated with the Sulphur Mountain Formation.

VEGA-PHROSO MEMBER

The Vega-Phroso member of Early Triassic age unconformably overlies Permian strata. It is typically a flaggy, brownish weathering unit consisting of grey siltstone and calcareous siltstone with minor shale and bioclastic limestone. Thin phosphatic beds (10-20 cm) occur locally in the upper part of the section. The unit varies from 81 to 272 metres in thickness.

WHISTLER MEMBER

The Whistler member, which overlies the Vega-Phroso member disconformably, is a recessive unit, 20 to 85 metres thick consisting of grey-weathering dark grey siltstone, shale and limestone. It outcrops in a northwesterly trending belt that extends from Meosin Mountain in the southeast to Watson Peak in the northwest. This unit tends to be darker in colour than both the overlying and underlying members. At many localities its lower contact is marked by a phosphorite bed that may contain a thin (5 to 20 cm) basal phosphatic conglomerate. This basal conglomerate was not seen in sections measured at Meosin Mountain but is present in the Wapiti Lake area. Elsewhere phosphatic and phosphorite beds are present throughout Whistler member. At Watson Peak siliceous phosphate lenticles are reported to be present in the upper part of the unit (Gibson, 1972). Between Wapiti Lake and Mount Palsson phosphorite beds contain-

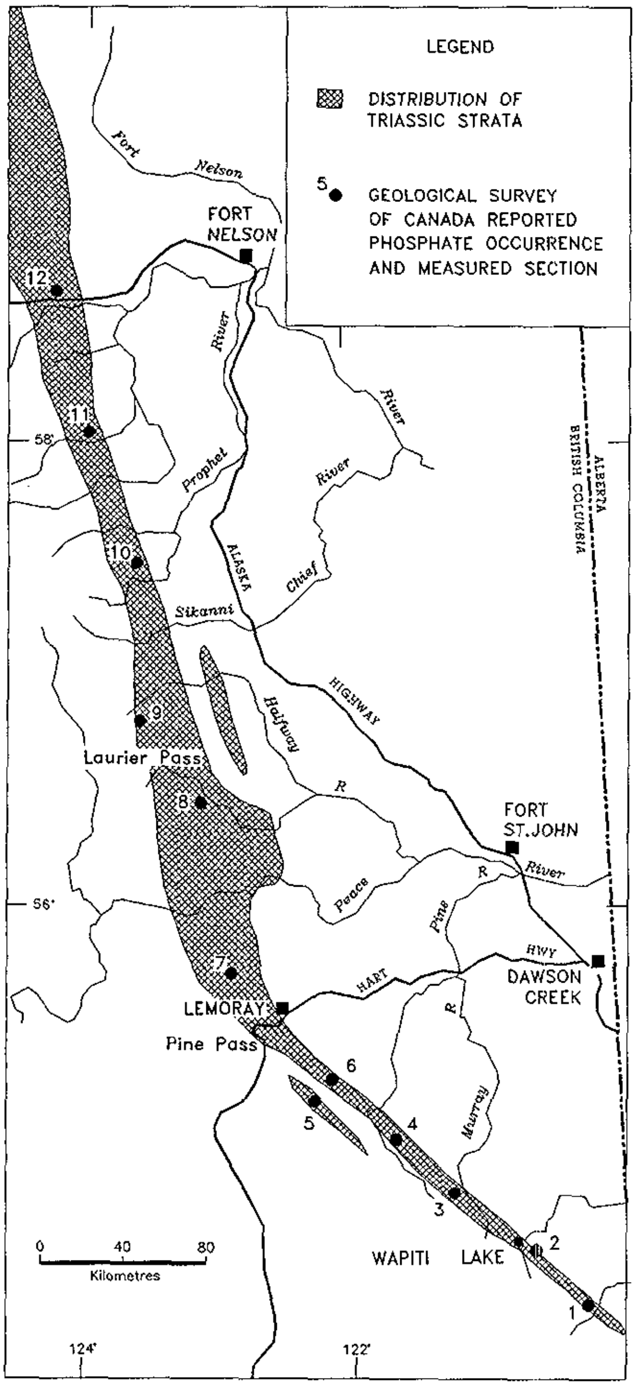


Figure 21. Distribution of Triassic strata in northwestern British Columbia.

ing phosphate grains and oolites occur at three distinct stratigraphic horizons. Coarse to very coarse-grained phosphate, some of which is oolitic, is reported to be present in a section measured in the Wolverine-Sukunka River area (Gibson, 1972). Gibson (1975) suggests that the better phosphate occurrences are associated with "shelf" or thinning trends reflecting areas of nondeposition or extremely slow sedimentation where phosphate deposition was not diluted by detritus. There may also have been some winnowing of detrital material, to be more concentrating the phosphorite.

Phosphate is interpreted to have been deposited in a shallow-water, high-energy environment above normal wave base (Gibson, 1975) during a marine transgression. Following the deposition of phosphate there was a deepening of the seas and conditions returned to those of deposition in a more basinal environment, below normal wave base along the outer margin of the shelf. MacDonald (1985) envisages that phosphate was deposited on an oxygenated intertidal or subtidal flat during a stillstand period at the end of the Lower Triassic. Phosphate was deposited environment.

LLAMA MEMBER

The Llama member is a resistant sequence of dolomitic and quartzitic siltstone and limestone with minor sandstone and dolostone, conformably overlying the Whistler member. It varies in thickness from 60 to 360 metres. Phosphate is reported in the lower part of this unit at a single section measured at Meosin Mountain (Gibson, 1972).

GRAYLING FORMATION

The Grayling Formation comprises strata of Early Triassic age north of Pine Pass and is correlatable with the lower part of the Vega-Phroso member of the Sulphur Mountain Formation. It consists of recessive, flaggy argillaceous siltstone, dolomitic siltstone and silty shale. Strata containing phosphate nodules are locally present in the upper part of the formation. The Grayling Formation, where present, unconformably overlies strata of Permian or Mississippian age and is conformable with the overlying Toad Formation.

TOAD FORMATION

The Toad Formation comprises Early to Middle Triassic strata north of Pine Pass. It is correlatable with the upper Vega-Phroso, Whistler and lower Llama members. Typically it consists of grey to dark grey weathering, generally dark grey siltstone, shale, calcareous siltstone and silty limestone, most of which are weakly to moderately carbonaceous. It varies in thickness from 155 to 820 metres, with an average thickness in excess of 300 metres.

Phosphate occurs in numerous beds throughout the middle part of the formation. The phosphate-bearing interval varies in thickness from a few tens of metres to approximately 290 metres. The basal part of the phosphatic section generally contains calcareous, ovoid concretions several centimetres in diameter. Phosphate is present as nodules, phosphatic lenses, phosphate cement and occasionally as pellets and as phosphatized fossil debris. Phosphorite is rare, but where present, consists of pellets, few oolites and nodules in a carbonate-quartz matrix. Many of the pellets have an irregular carbonate core suggesting that replacement of carbonate by phosphate may have taken place. Also present in the cores are quartz, feldspar, shell fragments and rarely pyrite. Pelletal phosphate is exposed at Richards Creek and along the Alaska Highway north of the Tetsa River.

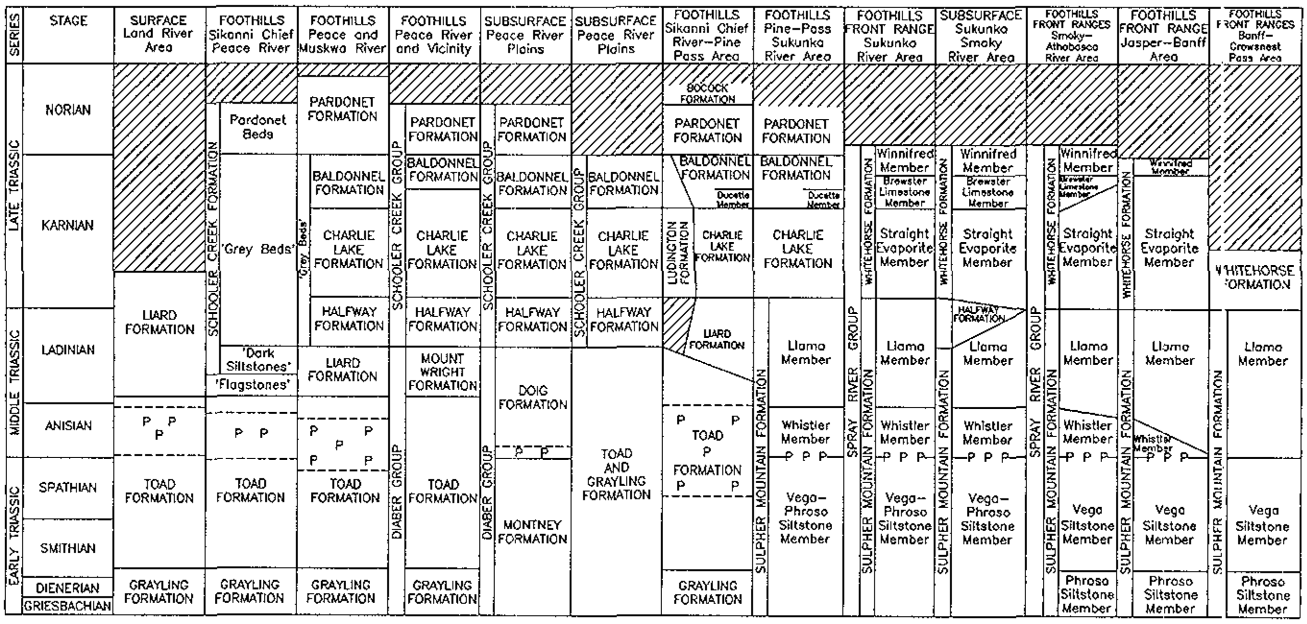


Figure 22. Correlation between Triassic formations and members of surface and subsurface areas of British Columbia and Alberta (modified from Gibson, 1975).

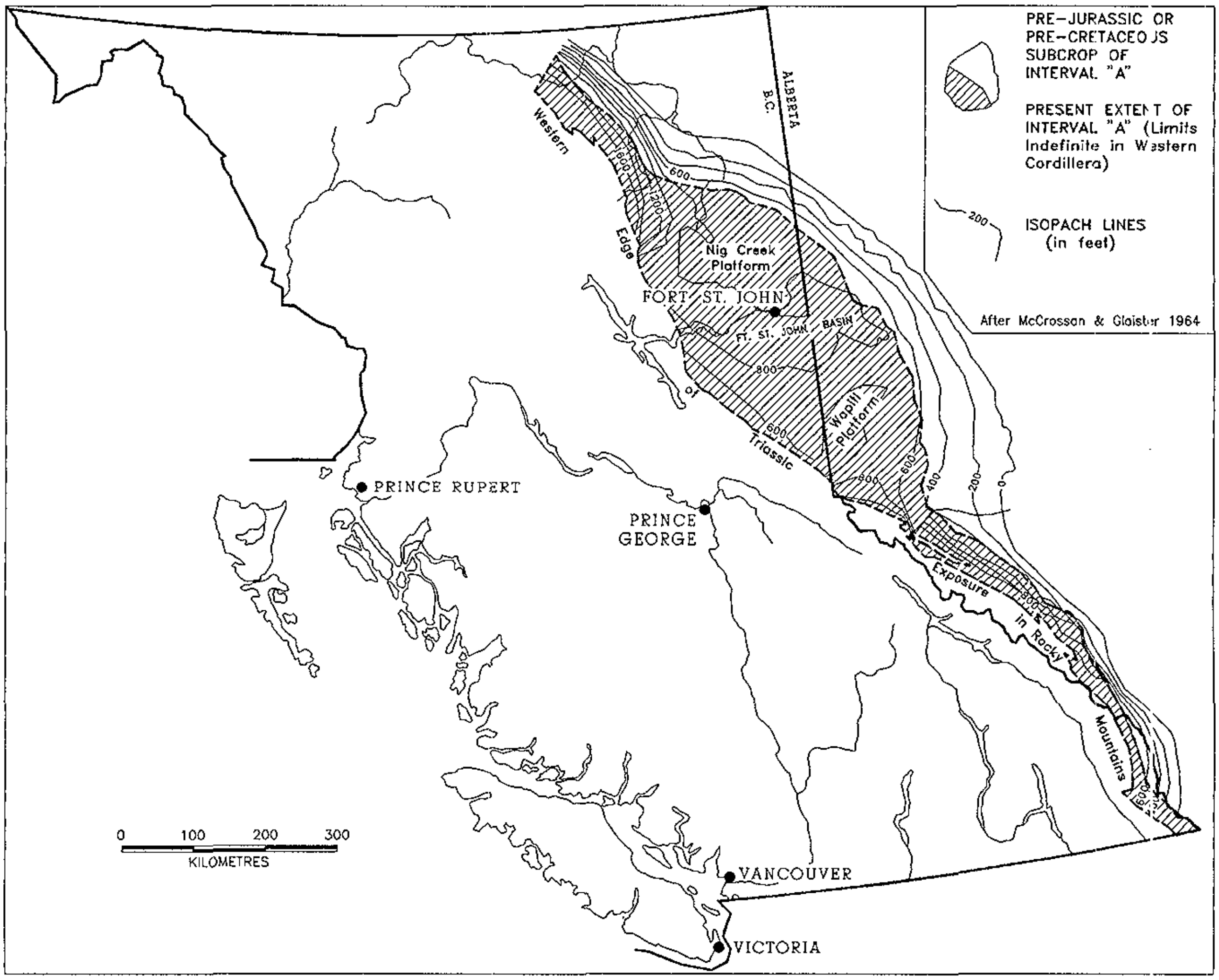
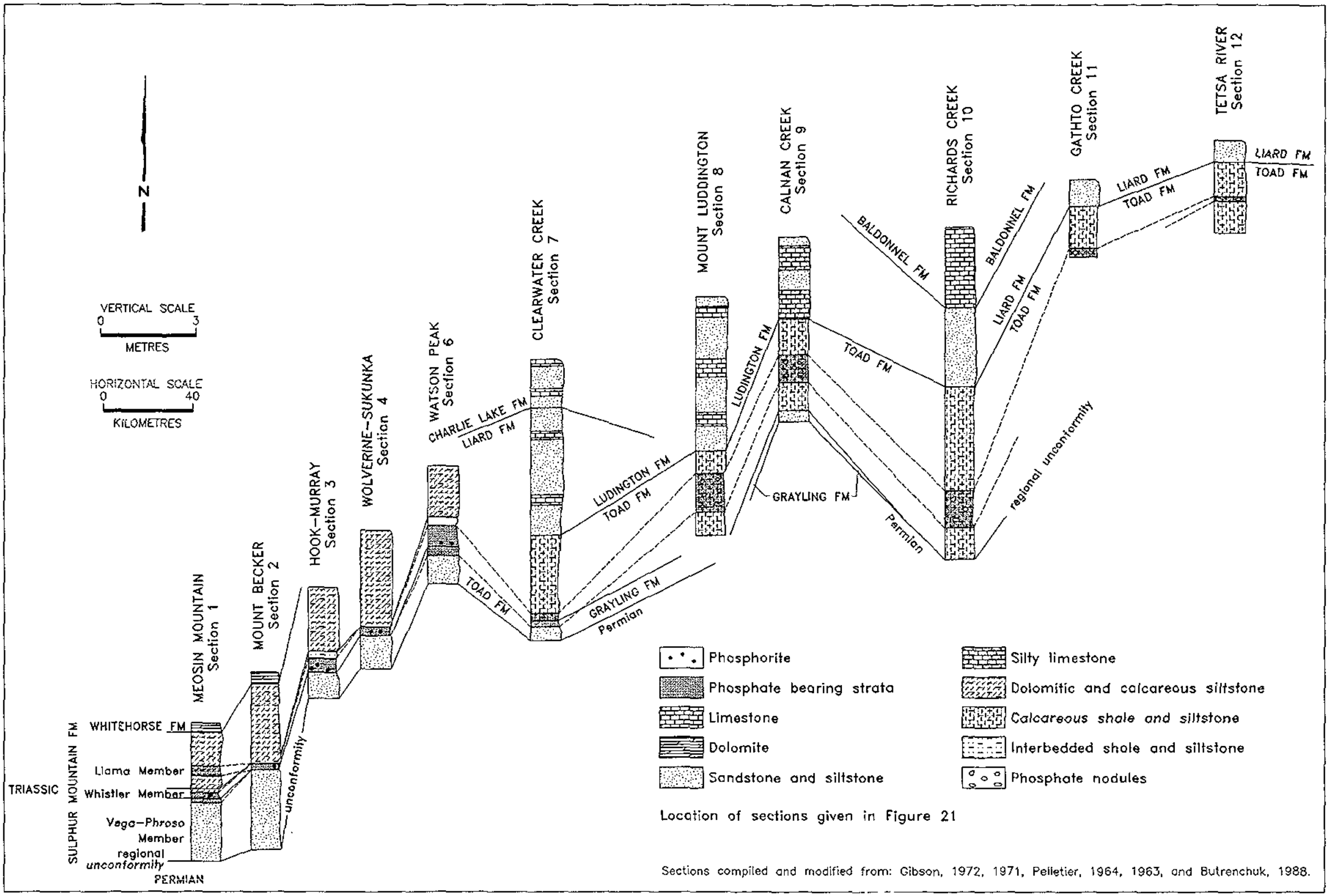


Figure 23. Paleographic map of the Early Triassic (after McCrossan and Glaister, 1964).



Location of sections given in Figure 21

Sections compiled and modified from: Gibson, 1972, 1971, Pelletier, 1964, 1963, and Butrenchuk, 1988.

Figure 24. Stratigraphic correlation of phosphate-bearing strata in the Triassic of northeastern British Columbia.

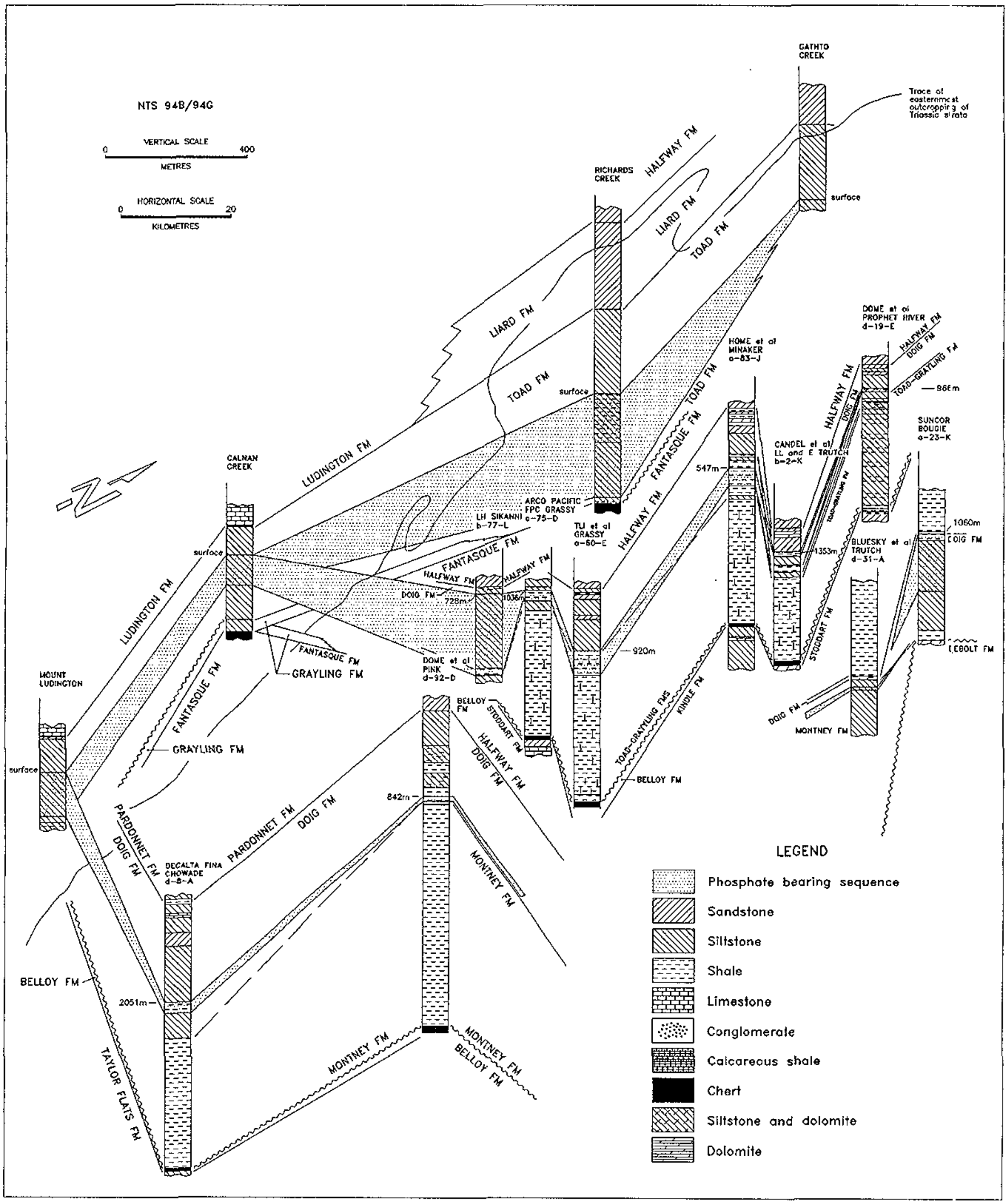


Figure 25. Stratigraphic position, thickness and correlation of phosphate-bearing strata on surface and in the subsurface, Halfway River - Trutch map sheets (94B and 94G).

Deposition of the Toad Formation is interpreted to have taken place in a deeper water, less restricted, open marine environment.

WHITEHORSE FORMATION

In northeastern British Columbia the Whitehorse Formation is restricted to the Sukunka River - Meosin Mountain area where it overlies the Sulphur Mountain Formation (*Gibson, 1975*) (*Figure 16, in pocket*). Deposition took place under very shallow water and probably evaporitic conditions, in a broad intertidal to tidal flat environment. Strata in this formation include dolostone, sandstone, siltstone, limestone and minor gypsum.

In southeastern British Columbia the Whitehorse Formation is poorly developed and is restricted to the areas west of the Elk River north of Elkford; north of Grave Lake; and in the Flathead River area south of Fernie (Gibson, 1969). It varies in thickness from 6 to 418 metres and consists of an assemblage of pale-weathering, variegated dolomite, limestone, sandstone and intraformational breccias (Gibson, 1974). Its contact with the underlying Sulphur Mountain Formation is gradational and its contact with the overlying Fernie Formation is disconformable. It is nonphosphatic.

TRIASSIC SUBSURFACE DEPOSITS

Evaluation of subsurface phosphate potential was restricted to a narrow belt paralleling the outcrop of Permian and Triassic sediments. In the subsurface, phosphate occurs in the Middle Triassic at the contact between the Doig and Montney formations or in rocks of equivalent age (Figure 25).

Phosphate is present as pellets, grains or occasional nodules. Pellet content varies from trace to 25% and rarely as much as 80% . In a few wells phosphate is reported as bands, stringers or lenses comprising as much as 30% of the rock. Host lithologies are dark grey to black shales and dark brown to grey siltstone. Limestone is occasionally present. All of these rocks are weakly calcareous, occasionally dolomitic and rarely glauconitic. Pyrite is also reported, but it is rare. A phosphatic conglomerate is reported in one hole (Home *et al.*, Minaker). Phosphate-bearing intervals usually produce a high radioactive response on gamma-ray logs.

In some of the wells siliceous or cherty black shale pellets are reported in Triassic strata where phosphate should be expected. These may in fact be phosphate pellets that have not been recognized.

JURASSIC PHOSPHATE

FERNIE FORMATION

Triassic strata are unconformably overlain by dark grey to black shales, phosphate and minor limestone, siltstone and sandstone of the Jurassic Fernie Formation (Freebold, 1957, 1969). In southeastern British Columbia this formation occupies a broad canoe-shaped synclinal structure covering an area of 2000 square kilometres and attains thicknesses of 70 and 376 metres with a general thickening westward (Figure 14, in pocket). A persistent pelletal phosphorite bed, 1 to 2 metres thick and generally containing greater than 15% P_2O_5 was deposited in a transgressive sequence at the base of the Fernie Formation in strata of Sinemurian age. It rests either directly on Triassic strata or is separated from the underlying rocks by a thin phosphatic conglomerate. The phosphatic interval may also be represented by two phosphate beds separated by phosphatic shale. Thicknesses in excess of 2 metres are attained locally, as at Mount Lyne where 4 metres of phosphate rock are present. Phosphatic shales of variable thickness, generally less than 3 metres, overlie the phosphate. The top of this sequence is sometimes marked by a yellowish orange calcareous bed 2 to 5 centimetres thick. Thin marcasite beds may also be present locally within the phosphatic interval.

A second phosphate horizon lies approximately 60 metres above the base of the Fernie. It is low grade (less than 1% P_2O_5) and sometimes associated with a belemnite-bearing calcareous sandstone horizon. This horizon was only observed above the railroad tracks south of the Highway 3 roadcut at Alexander Creek and in a poorly exposed outcrop north of Mount Lyne, where it occurs in shale rather than sandstone.

In northeastern British Columbia exposures of Fernie Formation parallel Triassic strata from the Jarvis Creek area to the Sikanni Chief River where the formation pinches out (Figures 19, 20 and 21, in pocket). Exposures are restricted to the foothills area. North as far as Wapiti River the basal sequence consists mainly of black phosphatic limestone. These strata, assigned to the Nordegg member, are of Sinemurian age, and are equivalent to those in the Fernie Basin of southeastern British Columbia. In the Halfway River area, equivalent strata consist of recessive, fissile, dark grey to black, calcareous shale (Irish, 1970) with no reported phosphate occurrences.

The Nordegg member of the Fernie Formation was deposited in a shelf or platformal environment. Glauconite is commonly reported in the subsurface in the Peace River area; chert is present in surface exposures. To the southwest the environment changes to a basinal facies. Sediments were deposited in fairly deep water under reducing conditions. Pellets are believed to have formed authigenetically below the water-sediment interface. The presence of pyrite supports the reducing environment. Cross-stratification and other indicators of shallow-water deposition are not seen, but moderate current activity is evidenced by occasional ripple marks seen on the eastern margin of the Fernie Basin. Deposition along the western margin of the basin probably took place in a deeper water environment where poorer phosphorites and mainly calcareous matrices were developed.

CHAPTER 4 PETROGRAPHY AND MINERALOGY OF SEDIMENTARY PHOSPHATE IN BRITISH COLUMBIA

KECHIKA FORMATION

Phosphate in the Kechika Formation is present as thin phoscrete layers 1 to 10 millimetres thick, as pellets, and as phosphatized trilobite remains (Photo 7). The phoscrete consists of colour-banded microphosphorite laminae that form a continuous surface except where broken by calcite-filled microfractures. Thin layers have been broken and incorporated into overlying beds. Pellets that are distinctly oolitic occasionally have carbonate cores. Very often broken pellets and phosphatized shell debris are found together with broken phoscrete fragments in limestone overlying preserved phoscrete beds.

The microphosphorite laminae can be present as either distinct beds or as thin veneers surrounding limestone nodules. Carbonate and phosphate grains with concentric layers of microphosphorite are the most distinctive pellets present in these phosphatic horizons.

ROAD RIVER FORMATION

The form in which phosphate is present in the Road River Formation is not readily apparent. There are thin black phosphatic laminae in the lower part of the formation, but phosphatic material is difficult to distinguish in thin section because of the fineness of the sediment and its carbonaceous content. Phosphate is probably present as minute grains or possibly as cement.

EXSHAW FORMATION

Thin sections show that the phosphate occurs as dispersed pellets 1 millimetre or less in size. They are subrounded and constitute approximately 10% of the rock by volume. Most of the pellets are structureless although a few are nucleated. MacDonald (1985) observed that most of the phosphate is also pelletal with nucleated and oolitic varieties predominant. Structureless nodules and intraclasts are also present. The basal phosphate consists of nodules up to 2 centimetres across, bone fragments, intraclasts and nucleated and rimmed pellets; the uppermost phosphate horizon consists of a conglomeratic mixture of nodules, bone fragments and minor pellets and intraclasts (MacDonald, 1985).

ISHBEL GROUP

Phosphate, as fluorapatite, is present in the Ishbel Group as nodules, pellets, cement, (Photo 8) intraclasts and

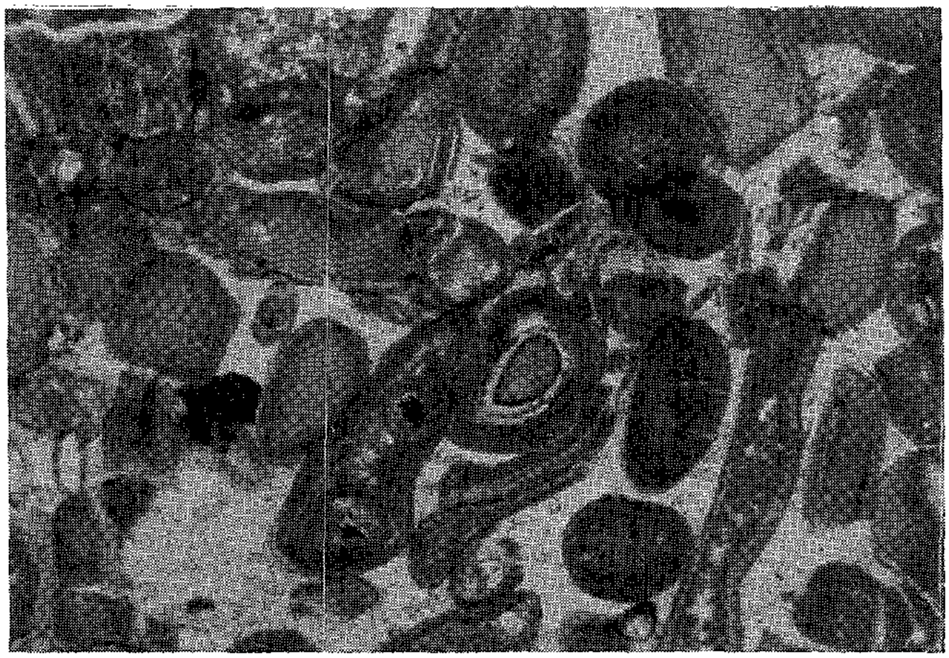


Photo 7. Photomicrograph (40x) showing phosphatic oolites and broken phoscrete layers from the Kechika Formation, Grey Peak.

as replacement of bioclastic debris that includes brachiopod shells, sponge spicules and possibly foraminifera.

The nodular variety is most common, occurring throughout the Permian section. Nodules are most prominent in the Johnston Canyon and Ranger Canyon formations, commonly occurring as ovoid structures that vary from 1 centimetre to greater than 7 centimetres in diameter (Photo 10). Locally they have irregular shapes and may be elongate parallel to the bedding. Internally they may contain one or more quartz nuclei as well as bioclastic material (Photo 9). Composition of these nodules is given in Table 4.

Pelletal phosphorite was observed only in the Johnston Canyon and Ross Creek formations. Pellets are generally structureless (Photo 10) although oolitic pellets, and a few others, have a radial structure. Less than 15% of the pellets are nucleated or encased; quartz, and to a lesser degree calcite, form the nuclei. Size of the pellets varies from 0.1 to 0.5 millimetre. These pelletal varieties have semidispersed to dispersed textures.

Phosphate is present as cement throughout the Ishbel Group. Primary cement was observed in the basal conglomerate of the Ranger Canyon Formation as well as in fine clastic rocks of the Johnston Canyon and Ross Creek formations. Phosphate cement is usually a brown colour in thin section.

Complete or partial replacement of bioclastic debris is most prominent in the Ross Creek and Johnston Canyon formations. Intraclasts are not abundant; where present they contain quartz nuclei that differ in grain size from quartz in the matrix or contain several phosphate pellets.

Host lithologies in the Ishbel Group are quartz-rich siltstones and fine-grained sandstones. The quartz is subangular to subrounded and generally well sorted. Feldspar, with varying amounts of calcite, is also present in the matrix. Dolomite, albite and illite may be present in minor amounts.

SULPHUR MOUNTAIN FORMATION

Phosphate is present in the Whistler member of the Sulphur Mountain Formation predominantly as pellets with lesser nodules, phosphate cement and phosphatic bioclastic material.

The pelletal phosphorite occurring at the base of the unit has the most significance (Photo 11). It is comprised of brown, dark brown or black pellets with occasional nodules and locally, phosphate cement. The pellets range in size from 0.05 to 0.5 millimetre and are variably sorted. Five to fifty percent of the pellets are either nucleated or encased with approximately varying amounts of quartz and calcite. Oolites comprise 1 to 15% of the pelletal material. Some phosphatized bioclastic debris is also present and is especially significant immediately south of Meosin Mountain. At this locality phosphate pellets are dispersed throughout a bioclastic matrix that has been partially or wholly phosphatized (Photo 12).

The matrix in the phosphorite is dominantly calcite although locally the matrix is quartz rich. Minor constituents include feldspar and dolomite, and locally, fluorite. Qualitative abundances of the minerals present in Whistler member phosphate rocks are given in Table 5 and the relative abundances of the major minerals are given in Appendix 20. Grain size of the matrix is also variable, most often smaller than the pellets. Locally, where the matrix is almost totally carbonate, the grain size of the pellets and the matrix may be the same.

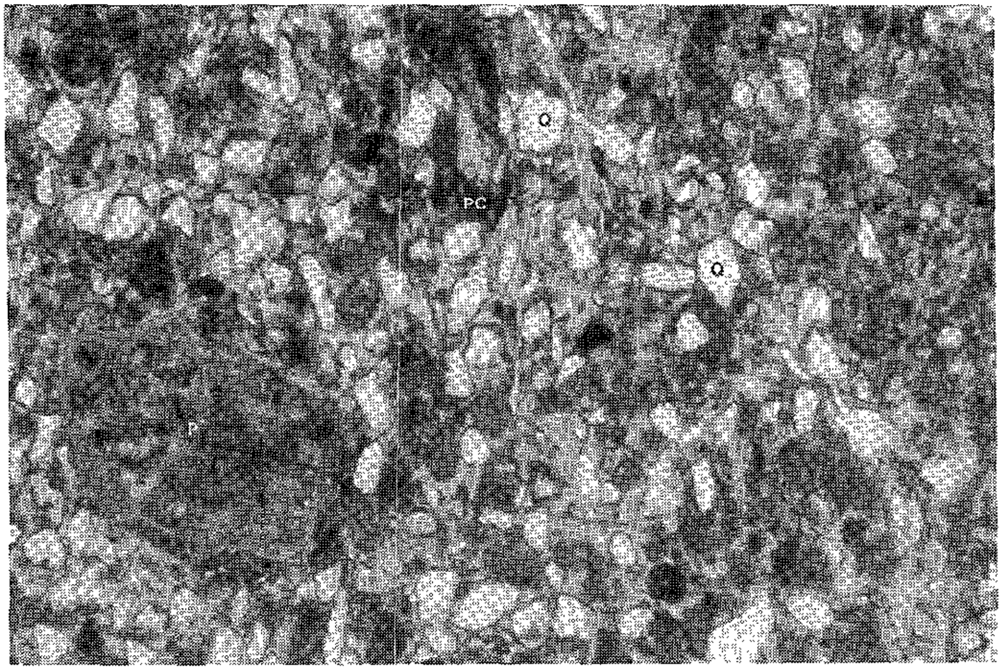


Photo 8. Photomicrograph (40x) showing phosphate pellets (P) and phosphate cement (PC) in a quartz-rich (Q) siltstone from the Johnston Canyon Formation, Mount Broadwood.

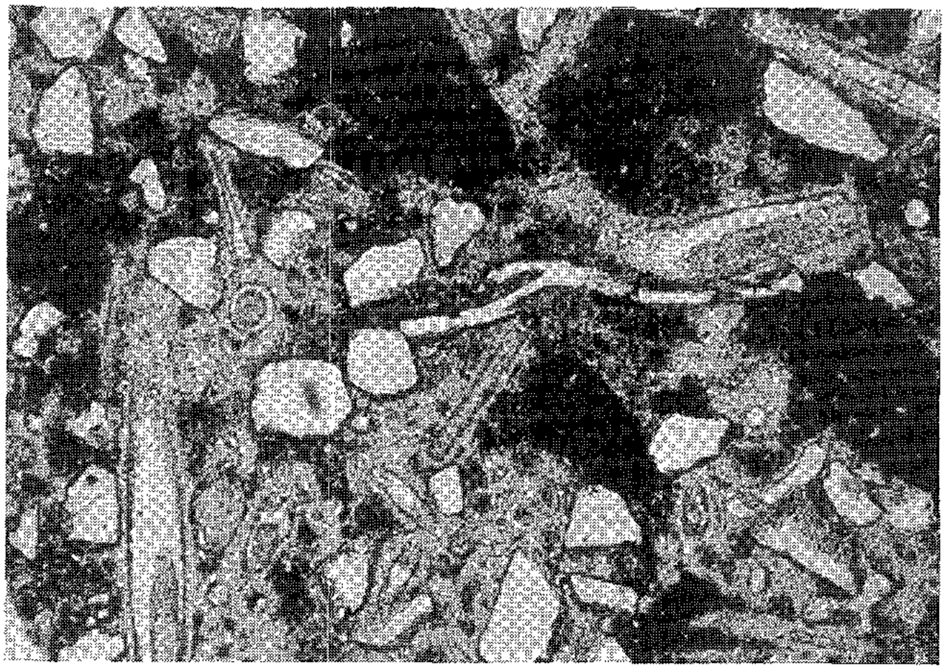


Photo 9. Photomicrograph (40x) of phosphate containing phosphate pellets (dark brown), quartz grains (white) and shell material from the Ishbel Group, Crowsnest Pass area.

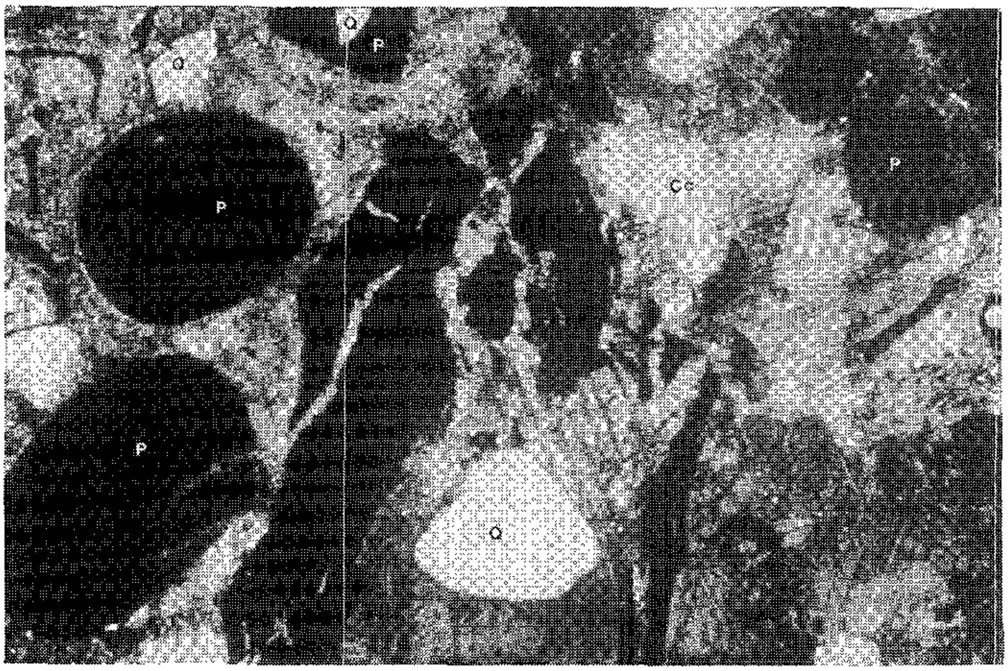


Photo 10. Photomicrograph (40x) of disseminated phosphate pellets (P) in a quartz (Q)-calcite (Cc) matrix in the basal Johnston Canyon Formation from the Fenster Creek area.

TABLE 4
QUALITATIVE MINERAL ABUNDANCES IN THE PERMIAN PHOSPHATES
(Determinedby x-ray diffraction)

Sample No.	Location	Minerals Identified
SBB86-2B	Mutz Creek	Quartz > **fluorapatite** > dolomite > minor K-feldspar.
SBB86-61 (nodules)	Lladner Creek	**Fluorapatite** ^ quartz >> minor dolomite, K-feldspar.
SBB86-71 (nodules)	Crowsnest Pass	**Fluorapatite** > quartz.
SBB86-79(2) (nodules)	Nordstrum Creek	**Fluorapatite** > quartz >> minor dolomite, K-feldspar.
SBB86-85(2)	MacDonald Thrust Fault	**Fluorapatite** ? quartz >> calcite >> trace K-feldspar.
SB87-45	Alaska Highway	Calcite > quartz > dolomite > apatite ^ buddingtonite.

TABLE 5
QUALITATIVE ABUNDANCE OF MINERALS IN THE WHISTLER MEMBER OF THE SULPHUR MOUNTAIN FORMATION
(Determinedby x-ray diffraction)

Sample No.	Location	Minerals Identified
SB87-6	Meosin Mountain	Calcite ? **fluorapatite** >> minor quartz, illite and dolomite.
SB87-7(4)	Meosin Mountain	Calcite >> quartz > **fluorapatite** >> trace dolomite.
SB87-11(2)	Wapiti Lake	**Fluorapatite** > quartz > calcite >> trace dolomite, feldspar and illite.
SB87-12	Wapiti Lake	**Fluorapatite** >> calcite > quartz >> trace dolomite.
SB87-15	Mount Palsson	**Fluorapatite** > calcite > quartz > minor dolomite > trace illite and feldspar.

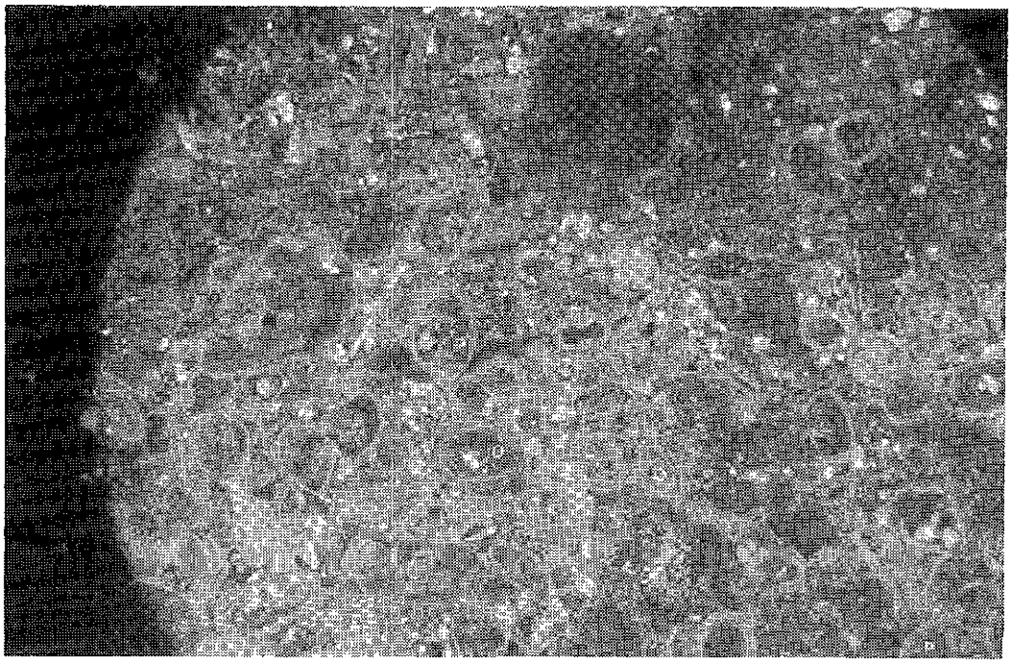


Photo 11. Photomicrograph (40x) of pelletal (P) and oolitic (O) phosphate in a quartzose matrix from the Whistler member of the Sulphur Mountain Formation, Wapiti Lake.

Many of the pellets exhibit textures suggesting replacement of original carbonate, possibly an oolitic limestone, that has been replaced or diagenetically altered to phosphate. Elsewhere alternating carbonate and phosphatic layers in the oolites suggests that there may have been some periodicity to the phosphate and carbonate availability while these oolites were forming.

TOAD FORMATION

The dominant form of phosphate in the Toad Formation is nodular, but pelletal phosphate occurs in more northerly locations and phosphatized fish skeletons, ammonoids and bioclastic debris are also present. Phosphate cement is rare. Much of the carbonaceous and calcareous siltstone in the middle Toad Formation is weakly to very weakly phosphatic; phosphate is present as distinct detrital grains as shown in Photo 13.

Nodules occur as black, ovoid structures, 1 to 3 centimetres in size. They occur in beds ranging from a fraction of a metre to in excess of 2 metres thick, although beds over 2 metres thick are rare. The nodules contain numerous small nucleii, or a rarely, a small ammonoid and are interpreted to have formed diagenetically. Many appear to have formed by replacement of carbonate, primarily calcite. Nodules with

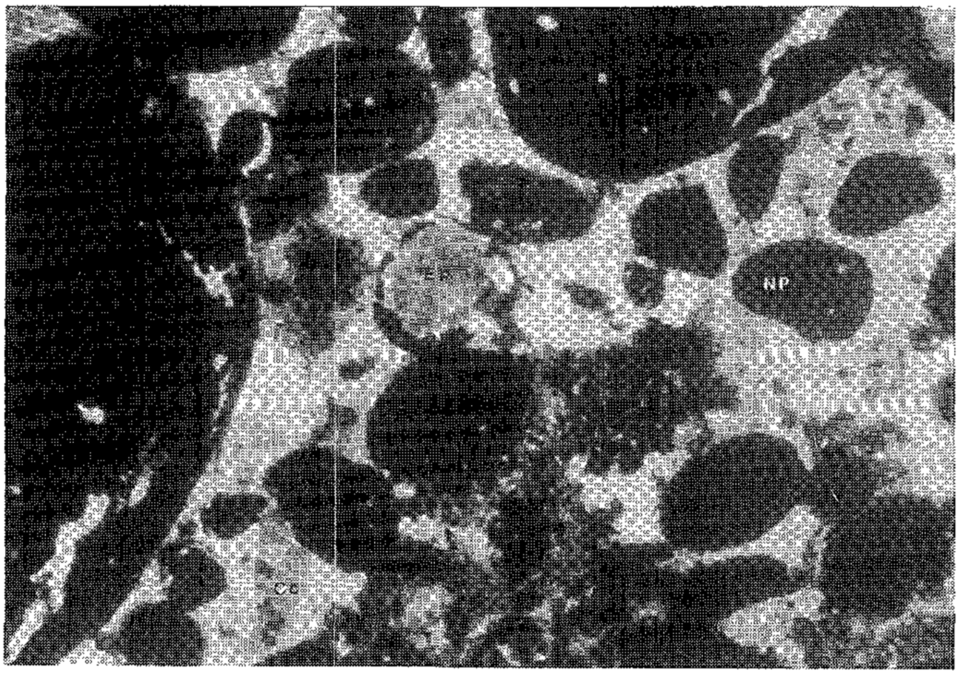


Photo 12. Photomicrograph (40x) of pelletal phosphorite from the Whistler member ofthe Sulphur Mountain Formation at Meosin Mountain. Pellets (black), encased pellet (EP) and nucleated pellet (NP) occur in a carbonate-rich (Cc) matrix.

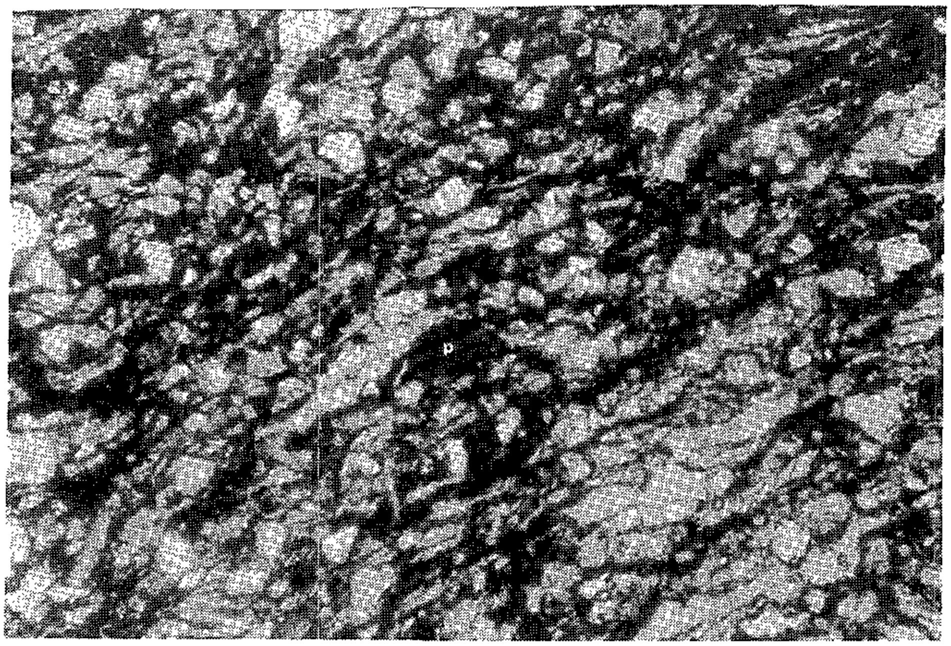


Photo 13. Photomicrograph (40x) showing a phosphate grain (P) in calcareous siltstone (cross-nicols) from the Toad Formation, Burnt River area.

TABLE 6
QUALITATIVE MINERAL ABUNDANCES IN THE TOAD FORMATION PHOSPHATE ROCKS
(Determined by x-ray diffraction)

Sample No.	Location	Minerals Identified
SB87-16(3)	Lemoray	**Fluorapatite** >> minor dolomite, quartz, illite with or without a mixed layer clay
SB87-19(1)	Lemoray	Quartz >> calcite > minor fluorapatite, illite and plagioclase > trace dolomite and K-feldspar.
SB87-34(2)	Mount Ludington	Calcite quartz ? **apatite** dolomite >> trace illite, plagioclase, K-feldspar.
SB87-35	Mount Ludington	Calcite >> **apatite** ^ quartz >> trace illite.
SB87-36(1)	Laurier Pass North	Calcite > quartz >> apatite ? dolomite > minor illite, plagioclase > trace K feldspar.
SB87-37(2)	Richards Creek	Quartz >> calcite > dolomite > **apatite** > plagioclase ^ minor muscovite, illite, K-feldspar þ trace pyrite.
SB87-37(4)	Richards Creek	Calcite >> quartz > dolomite ? apatite >> trace K-feldspar, illite þ plagioclase.
SB87-40	Alaska Highway	Calcite > quartz > **fluorapatite** >> minor dolomite > trace feldspar.
SB87-43	Alaska Highway	Calcite >> apatite ? quartz >> minor dolomite þ trace K-feldspar, pyrite.
SB87-43(1)	Alaska Highway	Quartz > calcite > **fluorapatite** > dolomite >> trace K-feldspar, illite.

reaction rims between the carbonate and phosphate are seen occasionally. At a locality north of Mount Ludington, highly corroded phosphate nodules appear to have been replaced by carbonate.

Pelletal phosphorite is relatively rare and restricted to more northerly locations although pelletal phosphorite at Lemoray may also belong to the Toad Formation. Pellets are brown to dark brown, 0.05 to 0.15 millimetre in diameter and subrounded. More than half of the pellets are nucleated around quartz grains; a few encased pellets are also present. Where pellets have carbonate cores, textures suggest replacement of carbonate by phosphate has taken place. The matrix of these pelletal phosphate beds varies from carbonate rich at Richards Creek to a quartz-calcite matrix with minor feldspar along the Alaska Highway north of the Tetsa River; some phosphate cement is also present.

Qualitative mineral abundances for these phosphate-bearing strata are given in Table 6. The presence of apatite rather than fluorapatite in many of the samples is significant. The apatite is most probably present in the matrix and may represent transported detrital material and not *in situ* deposition of phosphate.

FERNIE FORMATION

The basal phosphate of the Jurassic Fernie Formation is essentially all pelletal phosphorite, although some nodular material is present locally at the Crow deposit and Lodge occurrences. Pellets are brown to dark brown (Photo 14), occasionally black, well sorted, subrounded to subangular with a grain size varying from 0.1 to 0.3 millimetre. Approximately 95% of the pellets are structureless and up to 50% are nucleated. Occasionally the pellets have an oolitic structure. Pellets are composed of fluorapatite and organic material that gives them their brown colour. The matrix is generally finer grained than the pellets. A general molding

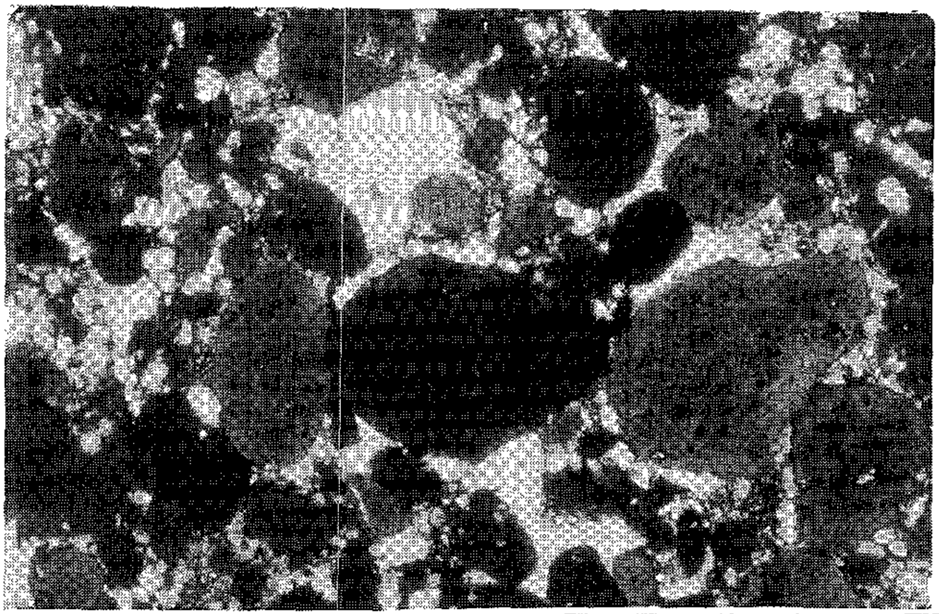


Photo 14. Photomicrograph (100x) in plain polarized light of pelletal phosphorite from the Fernie Formation - Crow deposit. Semi-compact pellets ocur in a matrix of quartz, calcite and minor clay and mica.

Photo 15. Photomicrograph (40x) in plain polarized light of pelletal phosphorite from the Fernie Formation located at the Lizard deposit. Pellets (P) and nucleated pellets (P) are present in a dominantly calcite (Cc) matrix.

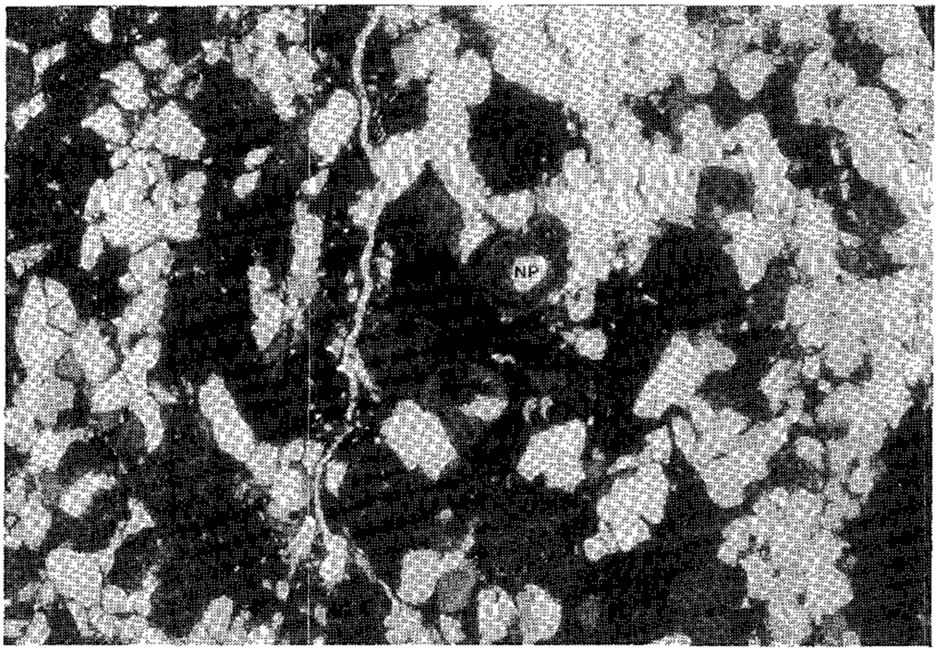


Photo 16. Photomicrograph (40x) of pelletal phosphorite in the Fernie Formation - Abby locality. Phosphate pellets (brown) occur in a quartz-rich matrix. Rare pellet is nucleated (NP).

of pellets is seen suggesting that their deposition may have been as plastic or gel-like material.

The phosphorite has a compact to semidispersed texture and contains 50 to 85% pellets by volume. Quartz is the principal component of the matrix except in the Lizard Range - Iron Creek area. Here, calcite is dominant and quartz is virtually absent (Photo 15). This zonation of calcite and quartz has been alluded to in Chapter 3. The variability of calcite and quartz is very evident in thin sections studied. At the Line Creek deposit and Abby occurrence (Photo 16) calcite is virtually absent. Some calcite is present in the Cabin Creek area and at the Crow deposit; feldspar and albite are present in minor amounts, illite, montmorillonite and sericite are present in trace to minor amounts. Dolomite is generally absent but does occur locally in trace amounts. Limonite, probably after pyrite, is usually present in amounts of 1 to 2%. The qualitative mineral abundances, as determined by x-ray diffraction on 14 samples is presented in Table 7. The relative abundance of the major minerals is presented in Appendix 21.

TABLE 7
QUALITATIVE ABUNDANCE OF MINERALS PRESENT IN THE BASAL FERNIE PHOSPHATE
(Determined by x-ray diffraction)

Sample No.	Location	Minerals Identified
Lizard	Lizard	Calcite > fluorapatite >> quartz > albite ± montmorillonite, mixed clay.
SBB86-3	Highway 3	Fluorapatite > calcite > quartz > dolomite, albite K-feldspar, illite/sericite.
SBB86-4F	Crow	Fluorapatite > quartz >> k-feldspar, calcite, illite, albite.
SBB86-11	Iron Creek	Calcite > quartz > fluorapatite >> albite > K-feldspar, illite.
SBB86-14	Bingay	Quartz > K-feldspar > fluorapatite >> albite > illite.
SBB86-15	Zip	Fluorapatite >> quartz > minor K-feldspar, illite, montmorillonite • albite.
SBB86-22	Harriet Lake	Quartz > albite > fluorapatite >> minor chlorite, illite • trace amphibole.
SBB86-37	Barnes Lake	Fluorapatite >> quartz >> K-feldspar, albite > trace illite, montmorillonite.
SBB86-38	Cabin Creek	Fluorapatite > quartz >> calcite > minor K-feldspar, illite • albite • montmorillonite.
SBB86-42	Cabin Creek	Quartz > fluorapatite >> K-feldspar > minor illite.
SBB86-52	Cabin Creek	Fluorapatite >> calcite ? quartz >> minor to trace K-feldspar, albite, illite, montmorillonite.
SBB86-54	Cabin Creek	Quartz >> fluorapatite > K-feldspar > albite > minor illite > trace montmorillonite.
SBB86-70	Mount Lyne	Fluorapatite >> quartz > K-feldspar, albite, illite.
SBB86-86	Lodge	Fluorapatite > quartz > minor K-feldspar, illite, montmorillonite.

CHAPTER 5 GEOCHEMISTRY

The geochemistry of phosphate deposits is an important consideration in the economics of their commercial exploitation. The presence of calcite and dolomite adversely affect the beneficiation of phosphate rock by increasing acid consumption in the acidulation process, the first step in the manufacture of phosphate fertilizers. Conversely, the ability to recover uranium, yttrium and rare-earth elements as byproducts of the acidulation process can provide a substantial economic benefit.

According to Krauskopf (1955) and Gulbrandsen (1966) the abundance of trace elements or phosphorites is due to their association with organic matter or to integration into the apatite lattice. High concentrations of arsenic, copper, lead and zinc are principally due to the presence of organic matter, whereas concentrations of strontium, uranium, thorium and rare earths are associated with fluorapatite.

From a processing point of view the abundance of lime, magnesia, alumina and organic carbon are important considerations. Major element and trace element analyses analyses for the various phosphate horizons in British Columbia are presented in Appendices 2 to 5 and 6 to 9 respectively. Results for phosphate and trace elements from the detailed chip sampling are presented in Appendices 10 and 11. Average for the trace element abundances for some British Columbia phosphate are compared to the Phosphoria Formation and the "average phosphorite" worldwide in Table 8.

MAJOR ELEMENT GEOCHEMISTRY

The ideal CaO/P_2O_5 ratio for fluorapatite ($Ca_{10}(PO_4)_6F_2$) is 1.31. Carbonate may substitute for phosphate up to a ratio of 1.57. Ratios greater than 1.57 generally indicate the presence of free carbonate in the phosphate rock. Phosphorites in the Fernie Formation show a zonal distribution of CaO/P_2O_5 ratios. Deposits along the western margin of the Fernie basin exceed the acceptable ratio while deposits to the east and southeast have ratios less than 1.60. Triassic phosphorites in the Sulphur Mountain and Toad formations generally have high ratios reflecting an abundance of carbonate. Permian phosphates show a wide range of CaO/P_2O_5 ratios, but in general they are also unacceptably high.

Fertilizer processing plants require an MgO content of less than 1%. Most Fernie phosphorite has an acceptable MgO content. Whistler member phosphorite has a high magnesium content locally as do many of the occurrences in the Toad Formation. Better grade Permian phosphate deposits have a low magnesium content. Kechika and Road River Formation phosphatic deposits are exceedingly high in magnesium.

The optimum value for the R_2O_3/P_2O_5 ratio is 0.1 (R_2O_3 equivalent to $Al_2O_3 + Fe_2O_3 + MgO$). Most phosphate deposits in British Columbia have ratios that exceed the optimum value. This generally reflects an overall high clay content and locally high dolomite content.

Sulphur present in phosphate rock may be due to the presence of sulphides, sulphates or organic matter. The most common sulphate minerals are barite, gypsum and celestite. Only barite has been recognized in British Columbia phosphate deposits. Sulphide minerals are most commonly present as pyrite and marcasite. Some sphalerite may be present locally, most commonly in deposits of Triassic age.

Fluorine may be present in phosphorites in the form of fluorspar or bound to apatite. The F/P_2O_5 ratio characteristic of fluorapatite varies between 0.08 and 0.12 (Slansky, 1986). Ratios for F/P_2O_5 for the various phosphate bearing formations in British Columbia are summarized in Table 9. Ratios in excess of 0.12 suggest the presence of fluorite.

Fluorine is most abundant in the Sulphur Mountain Formation where values generally exceed 2% and in the Fernie Formation where the fluorine content averages 1.43%. Permian phosphates generally contain less than 2%.

TRACE ELEMENT GEOCHEMISTRY

Marine sedimentary phosphate deposits generally contain uranium in the range 50 to 300 ppm, with most containing less than 100 ppm (Slansky, 1986). It is believed to replace calcium in the apatite lattice (Altschuler *et al.*, 1958) and varies directly with phosphate content. Also, it is generally thought that reworking will increase the uranium content while weathering tends to deplete it.

Uranium shows a moderate to strong correlation with phosphate grade based on results reported in Appendices 10 and 11 (Figure 29). The uranium content of 16 samples from the Fernie Formation ranged from 1 to 75 ppm (Appendix 9) and averages 33 ppm (Table 8). Eight samples from phosphatic rocks in the Ishbel Group returned analyses of 4 to 103 ppm (Appendix 7), with a mean of 36 ppm (Table 8). In comparison, the average uranium content of the Phosphoria Formation is 90 ppm (Slansky, 1986). Uranium is highest in the Whistler member phosphorite generally exceeding 100 ppm (Appendix 8). Uranium, based on results reported in Appendices 10 and 11, shows a moderate to strong correlation with phosphate grade (Figure 26).

Rare earth contents in phosphorites range from 0.01 to 0.15% with marine phosphorites tending to be enriched in the heavier lanthanides and depleted in cerium. Because these elements can be incorporated into the apatite lattice they tend to show a strong relationship to the phosphate grade. While yttrium (Figure 27) and lanthanum (Figure 28) tend to have a strong correlation in British Columbia phosphorites, the correlation between cerium and phosphate is, at best, moderate; the Whistler phosphorite shows virtually no correlation between cerium and phosphate. Yttrium, lanthanum and cerium are highest in the Fernie phosphorite averaging 480, 195 and 130 ppm respectively (Table 8). The

TABLE 8
AVERAGE TRACE ELEMENT CONTENT IN PHOSPHATE ROCKS SAMPLED IN THIS STUDY AND AVERAGE VALUES OBTAINED BY GULBRANDSEN (1966) AND ALTSCHULER (1980)

Element*	Average Shale	Phosphoria Fm.	Average Phosphorite	Ishbell Group (n=8)	Triassic[2] (n=21)	Fernie[3] Fm. (n=16)
Ni		100	53	40	63	42
Cr	90	1000	125	53	110	--
Sr	300	1000	750	396	736	785
Rb	450	--	--	4	32	--
Y		1000	260	184	121	480
As	13	40	23	3	11	<30
Ba	580	100	350	165	609	497
Ag	0.07	3	2	<0.5	0.9	<0.5
Zn	95	300	195	104	695	86
Cu	45	100	75	22	30	37
Pb	20	<10	50	9	11	13
Mo	2.6	30	9	7	9	<5
Cd	0.3	<50	18	1.5	16	0.9
U	3.7	90	120	36.5	64	33
Th	--	--	--	6.5	23	6
Sc	0.6	13	4.6	3.1	16	3.2
La	45	300	133	91	64	195
Ce	91	45**	104	68	42	130
V	130	300	100	98	528	63
Ti	4600	--	640	603	--	1384
Au	0.01	--	--	6	<20	<20

*All elements in ppm except for gold (Au) in ppb.
**Based on 2 samples from the Warm Springs phosphate deposit.
n = number of samples included in the calculation.
[1] From Appendix 7.
[2] From Appendix 8.
[3] From Appendix 9.

TABLE 9
F/P_2O_5 RATIOS FOR PHOSPHATE-BEARING FORMATIONS IN BRITSH COLUMBIA

Permian		Triassic		Jurassic	
Sample No.	F/P_2O_5	Sample No.	F/P_2O_5	Sample No.	F/P_2O_5
SBB86-85	0.06	SB87-6	0.08	LIZ	0.06
SBB86-17	0.1	SB87-7(4)	0.07	SBB86-3	0.08
SBB86-41	0.1	SB87-11(2)	0.07	SBB86-4	0.06
SBB86-57	0.07	SB87-12	0.07	SBB86-6	0.06
SBB86-62	0.09	SB87-15	0.07	SBB86-11	0.09
SBB86-71	0.07	SB87-16(3)	0.06	SBB86-13D	0.06
SBB86-79(1)	0.06	SB87-19(1)	0.16	SBB86-15	0.06
SBB86-84	0.23	SB87-32	0.14	SBB86-22	0.1
SB87-G(1)	0.06	SB87-32(1)	0.17	SBB86-37	0.06
SB87-G(2)	0.06	SB87-34	0.19	SBB86-38	0.08
SB87-37	1	SB87-34(2)	0.06	SBB86-40	0.08
SB87-45	0.08	SB87-35	0.09	SBB86-42	0.09
		SB87-36	0.9	SBB86-52	0.07
		SB87-36(1)	0.08	SBB86-54	0.12
		SB87-36(2)	0.07	SBB86-70	0.06
		SB87-37(1)	0.13	SBB86-86	0.07
		SB87-37(2)	0.09		
		SB87-37(4)	0.09		
		SB87-40	0.08		
		SB87-43	0.08		
		SB87-43(1)	0.08		

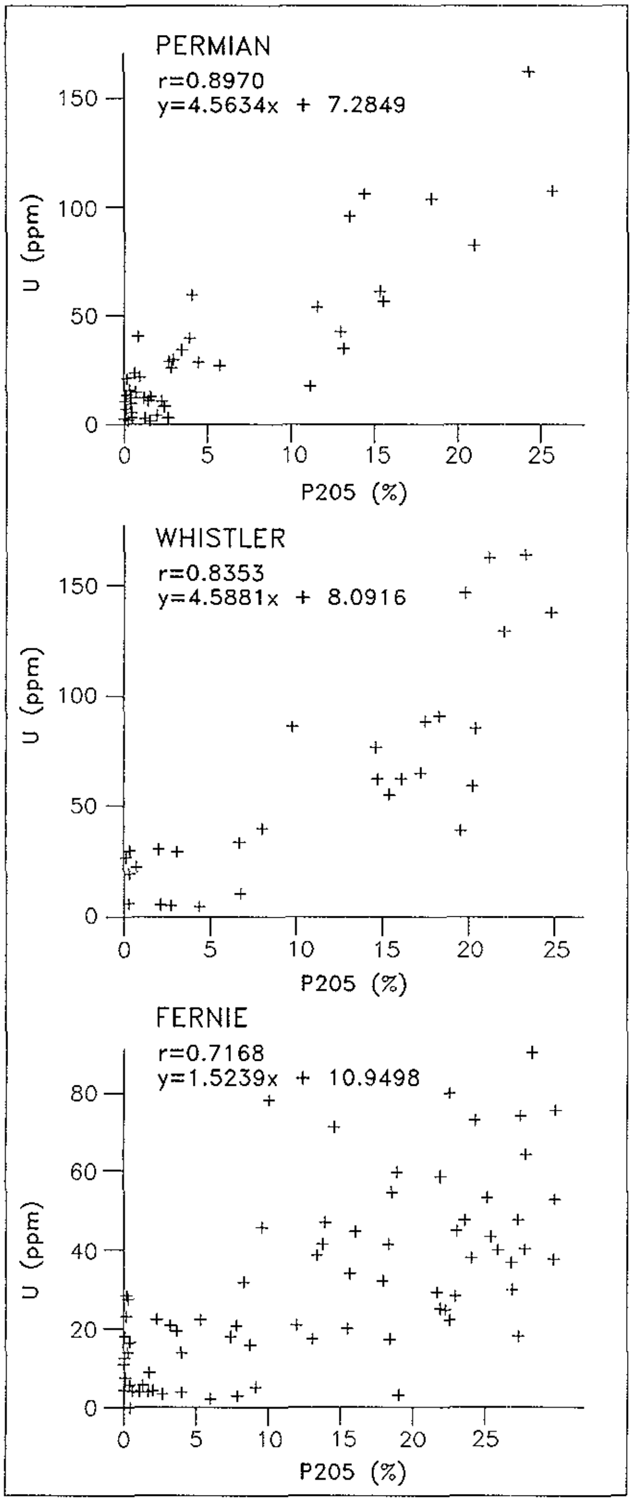


Figure 26. Correlation between uranium and phosphate for Permian, Whistler member and Fernie Formation phosphates.

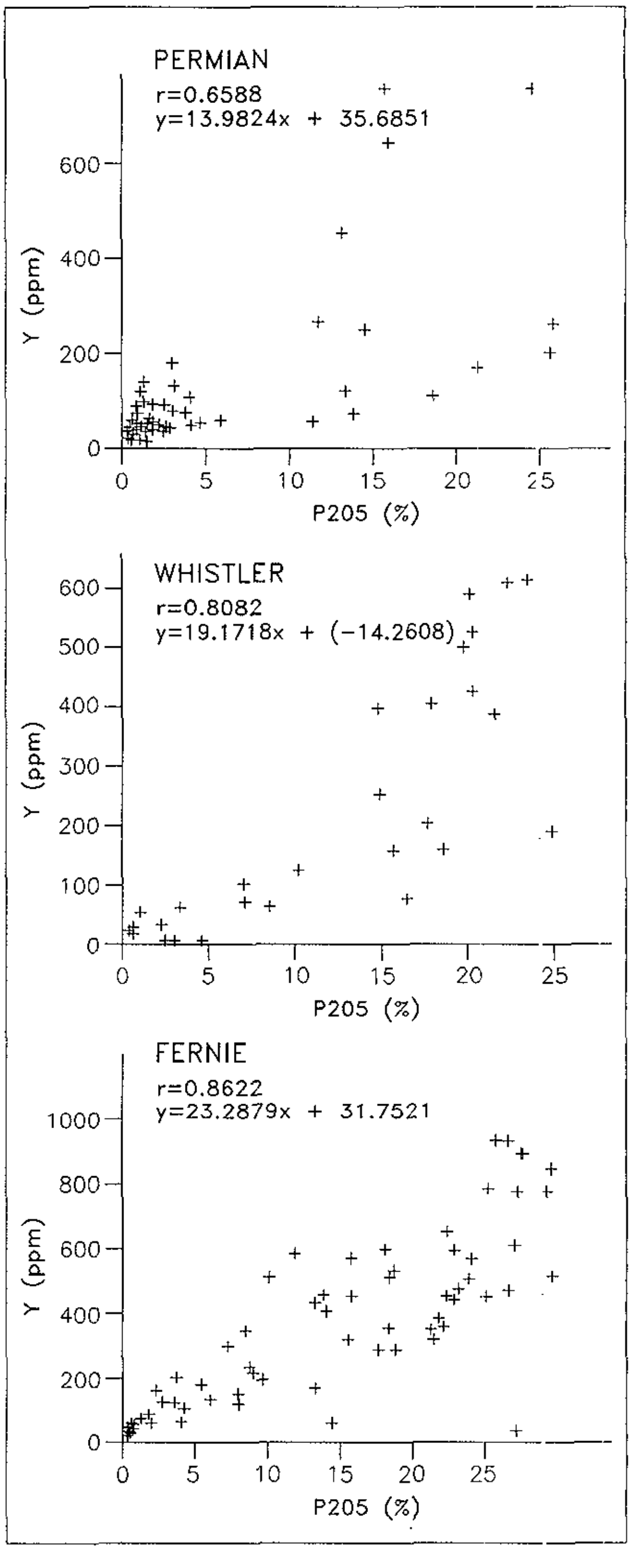


Figure 27. Correlation between yttrium and phosphate for Permian, Whistler member and Fernie Formation phosphates.

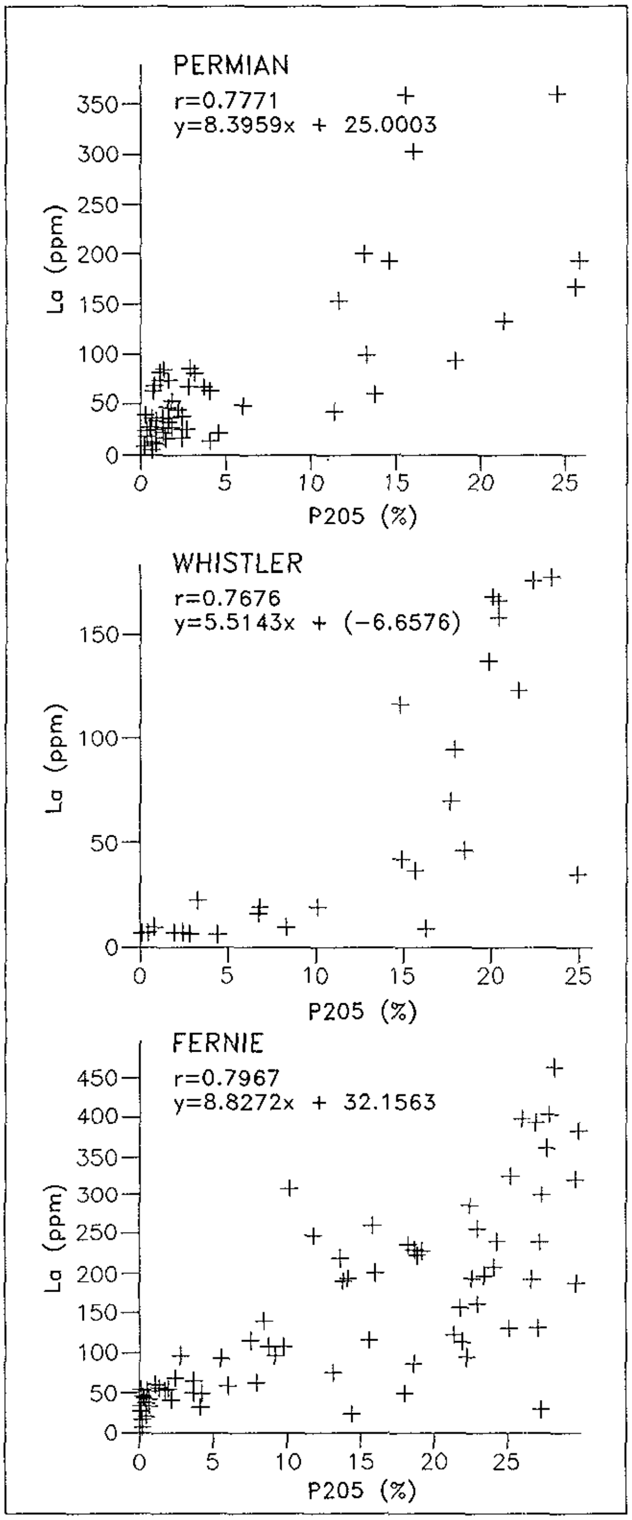


Figure 28. Correlation between lanthanum and phosphate for Permian, Whistler member and Fernie Formation phosphates.

Whistler member phosphorite also contains significant amounts of yttrium, averaging 250 ppm overall and 337 ppm *in the Wapiti Lake area (Appendix 12).*

Thorium content in marine phosphates is generally low, averaging 6 to 7 ppm (Altschuler, 1980). The thorium content of British Columbia deposits approximates the average, as compared to a mean of 11 ppm in the Phosphoria Formation.

Selenium generally shows some enrichment in phosphorites compared to the average shale and is believed to correlate with the amount of organic material present. Selenium in phosphorites of the Fernie Formation and Ishbel Group varies from 1 to 6 ppm with slightly higher values in the Ishbel Group. Triassic phosphate deposits vary from 5 to 55 ppm and average 16 ppm. These higher values reflect the higher organic carbon content present in these sediments.

Arsenic in phosphate deposits in British Columbia averages less than 9 ppm compared to a mean of 23 ppm for phosphorites in general (Altschuler, 1980). Cadmium is also low for all deposits averaging between 0.9 and 16 ppm. Neither of these metals are present in sufficient quantity to pose any potential health or environmental problems.

The Fernie Formation contains above average values for strontium and barium, 954 ppm and 522 ppm respectively, compared to 750 ppm and 350 ppm for the average phosphorite. The highest values for both barium and strontium are in the Triassic phosphate deposits, averaging 609 and 736 ppm respectively.

Vanadium shows either a poor or a negative correlation with phosphate grade. With the exception of the Triassic phosphate deposits, vanadium shows no enrichment from average shale.

Cadmium is a toxic metal that occurs in most phosphate rock. Because of its toxicity new regulations relating to the maximum allowable in the manufacture of fertilizers are now under consideration. All phosphate deposits in British Columbia have below average amounts of this metal with Fernie Formation averaging the lowest at 0.9 ppm.

Zinc is enriched in Triassic phosphates, averaging 695 ppm, compared to both the average phosphorite and shale. Detailed sampling (Appendix 11) of these deposits returned *values in excess of 1000 ppm at four localities. Both the* Fernie and Permian phosphates contain below average amounts of zinc.

CHAPTER 6

DESCRIPTION OF PHOSPHATE LOCALITIES

PHOSPHATE LOCALITIES IN THE FERNIE BASIN

Phosphate is present in the Fernie Basin in the Permian Ishbel Group and the Jurassic Fernie Formation. Twenty-nine occurrences and deposits are described in the following section; numbers in parentheses refer to numbered localities on Figure 14, in pocket).

FORSYTH CREEK - CONNOR LAKES (1) — *NTS: 82J/2*

MINFILE:	082JSW029, 030
Lat: 50°17′50″	Long: 115°02′45″

Several exposures of phosphate in the Ross Creek and Ranger Canyon Formations lie north of Forsyth Creek, in the Connor Lakes area. These strata are unconformably overlain by siltstone of the Triassic Sulphur Mountain Formation (Photo 17). Two sections were measured in this area (Figures 29 and 30). The Ranger Canyon Formation consists primarily of a thick, resistant sequence of cherts that is overlain by a siltstone bed 1 metre thick containing 10 to 15% black, subrounded phosphate nodules, averaging 5 centimetres in diameter (Photo 18). They contain 25.8 to 28% P_2O_5 but a sample collected across the sandstone bed assayed only 1.6% P_2O_5. A massive to nodular phosphate bed, 0.5 metre thick, underlies the chert bed in the more northerly section (Figure 34). It contains 18.6% P_2O_5. It is underlain by a phosphatic interval, 10 metres thick. With the exception of the uppermost bed, the phosphate content is less than 5%

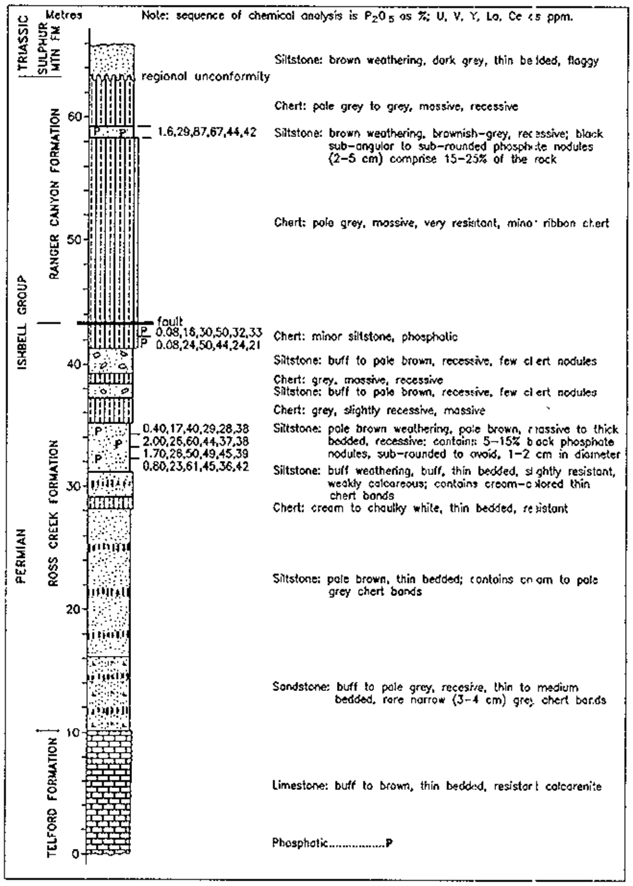


Figure 29. Stratigraphic Section 62, Forsyth Creek.

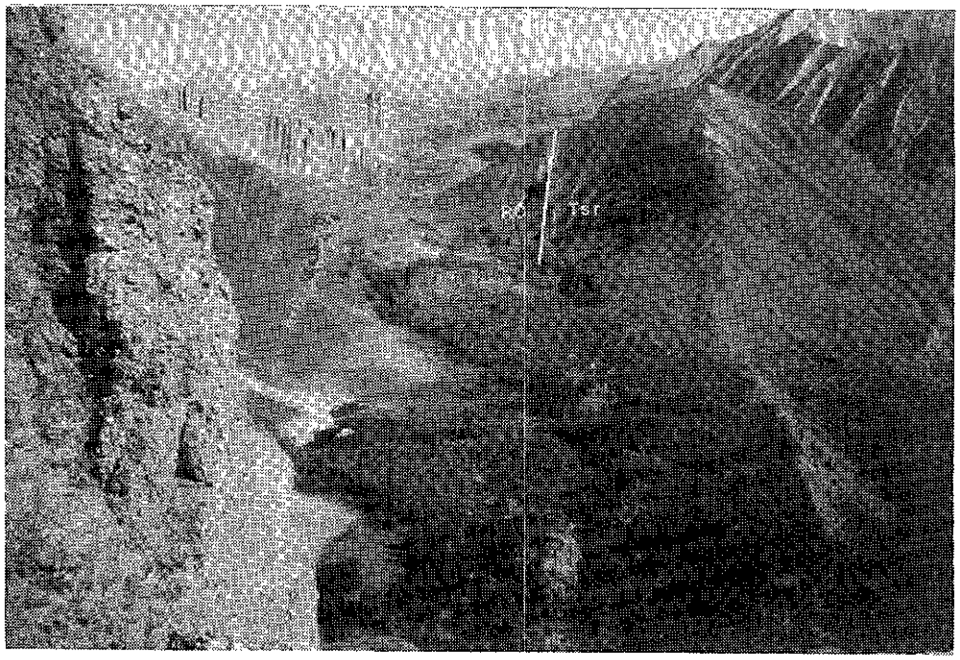


Photo 17. View looking north along contact between Permian Ranger Canyon Formation (Rc) and Triassic Sulphur Mountain Formation (TSR) north of Forsyth Creek. Phosphate-bearing siltstone (P) occurs along the upper contact of bedded chert.

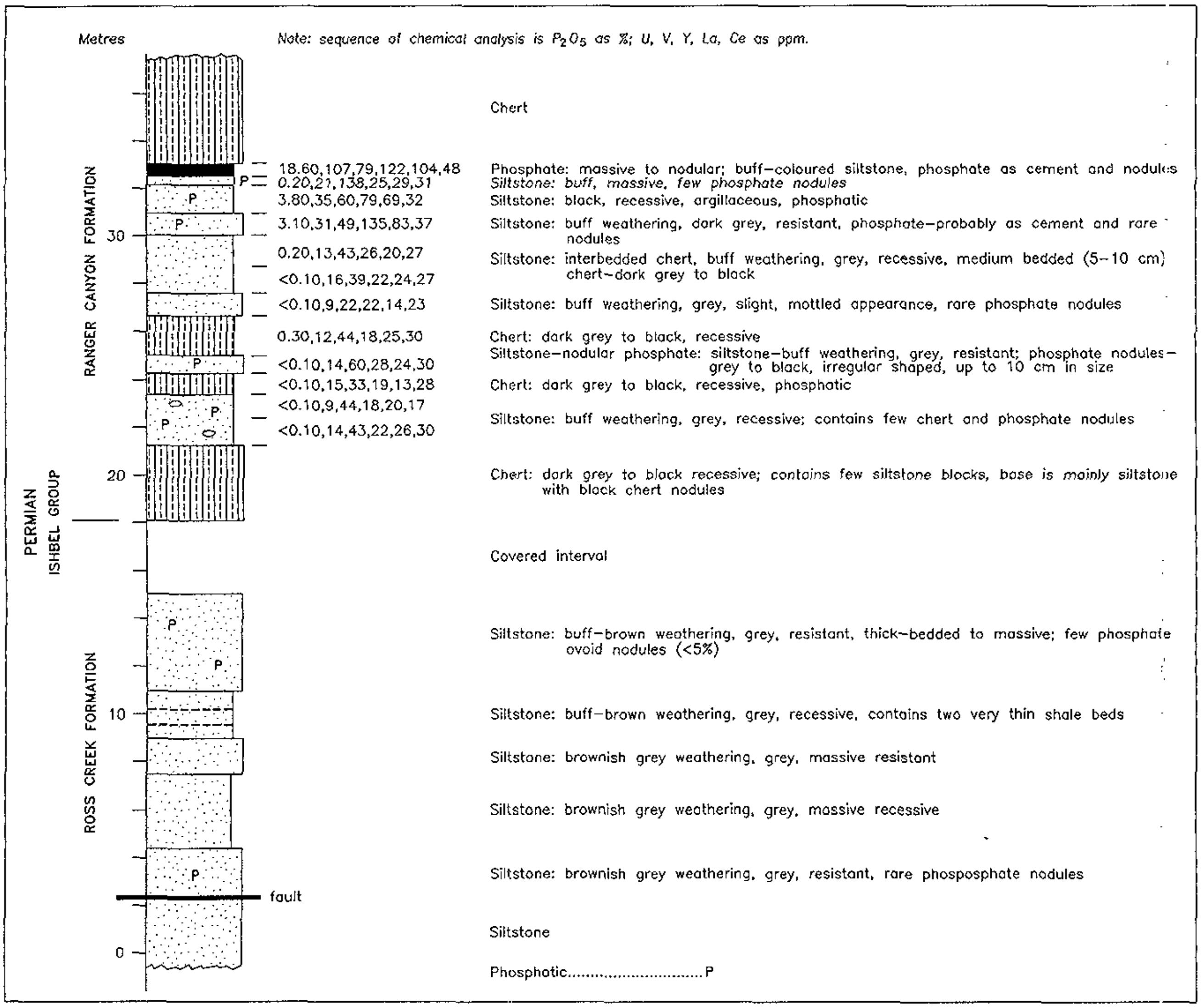


Figure 30. Stratigraphic Section 6, Forsyth Creek.

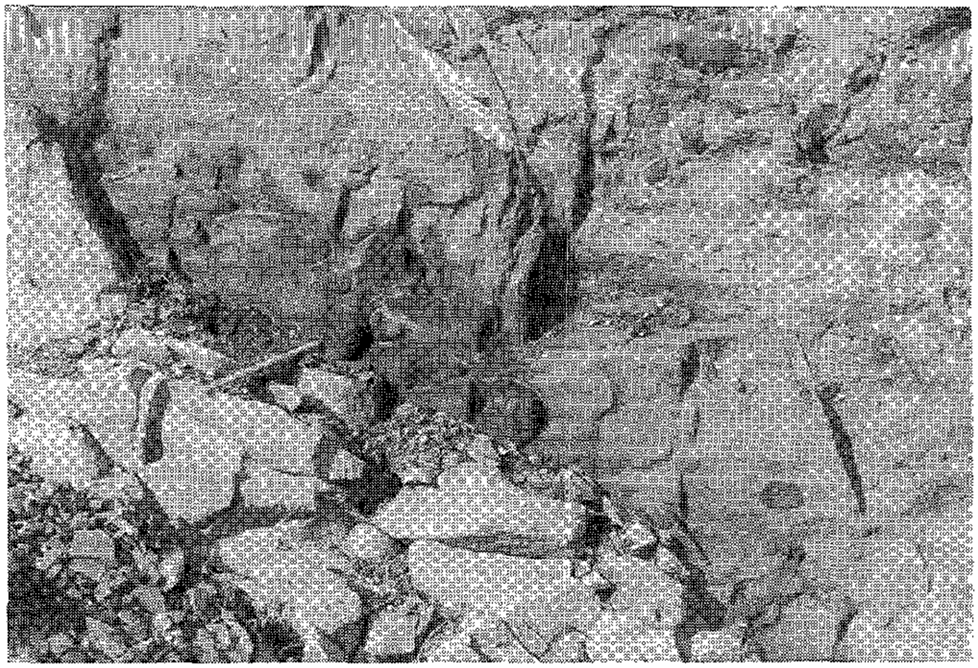


Photo 18. Phosphate nodules (black) in a 1-metre-thick siltstone bed overlying chert at the top of the Ranger Canyon Formation in the Connor Lakes area north of Forsyth Creek.

The geologyof this area is complicated by structural thickening due to steeply dipping normal faults, particularly in the more northerly section. Several fault repetitions can be seen in outcrop, especially in beds beneath the chert horizon. Along strike to the north faulting becomes less prevalent and the phosphatic interval thins dramatically.

The Ross Creek Formation contains a number of sandstone beds with phosphate nodules. The nodules are a minor component of the rock and the phosphate grade is low, averaging approximately 0.9% P_2O_5.

MACDONALD THRUST FAULT (2) NTS: 82G/2

MINFILE:	Mt. Broadwood 082GSE069 Fenster Creek 082GSE066 Ram South 082GSE067
Lat: 49°10′30″ to 49°18′00″	Long: 115°49′05″ to 114°56′55″

Several exposures of phosphate were examined along the MacDonald thrust fault at the southern margin of the Fernie basin. Stratigraphic sections were measured at Mount Broadwood, north of Fenster Creek and at a locality approximately 4 kilometres northwest of Cabin Pass.

Low grade phosphate occurs in the basal portion of the Johnston Canyon Formation and can be traced almost continuously from the Fernie ski-hill in the northwest to Burnham Creek in the southeast (Figure 31). It varies in thickness from less than 1 metre in the Burnham Creek (Section 41) area to 22 metres near Mount Broadwood (Section 17).

Phosphate is most commonly present as nodules, but also as phosphate cement, phosphatic replacement of shell material and rarely, as intraclasts. It also occurs as clasts and cement in a thin basal conglomerate that appears to extend along the entire length of the fault. Host lithologies are typically siltstones and fine-grained sandstones with minor shale. Locally these clastic strata are calcareous.

At Mount Broadwood, where the thickest phosphatic interval was observed, individual phosphate beds contain

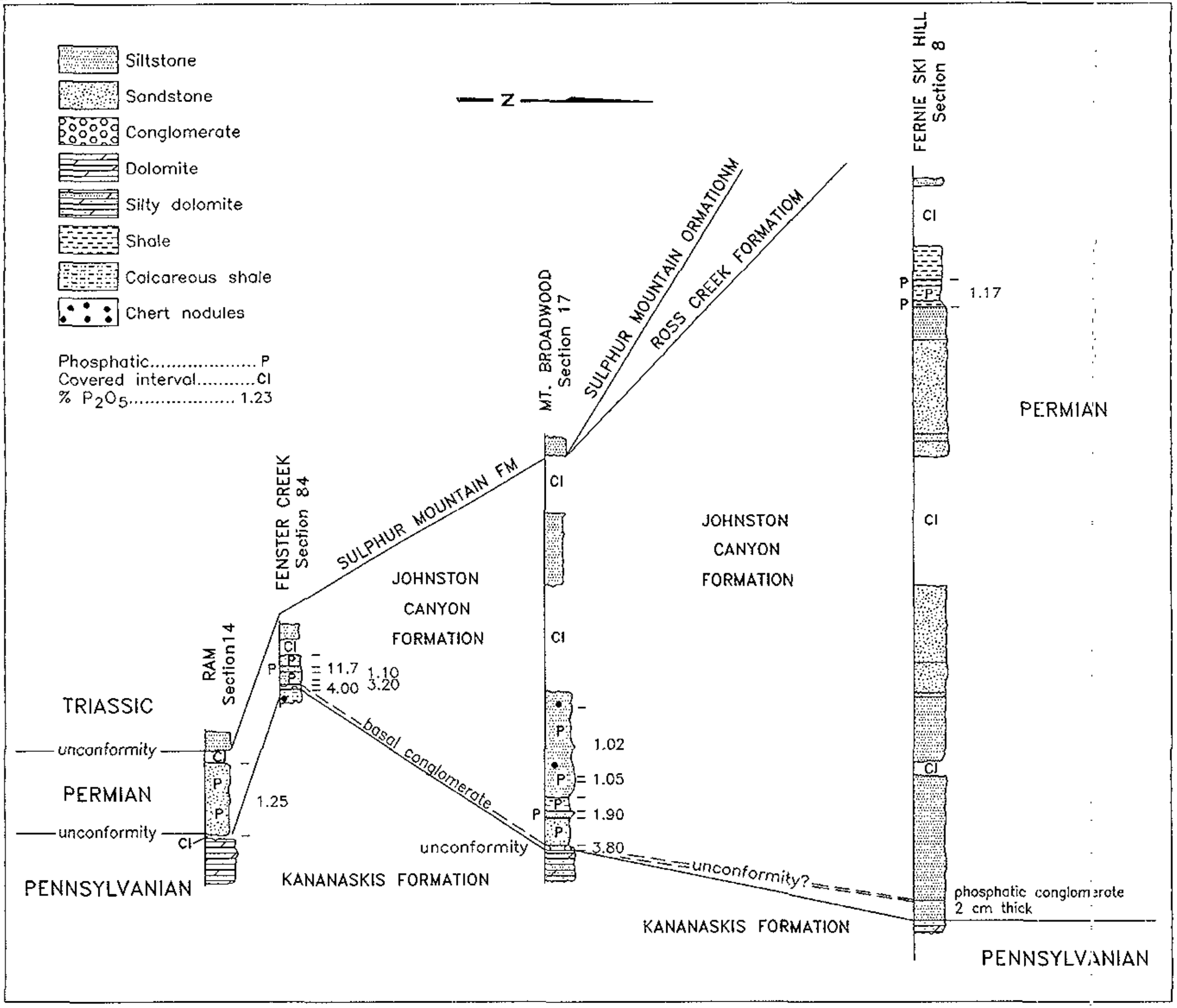


Figure 31. Stratigraphic correlation of phosphate-bearing strata, Johnston Canyon Formation, Fernie ski-hill - Cabin Creek area.

0.2 to 2.66% P_2O_5. Phosphate is typically nodular (Photo 19) although it is also present as cement. The basal conglomerate, which is 30 centimetres thick, contains 3.20% P_2O_5.

At the Fenster Creek locality, clastic beds are more calcareous and contain relatively abundant bioclastic debris. A calcareous sandstone bed 0.5 metre thick contains 11.70% P_2O_5. The basal conglomerate contains 4.0% P_2O_5.

Near Cabin Pass only nodular phosphate is present and individual beds contain less than 2% P_2O_5.

Nodular phosphatic beds of the Ranger Canyon Formation may also be present locally.

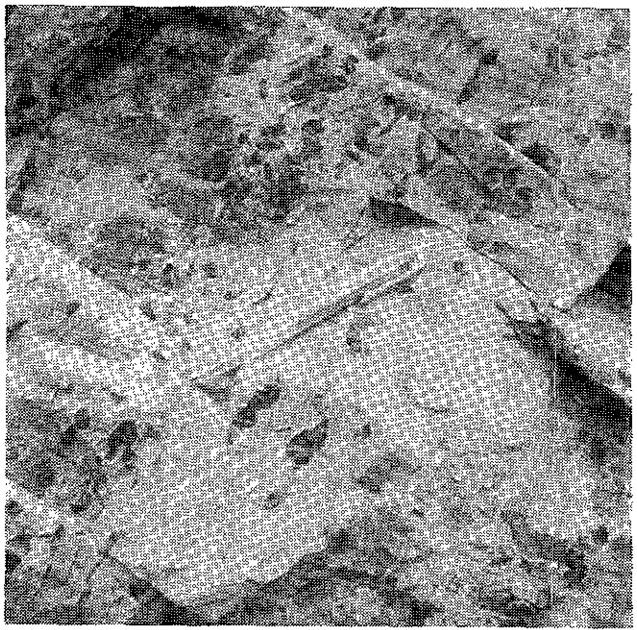


Photo 19. Phosphate nodules and intraclasts in siltstone of the Johnston Canyon Formation, Mount Broadwood.

FERNIE SKI-HILL (3) *NTS: 82G/6*

MINFILE: 082GSW060

Lat: 49°27′40″ Long: 115°06′20″

In the Lizard Range, and specifically at the Fernie ski-hill, Permian strata are overturned. This locality provies the rare opportunity to measure a section across the entire Permian sequence (Figure 32). The Johston Canyon Formation is approximately 100 metres thick and contains a few very thin phosphatic shale beds in the upper part of the section. The basal conglomerate, which occurs throughout the region, is represented by a bed only 21 centimetres thick.

The Ross Creek Formation is approximately 25 metres thick and contains three rare very low-grade phosphatic shale beds. The author has placed these strata in the Ross Creek Formation. This designation is far from certain as these beds may be part of the underlying Johnston Creek Formation or the overlying Ranger Canyon Formation.

The Ranger Canyon Formation as defined here is approximately 50 metres thick and consists of chert and sandstone. Close to the top there is a phosphate bed 50 centimetres thick containing 13.30% P_2O_5 (Photo 20). Phosphate is present as nodules, pellets and cement. The nodules may contain quartz grains and chert spicules or may be devoid of any extraneous material. The phosphate bed itself is composed of quartz, potash feldspar, minor illite, sericite, calcite and albite and is underlain by phosphatic sandstone and chert.

WEIGERT CREEK (4) *NTS: 82G/15*

MINFILE: 082GNE038, 039

Lat: 49°57′45″ Long: 114°56′25″

Phosphate is exposed at two localities along a four-wheel-drive road that extends northward from the main

Photo 20. Phosphorite bed from the top of the Ranger Canyon Formation, Fernie-ski-hill.

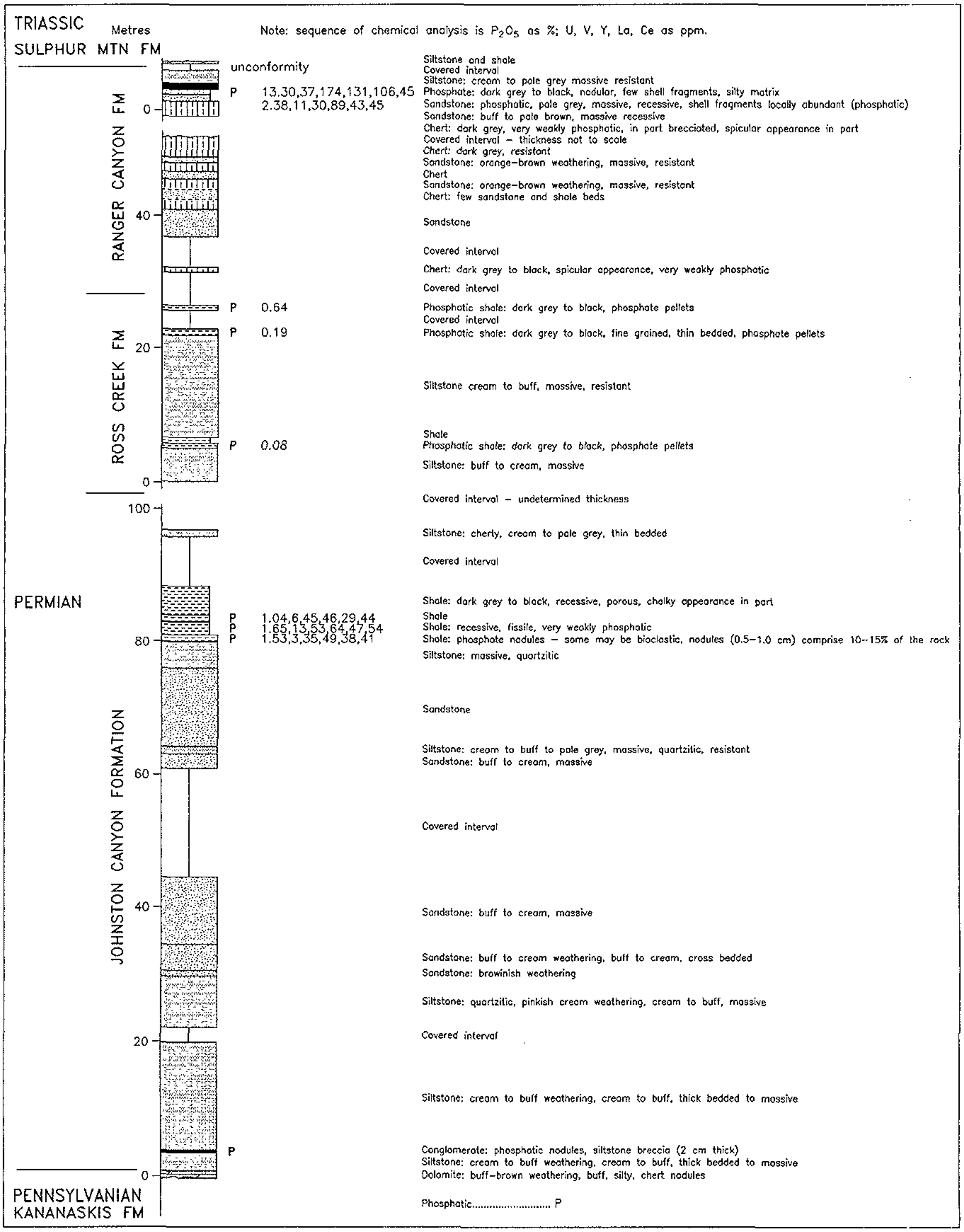


Figure 32. Stratigraphic section 8, Fernie ski-hill.

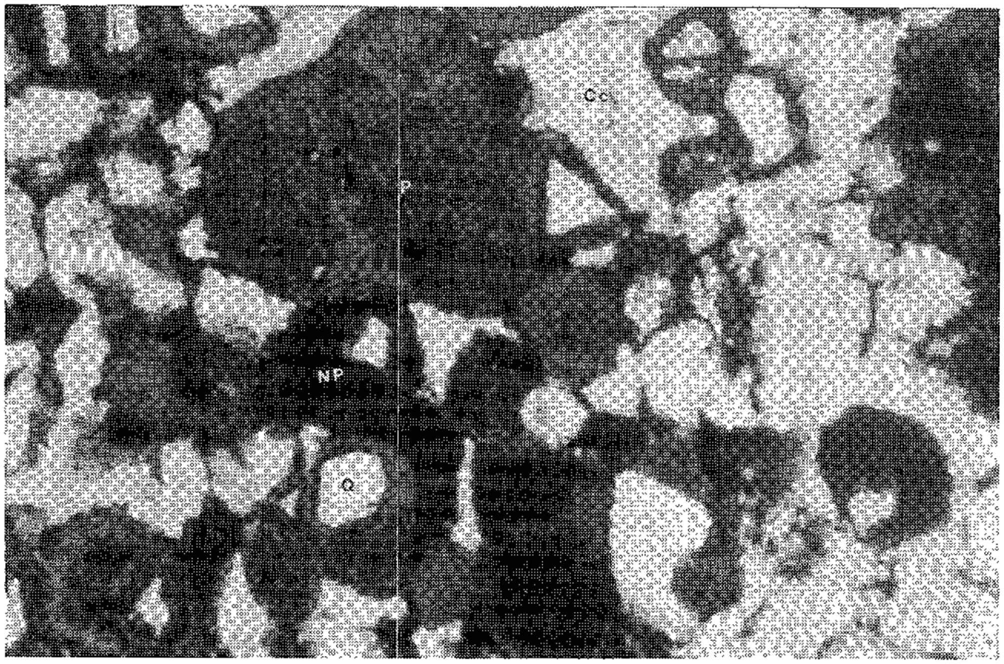


Photo 21. Photomicrograph (40x) of pelletal phosphorite from the Johnston Canyon Formation, Weigert Creek. Phosphate pellets (P) and nucleated pellets (NP) occur in a calcite (Cc) quartz (Q) matrix.

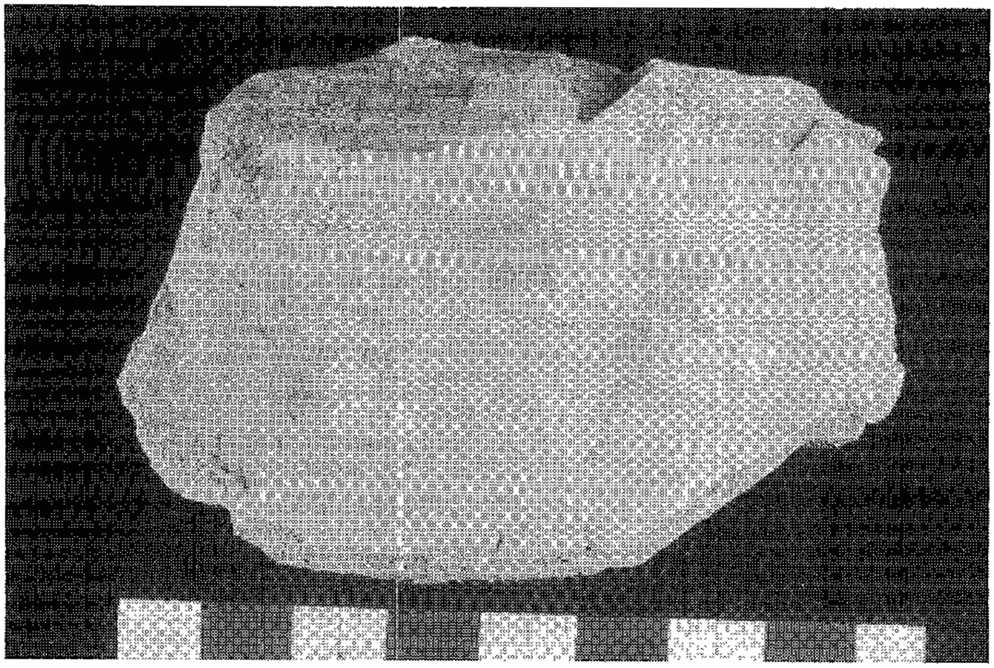


Photo 22. Pelletal phosphorite from the Johnston Canyon Formation, headwaters of Nordstrom Creek.

Weigert Creek logging road north of Sparwood. It is interpreted to occur along the limbs of a north-trending anticlinal fold in the Johnston Canyon Formation. Lithologies include sandstone, shale, dolomitic siltstone and conglomerate.

The western exposure consists of a phosphorite bed 2 metres thick averaging 14.25% P_2O_5 and comprised of semidispersed, subrounded, generally structureless pellets (Photo 21). Approximately 5% of the pellets are nucleated and a very few are oolitic. Some phosphate cement is also present. The pellets, which comprise 40 to 50% of the rock by volume, occur primarily in a quartz matrix with some feldspar.

The eastern exposure consists of a phosphorite bed 1 metre thick containing 15.8% P_2O_5 (Photo 37). The phosphorite is pelletal, with the pellets comprising 50 to 60% of the rock by volume. They are subrounded, brown to dark brown, with a grain size of 0.1 to 0.5 millimetre. Less than 5% of the pellets are nucleated or encased. Rare oolitic radial structures may also be present. The matrix is comprised mainly of calcite with minor quartz and clay minerals.

NORDSTRUM CREEK (5) *NTS: 82G/15*

MINFILE: 082GNE037

Lat: 40°51′50″ Long: 114°59′55″

Three phosphate beds are poorly exposed over a 60-metre width near the headwaters of Nordstrum Creek southwest of Fernie, at the end of a seismic survey line. The area between the phosphate beds is covered by overburden. The host rocks are buff-brown-weathering sandstone and pale grey quartzitic siltstone of the Johnston Canyon Formation.

The most westerly bed has an exposed thickness of 1 metre and contains 21.20% P_2O_5 as nodules, pellets and cement (Photo 22). The matrix consists of quartz, bioclastic debris and minor feldspar.

The two easterly beds contain approximately 5% phosphate nodules by volume and less than 2% P_2O_5. The nodules are composed of fluorapatite, quartz, and minor dolomite and potash feldspar. Both of the beds are 1 metre or less thick.

LINE CREEK (6) *NTS: 82G/15W*

Line Creek MINFILE 082GNE028

Harriet Lake 082GNE030

Lat: 49°5′00″ Long: 114°48′00″

Cominco Ltd. owns six phosphate leases in the West Line Creek area in the Wisukitsak Range, east of the Elk River. A phosphate horizon varying in thickness from less than 1 metre to in excess of 3 metres occurs at the base of the Fernie Formation. It can be traced along strike for 15 kilometres (Figure 33); 8 kilometres of strike length are covered by the Cominco leases.

A steep, easterly dipping phosphate sequence 4.9 metres thick is exposed on Mount Lyne, site of Cominco's bulk sample (G.L. Webber, personal communication, 1986) (Figure 34). The base of this sequence is marked by a marcasite band 5 centimetres thick and the top by a yellow-orange cherty limestone bed 10 centimetres thick. The basal 2 metres of the phosphatic sequence averages 23.2% P_2O_5 and is overlain by 1 metre of interbedded shale and phosphate, than a bed of lower grade phosphate, 90 centimetres thick, containing 13.4% P_2O_5, and capped by 2 metres of phosphatic shale with a phosphate content averaging less than 5% P_2O_5.

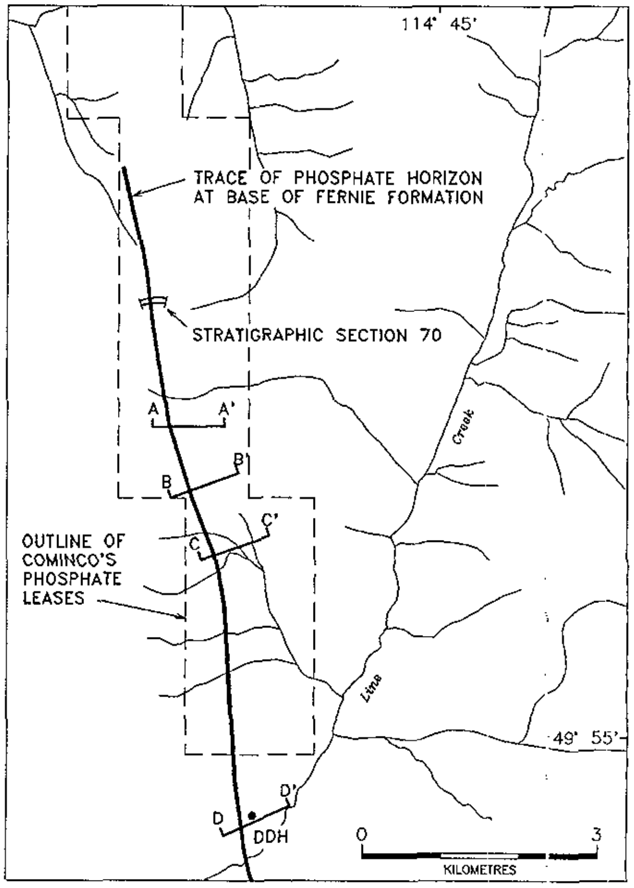


Figure 33. Location of phosphate horizon in the Line Creek area.

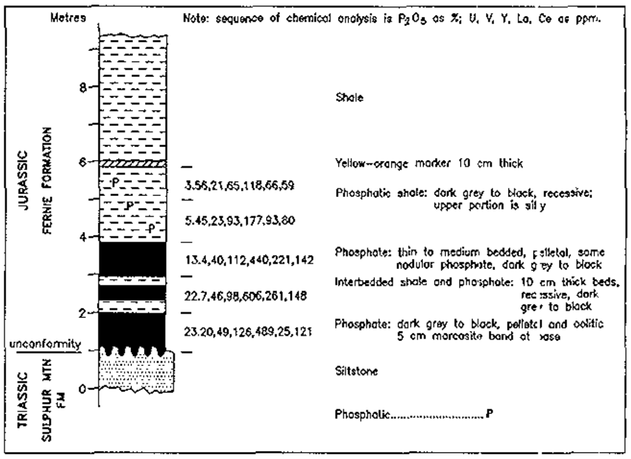


Figure 34. Stratigraphic section, 70, Mount Lyne.

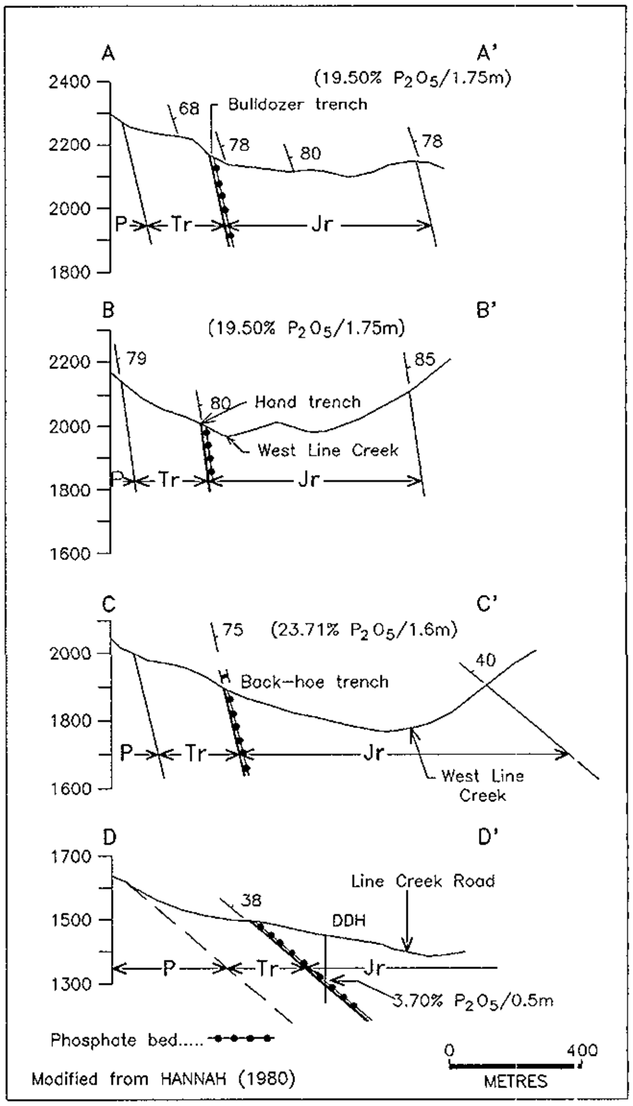
The phosphorite at Mount Lyne is typically pelletal with a compact (Photo 23) to semidispersed texture. The pellets are chestnut-brown to dark brown, ovoid, moderately well sorted and generally structureless. Less than 5% are nucleated. The matrix is comprised almost entirely of quartz, with trace amounts of sericite and illite. Neither petrographic nor x-ray diffraction work reveals the presence of any carbonate.

Between the Line Creek access road and Mount Lyne, Crows Nest Resources Ltd. obtained values of 3.7% P_2O_5 in a diamond-drill hole and 23.7% P_2O_5 across 1.6 metres in a backhoe trench (Hannah, 1980). The phosphate bed dips between 45 and 70° east throughout its strike length (*see* Figures 33 and 35). Along strike, a distance of approximately 11 kilometres from Mount Lyne to the south, near Harriet Lake, this phosphatic interval thins to 85 centimetres and contains 13.8% P_2O_5.

CROW (7) NTS: 82G/10

MINFILE: 082GNE025
Lat: 49°39′45″ Long: 114°42′30″

The Crow property, consisting of four phosphate leases, is located at the west end of the Crowsnest Pass, 2.5 kilometres north of the gas pipeline pumping station on Highway 3 (Figure 14). Phosphorite was discovered by Telfer at the base of the Fernie Formation in the early 1900s. Exploration continued intermittingly until the mid-1970s by the Consolidated Mining and Smelting Company of Canada, Limited (now Cominco Ltd.). During this time they completed 600 metres of underground work and shipped an 1800-tonne sample to Trail for metallurgical testing in 1931. Further testing was done in the mid-1960s. Beneficiation work by Cominco has yielded acceptable concentrate grades with recoveries of approximately 75% (Kenny, 1977).



Modified from HANNAH (1980)

Figure 35. Cross-sections through Fernie phosphate, West Line Creek.

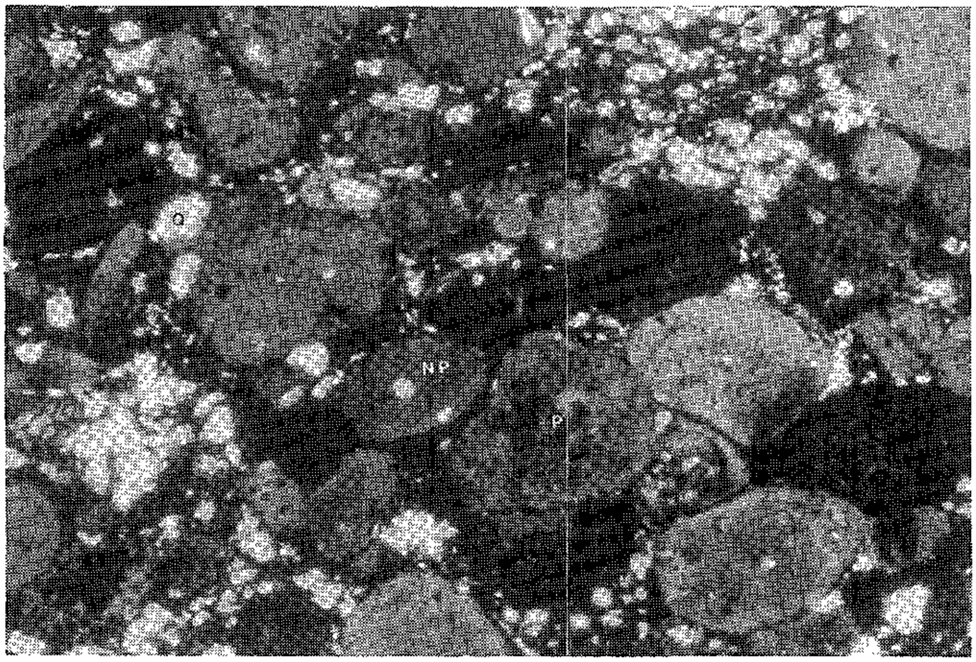


Photo 23. Photomicrograph (40x) of pelletal phosphorite, basal Fernie Formation, Mount Lyne locality. Phosphate pellets (P) and nucleated pellets (NP) with a compact texture occur in a quartz (Q) matrix.

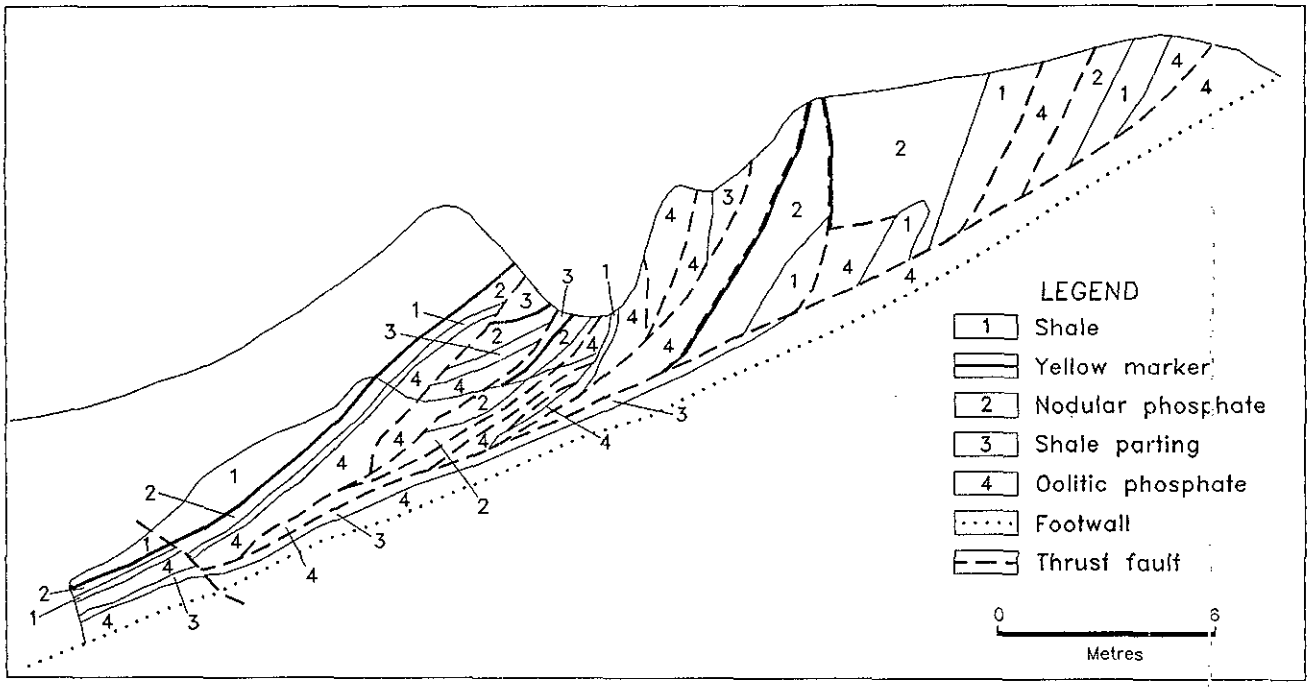


Figure 36. Cross-section through the Crow deposit (from Telfer, 1933).

The adit and underground workings are now inaccessible. Only one old trench and a few surface exposures south of the underground workings are available for examination. Telfer (1933) describes the phosphate horizon as consisting of three beds: a lower oolitic high-grade phosphorite, a shale parting and an upper nodular phosphorite with a yellow marker bed at the top. The high-grade phosphorite bed consists of structureless pellets and rare pellets with an oolitic texture. The beds average approximately 1 metre in thickness, but are repeated as many as four or five times by easterly directed thrusting (Telfer, 1933).

Telfer describes a section through an inclined shaft at the southern end of the underground workings where stacking of fault slices has compressed almost 100 metres of dip-length to less than 40 metres (Figure 36). The resulting thickening of the phosphorite beds extends over a strike length of 150 metres. Similar structural thickening occurs at the northern end of the exploration drift and midway along the workings where it is associated with a 90° change in strike direction. A raise at this point shows the thickening extends 150 metres up-dip before the beds resume their normal thickness and continue to the surface.

The southernmost area of structural thickening can be seen in the old trench above the workings. The phosphate horizon is exposed over an interval of 19 metres within which a phosphorite bed 1 metre thick is repeated four times. Sampling from this trench indicates an average phosphate content of 26.20% P_2O_5, with 757 ppm yttrium, 319 ppm lanthanum, 183 ppm cerium, 1288 ppm strontium and 41 ppm uranium (Table 10).

The phosphate horizon, although not seen in outcrop, is believed to be continuous into the headwaters of Alexander Creek where it is exposed in two roadcuts. The top and bottom of the phosphorite are covered, but it has a minimum thickness of 30 centimetres and assays from 27.4 to 29.4% P_2O_5. Bedding in this area dips west at approximately 25°.

ALEXANDER CREEK - HIGHWAY 3 (8) NTS: 82G/10

MINFILE:	Alexander Creek South 082GNE029 Highway 3 Roadcut 082GNE033
Lat: 49°39′15″	Long: 114°44′10″

A phosphorite bed 1.2 metres thick is exposed in a roadcut on Highway 3 near Alexander Creek (Figure 37) unconformably overlying shale and siltstone of the Sulphur

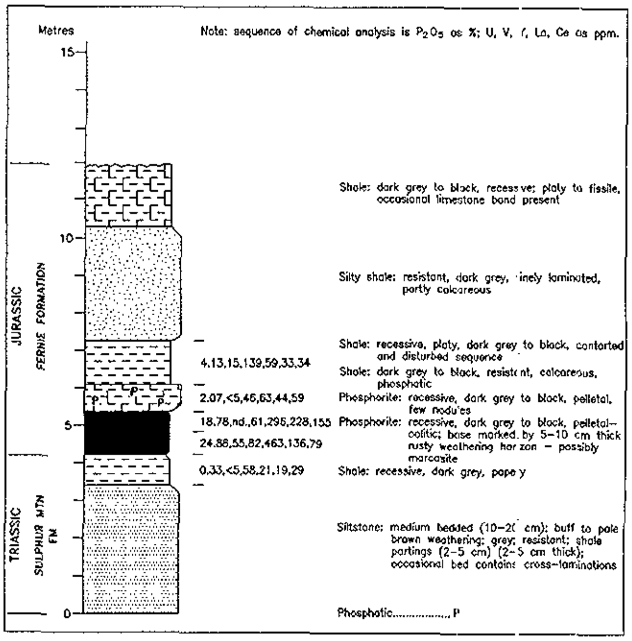


Figure 37. Stratigraphic section 3, Highway 3 roadcut, approximately 8 kilometres east of Michel.

TABLE 10
ANALYTICAL RESULTS, CROW DEPOSIT

Sample Number	Width (metres)	P_2O_5 (%)	Sc	Cu	Pb	Zn	Sr	Y	U	Th	V	La	Ce	Ti	Ba
SBB86 4A	1.00	6.6	2.3	44	20	126	1214	485	32	<6	89	200	116	1253	929
SBB86 4B	1.00	6.6	3.3	41	22	180	1290	946	38	5	94	406	244	939	1398
SBB86 4C	1.00	25.7	3.6	40	27	241	1293	946	42	2	91	409	222	935	1387
SBB86 4D	1.00	25.1	2.6	40	25	175	1307	792	5	<6	90	332	205	85	1739
SBB86 4E	0.70	27.0	2.8	40	22	108	1337	617	50	<6	94	247	126	1248	1135
Average	*0.94*	*26.2*	*2.92*	*41*	*23*	*166*	*1288*	*757*	*41*	*<6*	*92*	*319*	*183*	*1072*	*1318*

Mountain Formation. The phosphorite is overlain by phosphatic shale, minor limestone and shale).

The phosphorite consists of brown to dark brown, subangular to subrounded, structureless pellets 0.1 to 0.3 millimetre in diameter. Approximately 5% of the pellets have nuclei of either quartz or calcite. The pellets are compact to semicompact and sometimes molded around previously formed pellets, suggesting that they were in a gel-like state when deposited. The matrix consists of quartz and calcite in equal amounts, with minor dolomite, albite, potassium feldspar and trace illite and sericite.

A second phosphate occurrence outcrops along Alexander Creek south of the highway. A phosphorite bed 1 metre thick overlies a conglomerate 5 centimetres thick at the base of the Fernie Formation (Figure 38). The phosphatic section is 5.5 metres thick, its upper limit marked by a yellowish orange weathering limestone bed 3 centimetres thick. Shale cut by numerous minor faults overlies the phosphatic sequence.

MARTEN (9) *NTS: 82G/10W*

MINFILE: 082GNE027
Lat: 49°34′00″ Long: 114°47′00″

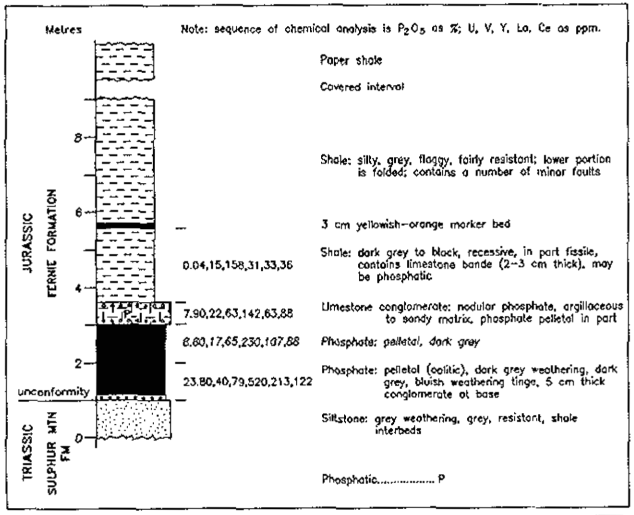


Figure 38. Stratigraphic section 31, Alexander Creek at Highway 3.

The Marten phosphate occurrence is in the valley of Michel Creek, approximately 8 kilometres south of McGillivray station. Exploration by the Consolidated Mining and Smelting Company of Canada, Limited in the early 1930s included some underground work. A phosphorite bed at the base of the Fernie Formation has an average grade of 15.2% P2O5 across 1.9 metres and has been traced along strike for approximately 1200 metres (J. Hamilton, personal communication, 1986). The bed is reported to strike northerly with moderate easterly dips.

SUMMIT LAKE (10) *NTS: 82G/10W*

MINFILE: 082GNE035
Lat: 49°39′10″ Long: 114°42′30″

A 3-metre section of Permian strata is poorly exposed on the western boundary of the Crowsnest Provincial Park, 0.5 kilometre north of Summit Lake. This section represents a condensed stratigraphic sequence and is tentatively assigned to the Johnston Canyon Formation. It overlies Kananaskis or possibly Tunnel Mountain strata of Permian age.

Phosphate is present as nodules in a sandstone bed 1 metre thick. Nodules are 2 to 5 centimetres in size, black and contain 27.5% P2O5. A sample across the sandstone bed assay 14.5% P2O5. This same bed is believed to continue south to the Flathead area and northward to Banff.

LIZARD (11) *NTS: 82G/11E*

MINFILE: 082GSW059
Lat: 49°29′22″ Long: 115°07′40″

The Lizard property, consisting of two phosphate leases held by Cominco Ltd., is located on Lizard Creek 5 kilometres southwest of Fernie (Figure 14). Only two caved adits and a dump are available for inspection. The area is overgrown by dense alder and thick underbrush with almost no outcrop.

Work by Cominco has indicated the presence of a phosphorite bed averaging 12.90% P2O5 across 3.4 metres (Taplin, 1967). In thin section (Photo 15) the phosphorite is seen to consist of brown to dark brown pellets averaging 0.2 to 0.3 millimetre in diameter. They are generally well rounded and structureless, with approximately 50% having a quartz nucleus. The matrix, which comprises 20% of the rock, is dominantly carbonate with lesser quartz and minor amounts of mica and clay minerals. Most of the carbonate matrix is the same grain size as the phosphate pellets. Deposition of phosphate as a gel is evidenced by molding of pellets around each other. In thin section there is no evidence that the phosphorite has been subjected to any significant weathering and upgrading of the phosphate content.

MUTZ CREEK AND UPPER MUTZ CREEK (12) *NTS: 82G/11E*

MINFILE: 082GNW055, 068
Lat: 49°30′40″ - 49°36′02″ Long: 115°05′00″

An overturned sequence of Mississippian to Jurassic rocks is exposed at several localities along a road that parallels Mutz Creek (Figure 14). Phosphatic chert and nodular phosphatic sandstone occur in two beds 40 to 50 centimetres thick and 10 to 20 centimetres thick separated by 1 to 2 metres of a brownish weathering nonphosphatic sandstone. These strata are assigned to the Permian Ranger Canyon Formation. Phosphate nodules weather a distinct white colour and stand out in relief on weathered surfaces (Photo 24). A sample across 40 centimetres contained 0.53% P_2O_5. This phosphate interval is located 25 metres below the base of a sequence of brownish weathering siltstones and shales of the Triassic Sulphur Mountain Formation.

In the same area within the Fernie Formation, a 3.1-metre interval of phosphorite and phosphatic shale is exposed above a conglomerate that occurs at the base of the Fernie. The phosphate interval averaged only 0.68% P_2O_5.

FAIRY CREEK (13) *82G/11E*

MINFILE: 082GNW054
Lat: 49°32′02″ Long: 115°04′55″

A phosphatic interval 4 metres thick is exposed near the top of the Ranger Canyon Formation on Fairy Creek (Figure 14). The upper 2 metres average 1.35% P_2O_5; the lower 2 metres average 0.32% P_2O_5. Phosphate occurs as ovoid nodules and very thin partings of massive phosphate along bedding planes.

ISLAND LAKE (14) *NTS: 82G/7*

MINFILE: Island Lake Two 082GNW031; Island Lake One 082GNW034
Lat: 49°31′30″ Long: 115°10′40″

Two phosphate occurrences are exposed in partially slumped trenches along the powerline in the Iron Creek - Island Lake area, west of Fernie (Figure 14). The trenches are believed to have been put in by Crows Nest Resources Limited while exploring for phosphate in 1966. At both localities a phosphorite bed 1 metre thick, with phosphate values ranging from 13.2 to 15.4% P_2O_5, occurs at the base of the Fernie Formation. The phosphorite is pelletal with a matrix of calcite and lesser quartz. Minor albite and trace amounts of potash feldspar and illite are also present.

HARTLEY LAKE(15) *NTS: 82G/11*

MINFILE: 082GNW030
Lat: 49°36′05″ Long: 115°04′30″

A phosphorite bed 50 centimetres thick is exposed at the base of the Fernie Formation in an overturned sequence exposed on a cliff face overlooking Hartley Lake (Figure 14). The phosphorite is pelletal, dark grey to black, reces-

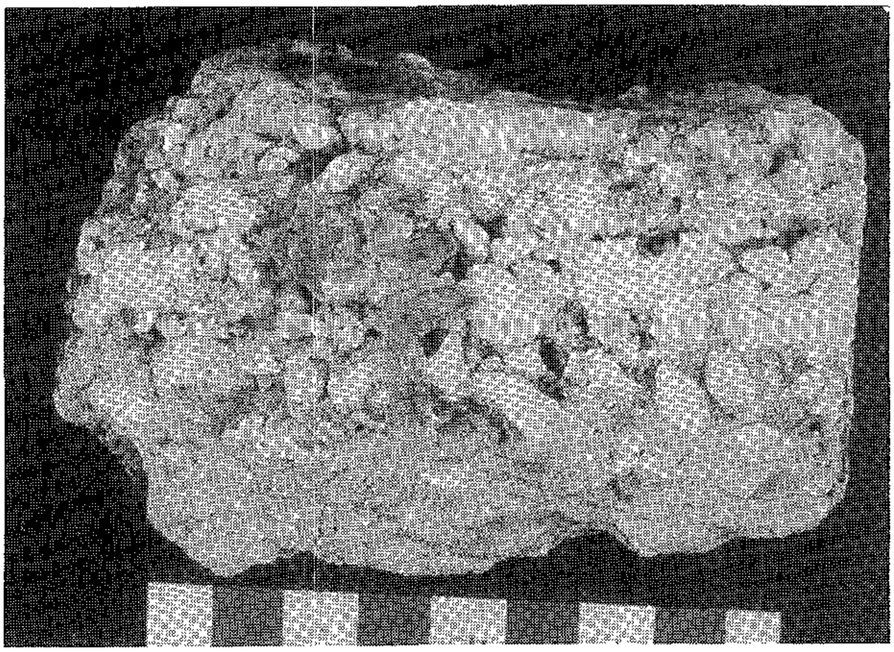


Photo 24. Phosphate nodules (white) in a brownish weathering sandstone, Ranger Canyon Formation, Upper Mutz Creek.

sive, and weakly calcareous; it grades 21.5% P_2O_5 and also contains 141 ppm vanadium, 160 ppm lanthanum and 84 ppm cerium. Stratigraphically underlying the phosphorite is a black dolomitic siltstone of the Triassic Sulphur Mountain Formation.

LLADNER CREEK(16) *NTS: 82G/10W*

MINFILE: 082GNE034
Lat: 49°41'40" Long: 114°56'10"

Fine siltstones of the Ranger Canyon Formation are exposed in a roadcut west of Lladner Creek (Figure 14). This sequence includes thin chert beds and a siltstone bed 50 centimetres thick containing black phosphate nodules. The phosphatic bed can be traced along strike for 40 metres and contains 4.2% P_2O_5.

ABBY (17) *NTS: 82J/7*

MINFILE: 082JSE016
Lat: 50°18'25" Long: 114°56'05"

The Abby occurrence is located along the Elk River forestry road 31.5 kilometres north of Elkford (Figure 14). It is exposed in a trench put in by Cominco Ltd. while exploring for phosphate in the mid-1970s.

Clastic rocks of the Fernie Formation unconformably overlie dolomite and dolomitic siltstone of the Whitehorse Formation. The base of the Fernie consists of a thin bed of phosphatic sandstone, overlain by a phosphorite bed 1.5 metres thick (Figure 39) which is in turn overlain by a phosphatic shale cut by a fault. A 1.0-metre phosphorite bed overlies the fault zone and is probably a repetition of the lower phosphorite bed. The phosphorite is pelletal with an average grain size of 0.1 millimetre. Phosphate content of the two beds averages 20.18% P_2O_5; the sandstone averages 3.81% P_2O_5. Phosphatic shale and shale overlie the phosphorite. A 1.0 metre sample from the overlying shale unit returned a value of 26.63% P_2O_5.

In thin section the phosphorite is seen to consist of light to dark brown, generally structureless subangular to subrounded pellets 0.1 to 0.2 millimetre in size (Photo 16). Less than 5% of the pellets are nucleated (generally quartz grains). The occasional pellet is oolitic. The matrix is comprised of subangular quartz grains with trace to minor amounts of potash feldspar, sericite and carbonate. The pellets comprise 50 to 60% of the rock by volume and are semi-compact to dispersed.

The phosphatic sandstone contains 10 to 15% fluorapatite pellets. The pellets are subrounded, brown and dispersed. Quartz with minor carbonate and trace feldspar, sericite and carbonate comprise the matrix. Quartz grains are subangular and moderately well sorted.

BINGAY CREEK (18) *NTS: 82J/2*

MINFILE: 082JSE011
Lat: 50°12'00" Long: 115°00'00"

This phosphate occurrence is located on Bingay Creek, 2.4 kilometres upstream from the Elk River forestry road, 19 kilometres north of Elkford (Figure 14). Vertical-dipping conglomerate, phosphorite, sandstone and shale of the Fernie Formation unconformably overlie silty dolomite of the Whitehorse Formation (Figure 40). The phosphatic sequence consists of a phosphorite bed 1.04 metres thick containing 11.80% P_2O_5, phosphatic sandstone and shale. The phosphatic sequence is marked by conglomerate (4 centimetres thick) at its base and is capped by an orange-weathering calcareous bed, 2 centimetres thick. The phosphorite is pelletal and contains a few shell fragments.

ELKFORD SKI-HILL (19) *NTS: 82J/2W*

MINFILE: 082JSE017
Lat: 50°01'30" Long: 114°57'30"

An overturned section of Ishbel Group and Sulphur Mountain Formation strata is exposed immediately above the chairlift on the Elkford ski-hill. This locality was briefly explored by Cominco Ltd. while exploring for phosphate along the Elk River valley.

A phosphorite bed 50 centimetres thick is exposed near the base of the Ross Creek Formation (Figure 41), overlain by 40 centimetres of phosphatic sandstone. A thin basal con-

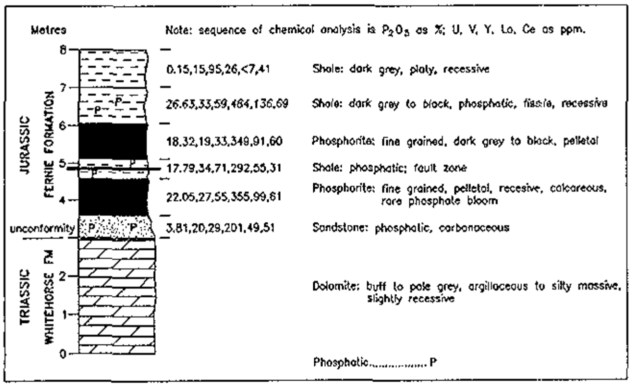


Figure 39. Stratigraphic section 13, Abby Ridge.

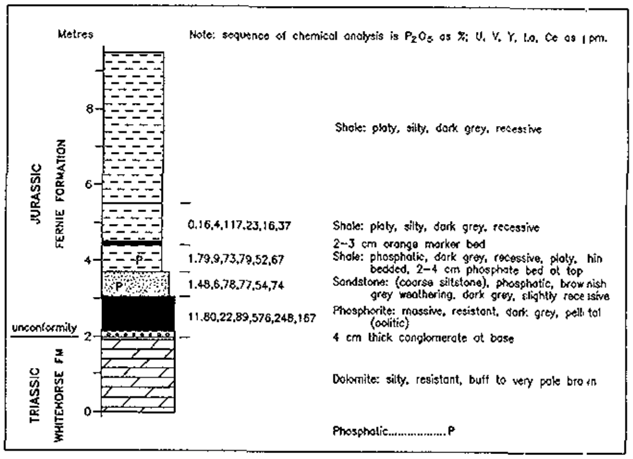


Figure 40. Stratigraphic section 14, Bingay Creek.

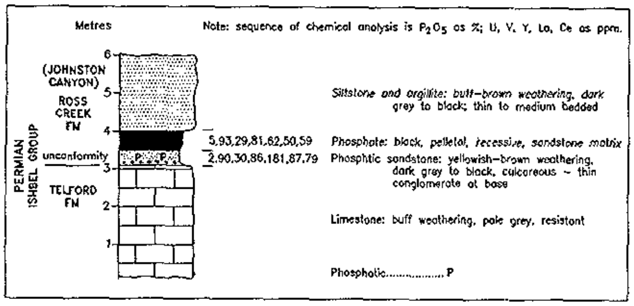


Figure 41. Stratigraphic section 80, Elkford ski-hill.

glomerate separates the phosphate sequence from limestone of the Telford Formation. The phosphate sequence is overlain by siltstone and argillite of undetermined thickness.

The phosphorite is composed of semicompacted ovoid pellets, 0.1 to 0.6 millimetre in size with rare compound pellets and oolites (Photo 25). Gangue minerals include quartz and calcite. A sample across the phosphorite bed contained 5.93% P_2O_5.

FORDING RIVER (20) *NTS: 82G/15*

MINFILE: 082GNE024
Lat: 49°54'20" Long: 114°50'55"

The Fording River phosphate occurrence, which has been known for a number of years, has been explored by both Crows Nest Resources Limited and Cominco Ltd. Work by Cominco included mapping, trenching and a 12-metre adit.

A gently southwest-dipping pelletal phosphorite bed occurs at the base of the Fernie Formation and is overlain by phosphatic shale and limestone. These strata are of Sinemurian age. The phosphate sequence is conformably overlain by belemnitic shales of Toarcian age and underlain unconformably by siltstone and minor shale of the Sulphur Mountain Formation (Figure 42).

The phosphorite bed is 80 centimetres thick and contains 19.10% P_2O_5. It is overlain by 74 centimetres of phosphatic shale containing 6.64% P_2O_5. Similar results were obtained by Cominco in the adit where a pelletal phosphorite bed 1.2 metres thick containing 21.3% P_2O_5 is overlain by 51 centimetres of phosphatic shale containing 6.5% P_2O_5 (Webber, 1975). The phosphorite is typically pelletal with pellets of fluorapatite present in a matrix of calcite and lesser quartz.

A diamond-drill hole completed by Cominco to the northwest, intersected 1.76 metres of phosphate containing 18.57% P_2O_5 at a depth of 49.4 metres (Webber, 1976). This phosphate horizon is believed to be present west of Grave Creek area where drilling by Cominco Ltd. intersected 1.5 metres of phosphate containing 16.93% P_2O_5 (Webber, 1976).

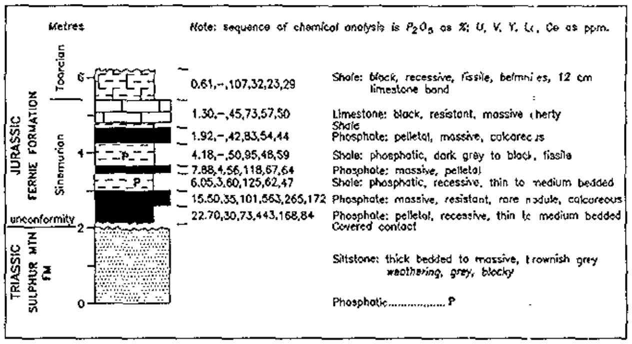


Figure 42. Stratigraphic section 6, Fording River.

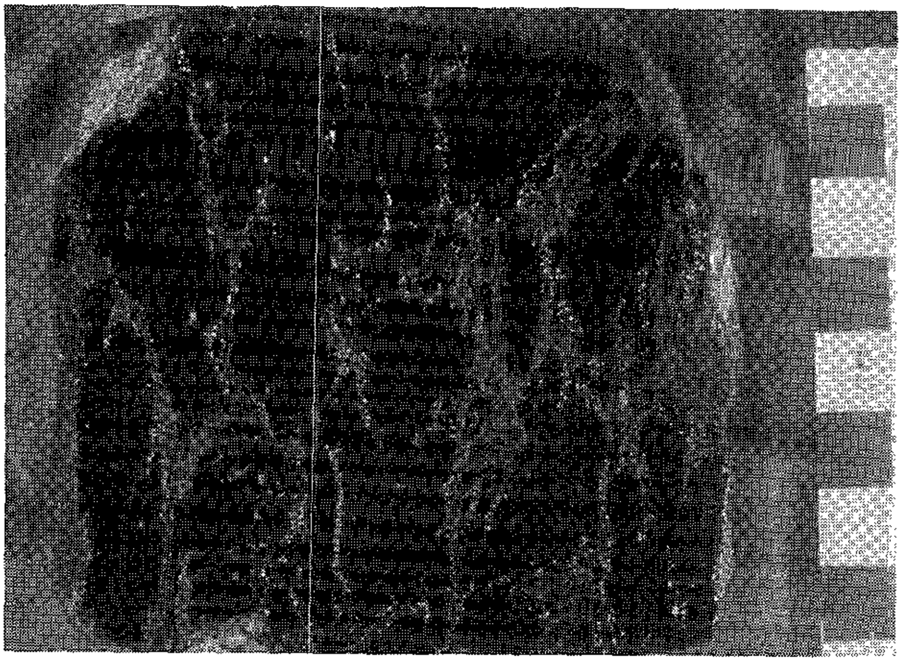


Photo 25. Hand specimen of basal Fernie phosphorite, Lodge phosphate occurrence. Irregular-shaped phosphate nodules occur in a pelletal phosphate matrix.

BARNES LAKE (21) *NTS: 82G/7*

MINFILE: PH 082GSE038; WW 082GSE051
Lat: 49°27′10″ *Long:* 114°40′50″

A phosphorite bed 0.8 to 1.2 metres thick is exposed at the base of the Fernie Formation on the limbs of a series of northerly plunging folds in the Barnes Lakes area (Figure 14). It unconformably overlies siltstone of the Sulphur Mountain Formation and is overlain by paper shales of the middle Fernie Formation. Exploration work by Western Warner Oils Ltd. and Medesto Exploration Ltd. consisted of geological mapping, trenching, seismic surveys and drilling (Dorian, 1975; Pelzer, 1977; Dales, 1978) and outlined 262 000 tonnes of phosphorite to a depth of 18 metres (60 feet). Phosphate grades in surface trenches were reported as 27.0 to 33.0% P_2O_5. A sample taken by the author assayed 22.4% P_2O_5, 452 ppm yttrium, 24 ppm uranium, 198 ppm lanthanum and 135 ppm cerium across 80 centimetres.

Nodular phosphate is also present in sandstone in the Johnston Canyon Formation. The phosphate-bearing sandstone bed is 30 to 40 centimetres thick with a phosphate content of 1.7% P_2O_5.

LODGEPOLE (22) *NTS: 82G/7W*

MINFILE: 082GSE062
Lat: 49°18′50″ Long: 114°55′30″

The Lodgepole phosphate occurrence is located immediately east of the junction of the Lodgepole and Ram Creek Forestry Roads south of Morrissey (Figure 14). Phosphate from this area was first reported by Telfer (1933) and has seen only minor exploration. MacDonald (1985) also reported the presence of phosphate-bearing strata in the lower Fernie Formation at this locality.

The only exposure found during this study is a 12-centimetre phosphorite bed occurring between two limestone beds at the base of the Fernie Formation. This phosphorite was previously described by Freebold (1969) and contains 14.3% P_2O_5. Thrust faults and small-scale folds are common in the area.

LODGE (23) *NTS: 82G/7*

MINFILE: 082GSE057
Lat: 49°16′50″ Long: 114°47′40″

The Lodge phosphate occurrence is located immediately south of the Lodgepole forestry road, 31 kilometres southeast of Fernie (Figure 14). Exploration for phosphate in this area was done by Imperial Oil Ltd. A phosphorite bed occurs in brown and black shale and siltstone at the base of the Fernie Formation. These strata unconformably overlie fine siltstone of the Sulphur Mountain Formation. The only outcrop of phosphate is strongly weathered and the thickness of the phosphorite was not determined. A large grab sample assayed 29.5% P_2O_5. In hand specimen the phosphate is both pelletal and nodular (Photo 25). Drilling interested 2.44 metres of phosphate averaging 17.33% P_2O_5 (Heffernan, 1978).

ZIP (24) *NTS: 82G/7*

MINFILE: 082GSE064
Lat: 49°16′05″ *Long:* 114°36′00″

The Zip phosphate occurrence is located on Morris Creek northwest of the junction of the Harvey Creek and Corbin logging roads (Figure 14). This locality was explored by First Nuclear Corporation Ltd. in 1980; work consisted of geological mapping and trenching (Hartley, 1981, 1982).

A phosphorite bed, 0.7 metre thick, is exposed at the base of the Fernie Formation and unconformably overlies dolomite and silty dolomite of the Sulphur Mountain Formation. It has been repeated several times by thrust faulting. Vanadium-rich shales overlie the phosphate (Hartley, 1981).

The phosphate at this locality has a very limited strike length as the Fernie Formation has been truncated by a trachytic syenite and the Flathead fault. Based on two samples, phosphate grades are in the range 23.9 to 27.1% P_2O_5 across a thickness of 0.7 metre.

CABIN CREEK (25) *NTS: 82G/2*

MINFILE: Cabin, CS 082GSE055;
Ram 082GSE056; Bighorn 082GSE060;
Storm Creek 082GSE061; Ram A 082GSE063;
Cabin G 082GSE068
Lat: 49°06′40″ Long: 114°40′45″

Exploration for phosphate in the Cabin Creek area began in 1978 when Imperial Oil Ltd. completed a program of geological mapping and drilling (Van Fraassen, 1978). In 1982 First Nuclear Corporation Ltd. reassessed the potential in the area, completing radiometric surveys, geological mapping and trenching (Hartley, 1982).

The Cabin Creek area covers the southern limit of the Fernie basin and the southernmost exposures of phosphate in both Permian and Jurassic strata in southeastern British Columbia. A total of 18 phosphatic sections were measured by First Nuclear Corporation, some of which were re-examined in the course of this study.

Permian strata are represented by the Ranger Canyon Formation above and below the MacDonald thrust fault and the Johnston Canyon Formation above the fault (Figure 43). Phosphate in the Johnston Canyon Formation is typically nodular with occasional pelletal phosphate present in a lower, dark grey to black, calcareous siltstone unit. The pelletal phosphate consists of dispersed pellets, 0.3 to 0.5 millimetre in diameter, in a matrix of calcite and quartz. Phosphatized shell material is also present. A thin phosphatic conglomerate marks the base of the Johnston Canyon Formation.

Phosphate is present in the Ranger Canyon Formation in a basal chert-pebble to cobble conglomerate (Photo 5) and as pellets or nodules in the upper part of the section. Within the conglomerate phosphate occurs both as phosphate pebbles and as cement. The conglomerate, in the one outcrop examined, is in excess of 2 metres thick and includes a 60-centimetre section at the top containing 9.58% P_2O_5. Only

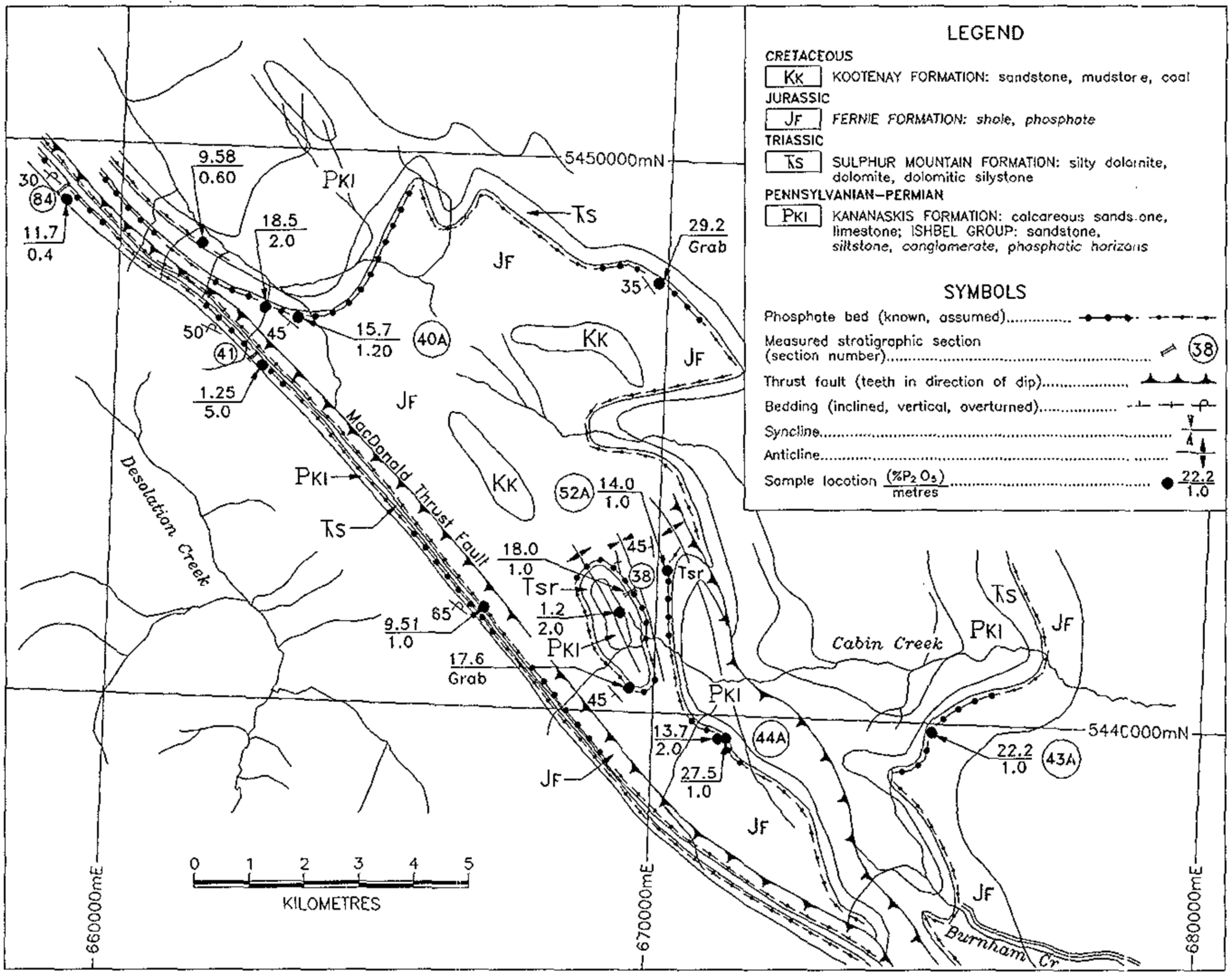


Figure 43. Geology and phosphate deposits in the Cabin Creek area.

minor phosphate is present in the upper part of the Ranger Canyon Formation.

In the same area, the phosphate horizon in the basal part of the Fernie Formation is exposed at several localities (Figure 48). A phosphorite bed averaging 1.5 metres thick and consisting of compact to semicompact pellets (Photo 26), outcrops along a strike length of approximately 27 kilometres. The pellets are typically subrounded to subangular, structureless, well sorted and 0.1 to 0.3 millimetre in diameter. Less than 2% of the pellets are nucleated. There has been some molding of pellets, suggesting deposition in a gel or plastic state. The matrix consists of quartz, calcite, minor potash feldspar and trace amounts of albite, dolomite and illite. Although subordinate to quartz, calcite may be abundant locally. The average phosphate content based on sampling at eight localities is 16.8% P_2O_5 and 272 and 188 ppm lanthanum and cerium respectively (Table 11).

In the measured section (Figure 44) two phosphorite beds are separated by a thin brownish coloured shale that may have a substantial bentonite component. The presence of bentonite in the Fernie Formation has been reported at a number of localities throughout the Fernie basin (Newmarch, 1953; MacDonald, 1985). To the north of this locality, at the headwaters of a tributary of the Storm Creek, the phosphorite bed thins to 1 metre with a phosphate content of only 14.0% P_2O_5. Here, the phosphorite is strongly weathered and contains 2 to 3% limonite. Further to the north, west of Hunger Lake, the phosphorite is at least 1

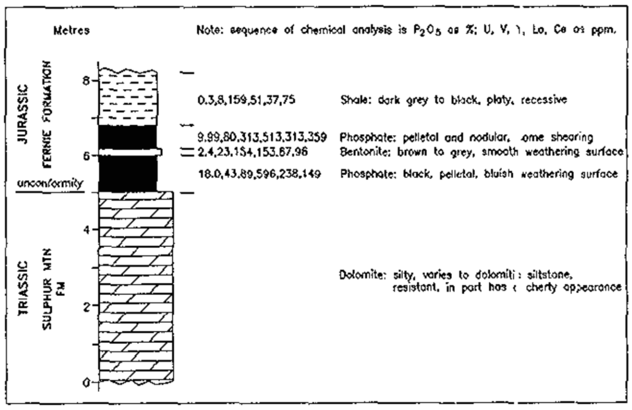


Figure 44. Stratigraphic section 38, Cabin Creek.

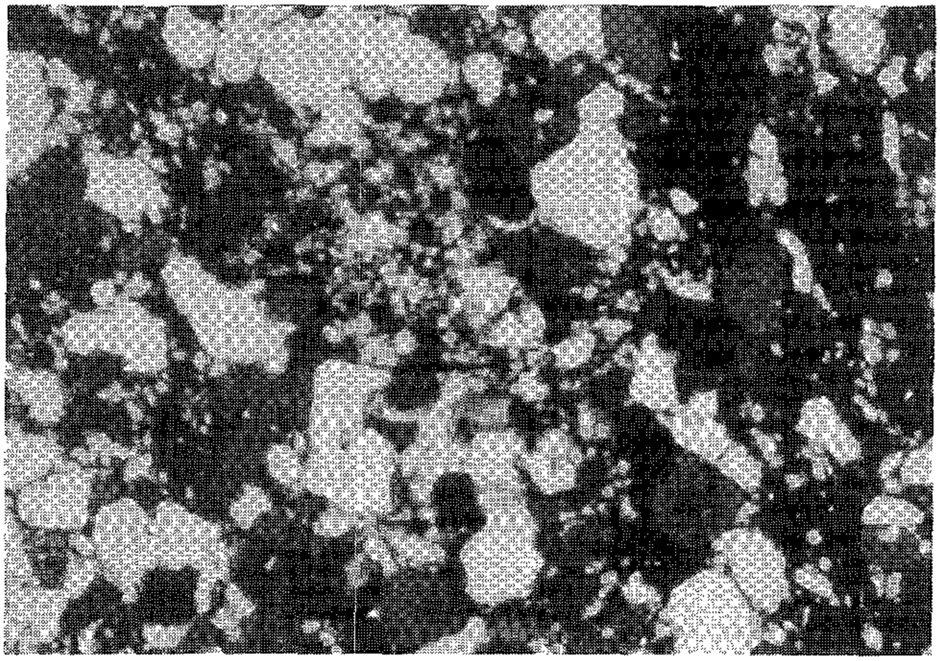


Photo 26. Photomicrograph (40x) of pelletal phosphorite from the Fernie Formation, Cabin Creek area.

TABLE 11
ANALYTICAL RESULTS CABIN CREEK PHOSPORITE

Sample Number	Width (metres)	P_2O_5 (%)	Cu	Pb	Zn	Sr	Y	U	Th	V	La	Ce	Ti	Ba
SBB86-37A	0.8	22.4	45	22	144	781	452	24	9	74	198	135	2181	230
SBB86-38A	1	18	37	25	204	602	596	43	15	89	238	149	2049	387
SBB86-38C	0.6	9.99	250	41	1500	620	513	80	9	313	313	359	2591	689
SBB86-40A	1.2	15.7	28	13	134	330	453	45	7	93	205	122	2511	323
SBB86-42A	1	18.4	28	11	91	512	520	56	13	92	230	151	2461	968
SBB86-42B	1	18.6	25	23	62	491	534	61	1	95	224	136	2470	528
SBB86-43A	1	22.2	40	20	175	565	659	81	29	108	295	199	1928	840
SBB86-44A	1	27.5	31	16	110	471	906	66	17	78	413	229	1290	231
SBB86-52A	1	14	30	15	115	365	415	48	15	85	196	147	2470	321
Average	0.95	18.53	57	21	282	526	561	56	13	114	257	181	2217	502

metre thick. A grab sample from this locality assayed 29% P_2O_5.

Phosphate within the Fernie Formation occurs both above aosphorite varies in thickness between 1 and 2 metres and assays from 18.4 to 27.5% P_2O_5. Above the fault the phosphorite is 1 metre thick with a grade of 9.51% P_2O_5.

Work by First Nuclear Corporation Ltd. in the Burnham Creek area, south of Cabin Creek, indicated the presence of phosphorite with grades in excess of 29% P_2O_5 (Hartley, 1982). MacDonald (1985) also obtained grades in excess of 29% P_2O_5 in this area as well as in the Storm Creek area. These localities were not examined by the author.

SHEEP MOUNTAIN (26) NTS: 82G/15W

MINFILE: 082GNE036
Lat: 49°51′55″ Long: 114°47′10″

A thin sequence of Permian strata, unconformably overlying dolomitic siltstone of the Pennsylvanian Kananaskis Formation and tentatively assigned to the Johnston Canyon Formation outcrops 500 metres east of Harriet Lake (Locality 6A, Figure 14). A phosphate-cemented chert-pebble conglomerate, 10 to 15 centimetres thick, containing 13.8% P_2O_5 marks the contact between Pennsylvanian and Permian strata. The conglomerate is overlain by a phosphatic cherty sandstone bed 70 centimetres thick that contains 0.7% P_2O_5.

NORTH SULPHUR CREEK (27) *NTS: 82G/11E*

MINFILE: 082GNW069
Lat: 49°44′25″ Long: 115°02′50″

Strata of the Permian Ishbel Group outcrop over a wide area in the Sulphur Creek area 15 kilometres north of Hartley Lake (Locality 15, Figure 14). Nodular phosphatic material is present in both outcrop and talus over much of this area.

Also at this locality a 90-centimetre-thick coquinoid bed assigned to the Ross Creek Formation contains a few phosphate nodules as well as disseminated phosphate pellets and cement. Some of the brachiopod shells within the coquinoid bed have been phosphatized. A single sample from this bed returned a grade of 0.9% P_2O_5 over 0.9 metre. Float containing phosphate nodules suggests that better grade phosphate may be present in the area.

TODHUNTER (28) *NTS: 82J/2W*

MINFILE: 082JSE018
Lat: 50°07′00″ Long: 114°45′30″

A small outcrop of Permian strata occurs along a logging road north of Todhunter Creek (Figure 14). A chert-bearing conglomerate 1 to 1.5 metres thick contains black phosphate pebbles. A sample of the conglomerate assayed 2.1% P_2O_5.

These strata are believed to be correlate with the Permian section that extends from Crowsnest Pass to Banff. They underlie Triassic rocks although at this locality the contact was not observed.

ALEXANDER CREEK NORTH (29)
NTS: 82G/10W

MINFILE: 082GNE027
Lat: 49°51′00″ Long: 114°47′00″

Two phosphorite occurrences are exposed in roadcuts near the headwaters of Alexander Creek (Figure 14). This phosphorite, which has a minimum thickness of 30 centimetres, occurs at the base of the Fernie Formation. It overlies siltstone of the Sulphur Mountain Formation. A sample across 30 centimetres returned an analysis of 29.4% P_2O_5. These beds are also enriched in barite, containing in excess of 1.6% barium. Lanthanum, uranium and cerium analyses are 472, 293 and 55 ppm. Similar, but slightly lower values for these metals were obtained at the Crow deposit.

PHOSPHATE LOCALITIES IN NORTHEASTERN BRITISH COLUMBIA

Phosphatic shale in northeastern British Columbia range in age from Upper Cambrian to Jurassic (see Chapter 3). Thirteen occurrences are described in the following section; numbers in parentheses refer to numbered localities on Figures 13, 16, 17, 18, 19 and 20, in pocket).

MEOSIN MOUNTAIN (30) *NTS: 93I/8*

MINFILE: 093I020, 021
Lat: 54°17′00″ Long: 120°19′00″

Exposures of the phosphate-bearing Whistler member of the Sulphur Mountain Formation are exposed, together with other Triassic and Permian strata, on the eastern flank of Meosin Mountain (Figure 16). Two sections measured in this area show that a phosphorite bed near the base of the Whistler member, 1.3 metres thick in the more northerly section (Figure 45) is not present in the section a kilometre to the south (Figure 46). Here several phosphate bearing beds are present but their phosphate content is lower.

Phosphorite in the more northerly of the two sections is composed of dispersed to semicompact brown to black, fine ovoid pellets and a few coarse pellets. The pellets, 0.05 to 0.5 millimetre in diameter, occur in a dominantly calcite matrix with a grain size of 0.1 to 0.3 millimetre. Minor quartz, clay and dolomite are also present in the matrix and fluorite is abundant locally. Approximately 10 to 15% of the pellets are nucleated or encased, with the cores generally composed of carbonate, or rarely quartz.

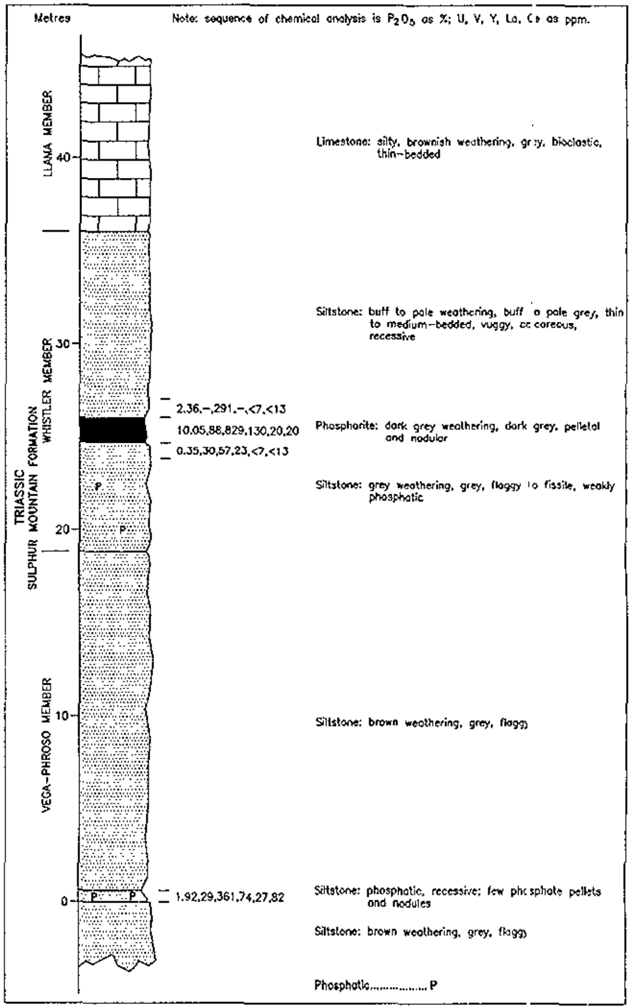


Figure 45. Section 87-6, Meosin Mountain north.

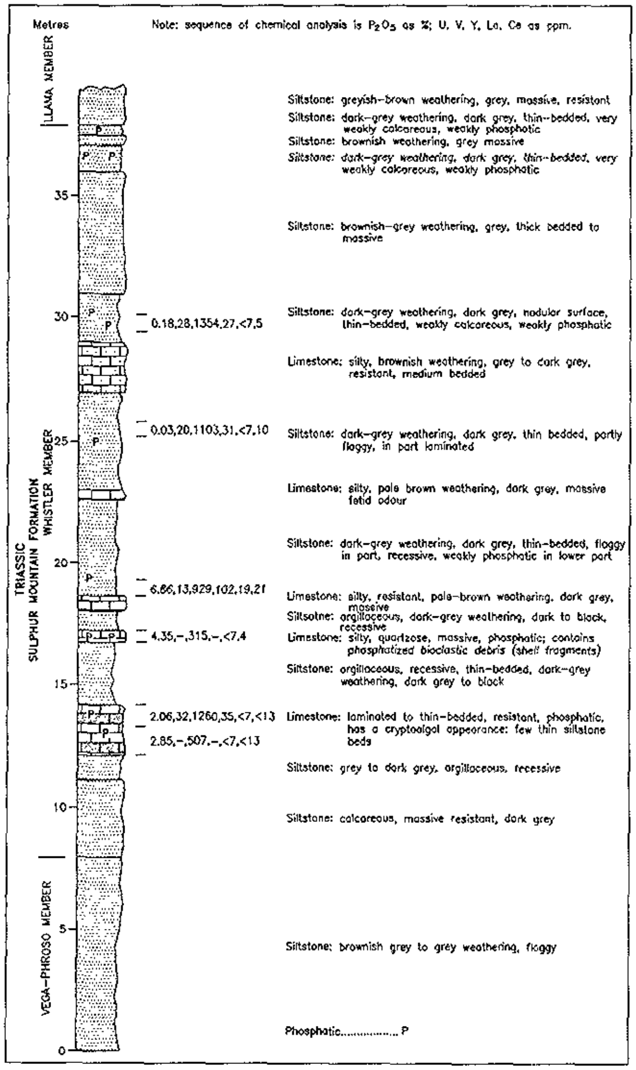


Figure 46. Section 87-7, Meosin Mountain south.

The coarse pellets are 1 to 2 millimetres in size and contain very fine grained quartz and some finer pelletal material. Some carbonate is also present.

In the southern section (Photo 27) dispersed pellets are present in a bioclastic limestone unit. The pellets are dark brown to black and structureless; a few have a quartz nucleus.

WAPITI LAKE (31) **NTS: 93I/7, 10**

MINFILE: 093I022

Lat: 54°30'00" Long: 120°40'00"

Claims in the Wapiti Lake area were staked by Esso Resources Canada Limited in 1979 and were the subject of an intensive exploration program, consisting of geological mapping, trenching and diamond drilling, completed in 1980 (Heffernan, 1980).

South of Wapiti Lake (Figure 16) the phosphate-bearing Triassic sequence has been folded into a series northwest-trending broad synclines and tight anticlines (Figure 47, Photo 28), modified by thrust faulting. The phosphorite bed lies at the base of the Whistler member of the Sulphur Mountain Formation. It varies in thickness from 0.8 to 3.2 metres with assays varying from 11.9 to 23.7% P_2O_5 and averages 19.7% over 1.0 metre (Heffernan, 1980; A. Legun, personal communication, 1987; this study). On the east limb of the Wapiti syncline the phosphorite outcrops on a dip slope, offering the potential for open-pit mining with a very low stripping ratio. The base of the phosphorite bed is marked by a thin phosphatic conglomerate that varies in thickness from 5 to 20 centimetres. In this area the phosphate has a high carbonate content as reflected by the CaO:P_2O_5 ratios. In places the MgO content and Corg contents are high (Appendices 12 and 13). The average content for lanthanum, cerium and ultrium are low compared to phosphate in the Fernie Formation.

Under the microscope the phosphorite is seen to be comprised of dispersed to compact pellets. The pellets are generally brown to dark brown with grain size ranging from

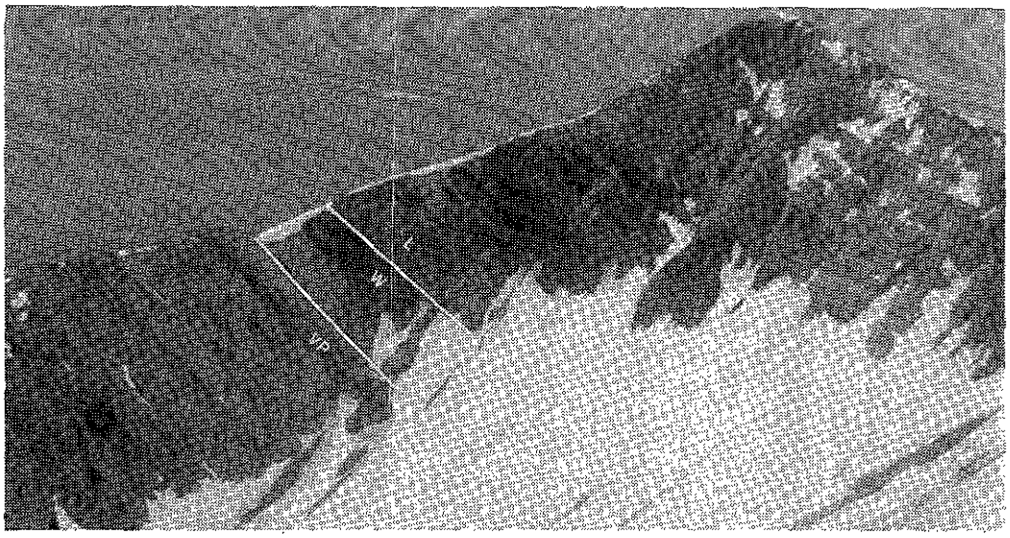


Photo 27. Stratigraphic section through Vega-Phroso (VP), Whistler (W) and Llama (L) members of the Sulphur Mountain formation south of Meosin Mountain.

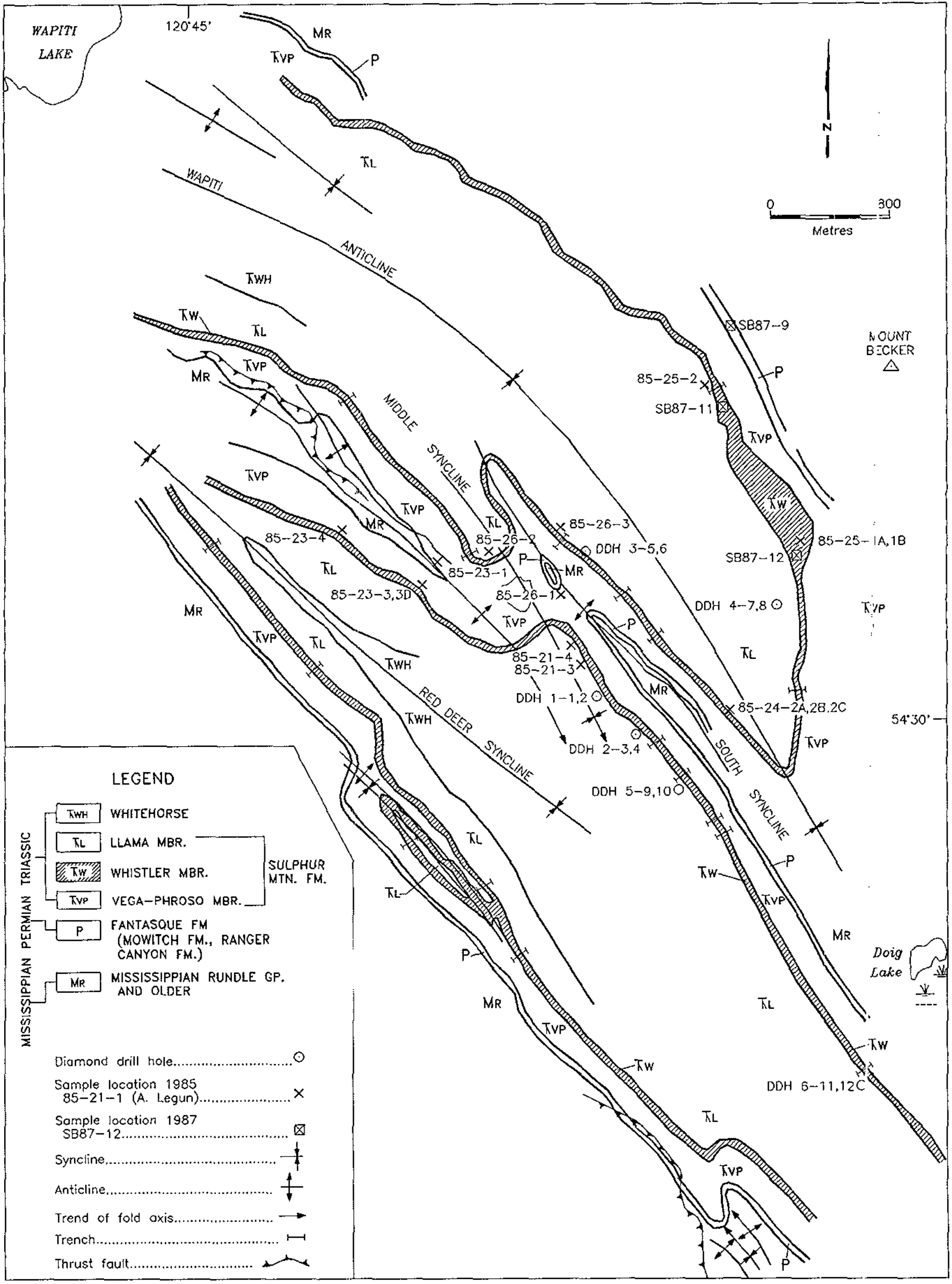


Figure 47. Geology of the Wapiti Lake area (modifed from Heffernan, 19080; Legun and Elkins, 1986).

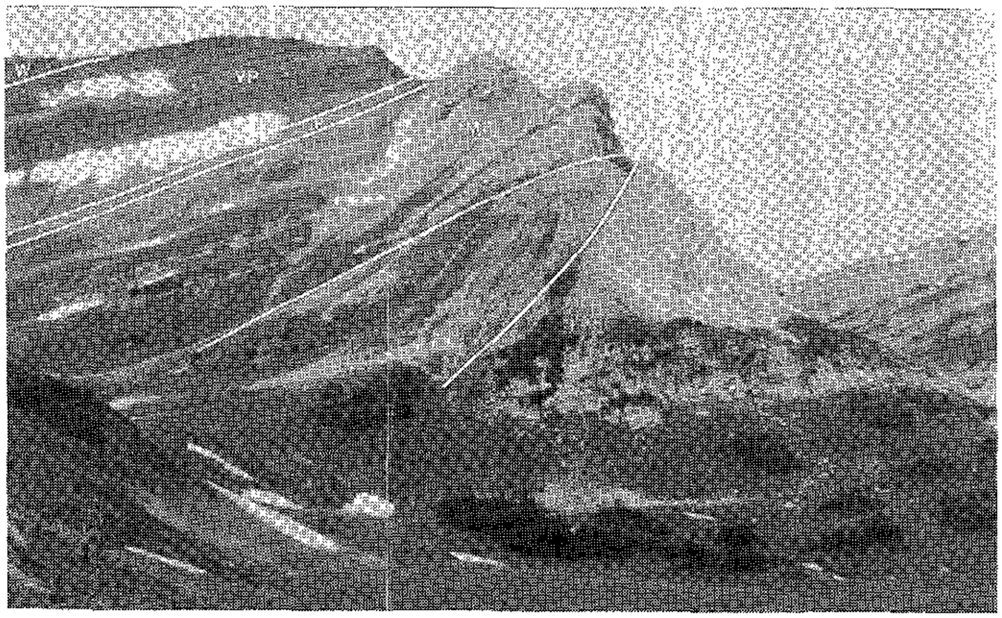


Photo 28. Folded Mississippian (MR), Permian (P) and Triassic Vega-Phroso (VP) and Whistler (W) member strata in the Wapiti Lake area.

0.05 to 0.30 millimetre, although larger nodules are occasionally present. The matrix is composed of variable amounts of quartz and calcite with minor dolomite and clay. It is generally finer grained than the pellets. Some 5 to 15% of the pellets are oolitic, some with alternating layers of carbonate and phosphate; 5 to 60% are either nucleated or encased (Photo 11). Many of the pellets have multiple nucleii; the nucleii may be either quartz or carbonate grains. Many of the pellets have an irregular carbonate core suggesting replacement of carbonate by phosphate. Fluorite is locally abundant in the matrix. Also present is the rare compound pellet. Some phosphate is also present as cement or as phosphatized bioclastic debris, generally Lingula shells.

In addition to the phosphorite bed at the base of the Whistler member, a sandstone bed containing abundant phosphate nodules occurs at the top of the Permian Mowitch Formation. This sandstone bed is 1 metre thick and contains 40 to 60% nodules by volume (Photo 29). A cream coloured chert bed 1 to 2 metres thick underlies the sandstone. A sample from the phosphate-bearing sandstone returned a grade of 15.94% P_2O_5.

MOUNT PALSSON (32) *NTS: 93P/4W*

MINFILE: 093P022
Lat: *55°05′55″* Long: *121°47′20″*

At Mount Palsson, immediately south of the Sukunka River (Figure 16) phosphorite is present in felsenmeer near the base of the Whistler member of the Sulphur Mountain Formation. The amount of material present suggests that the phosphorite occurs in a bed that is approximately 1 metre or less thick. Host lithologies are fine argillaceous and calcareous siltstones.

In thin section the phosphorite is seen to be comprised of semicompact to compact fluorapatite pellets with a few oolites. Pellets are brown to dark brown, generally ovoid, and 0.1 to 0.3 millimetre in diameter. The matrix which is composed of quartz with minor calcite, dolomite, feldspar and illite is finer grained than the pellets. Rare nodules and compound pellets are also present. Nodules contain both pellets and inclusions of quartz. Two samples from this lo-

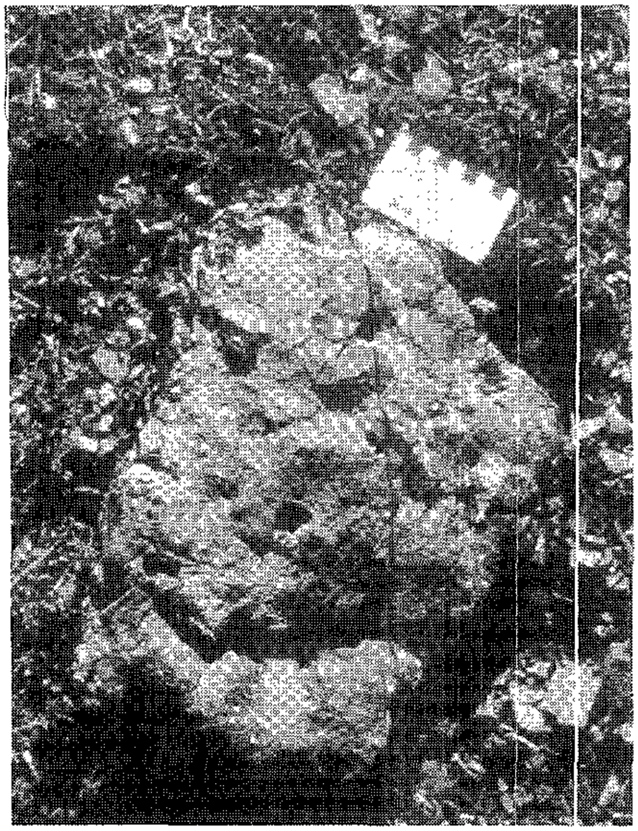


Photo 29. Phosphate nodules (blue) in a sandstone bed at top of the Permian Mowitch Formation, Wapiti Lake area.

cality averaged 26.4% P_2O_5, 566 ppm vanadium, 44 ppm lanthanum, 42 ppm cerium and 227 ppm yttrium.

BAKER CREEK (33) *NTS: 93O/1*

MINFILE: 093O038
Lat: 55°09′10″ Long: 122°06′45″

This poorly exposed occurrence is located north of the Sukunka River (Figure 17) 5 kilometres northwest of the headwaters of Baker Creek. Here a sandstone bed 1 metre thick contains 20 to 30% phosphate nodules. It overlies a chert bed near the top of the Permian Mowitch Formation. A sample from this locality contained 11.66% P_2O_5.

LEMORAY (34) *NTS: 93O/10*

MINFILE: 093O011
Lat: 55°31′20″ Long: 122°32′30″

A sequence of Triassic strata outcrop north of the Pine Pass Highway near Lemoray (Figure 17). These rocks are believed to belong to the Toad Formation and the Charlie Lake Formation. The sequence has been folded into a series of anticlines and synclines and is overlain by shales of the Jurassic Fernie Formation.

The Toad Formation consists of fine siltstone, weakly calcareous siltstone, silty limestone and minor sandstone. Phosphatic beds occur sporadically throughout the section and include a phosphorite bed 1 to 2 centimetres thick. The phosphorite is overlain by a thin crossbedded siltstone in which bedding is marked by black phosphatic laminae.

In thin section the phosphorite is seen to consist of ovoid pellets in a fine-grained dolomite, quartz and clay matrix (Photo 30). Some chert is also present. Pellets are subangular to rounded, dark brown to black and vary from 0.10 to 0.30 millimetre in diameter. Approximately 5% of the pellets are nucleated with either quartz or carbonate grains. Texturally the pellets vary from dispersed to compact.

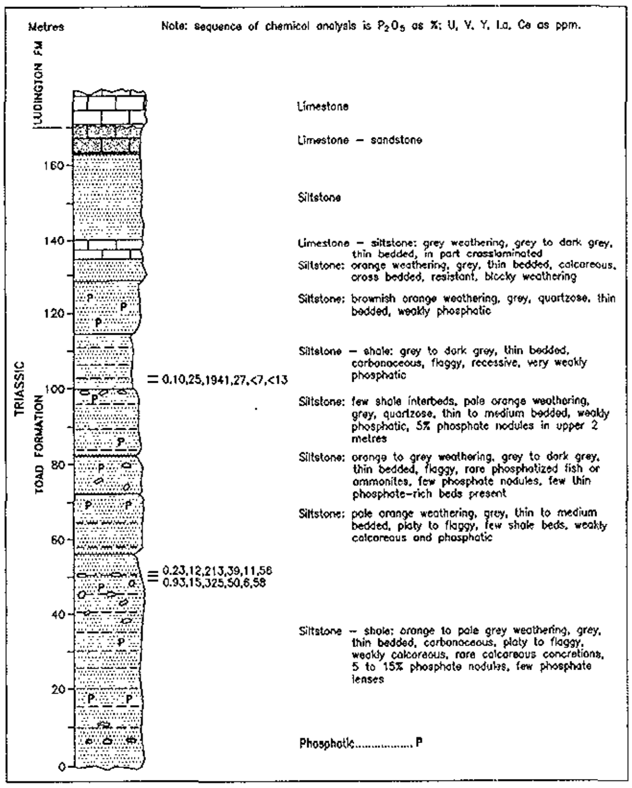


Figure 48. Section SB87-34, Mount Ludington.

MOUNT LUDINGTON (35) *NTS: 98B/6*

MINFILE: 094B029
Lat: 56°27′50″ Long: 123°14′30″

The presence of phosphate bearing strata in the Mount Ludington area south of the Graham River (Figure 18) was first reported by Gibson (1972) in a stratigraphic section measured at this locality. Phosphate occurs over a stratigraphic interval of 150 metres in the Middle Triassic Toad Formation (Figure 48) as nodules, phosphate-cemented siltstone, phosphate lenticles and phosphatic fossil debris including rare phosphatized fish skeletons. The host rocks are dark grey to black carbonaceous and calcareous siltstones and shales. There is a marked change to lighter coloured rocks at the top of the phosphate interval (Photo 31). The lower part of the phosphatic sequence is marked by the presence of large calcareous concretions.

Phosphate nodules are black, ovoid to spherical, sometimes irregular, 1 to 3 centimetres in diameter and comprise 5 to 20% of the rock by volume. They stand out in relief on weathered surfaces. Individual nodular units are generally 1 to 2 metres thick and rarely as much as 10 metres thick.

LAURIER PASS NORTH (36) *NTS: 94B/13*

MINFILE: 094B030
Lat: 56°50′55″ Long: 123°31′30″

Phosphate occurring in the Toad Formation was reported by Gibson (1972) from a section measured in the headwaters of Calnan Creek. To the south, toward Laurier Pass (Figure 18) phosphatic strata are exposed on both limbs of a broad open anticline over a stratigraphic interval of at least 100 metres (Figures 49 and 50).

As at Mount Ludington, phosphate is dominantly nodular, although phosphatic cement is also be present. Nodular beds are generally 1 to 3 metres thick. The nodules are black in colour, ovoid to spherical and occasionally irregular in shape and range in size from 1 to 3 centimetres across; they may contain multiple quartz nucleii, no internal structure or, rarely, an ammonite. They are interpreted to have formed diagenetically, probably below the sediment-water interface.

Host lithologies consist of shale, carbonaceous and weakly calcareous quartzose siltstones. Most of these rocks are weakly phosphatic. Calcareous concretions (Photo 32) occur in the lower part of the phosphatic sequence together with an abundance of phosphatic lenticles.

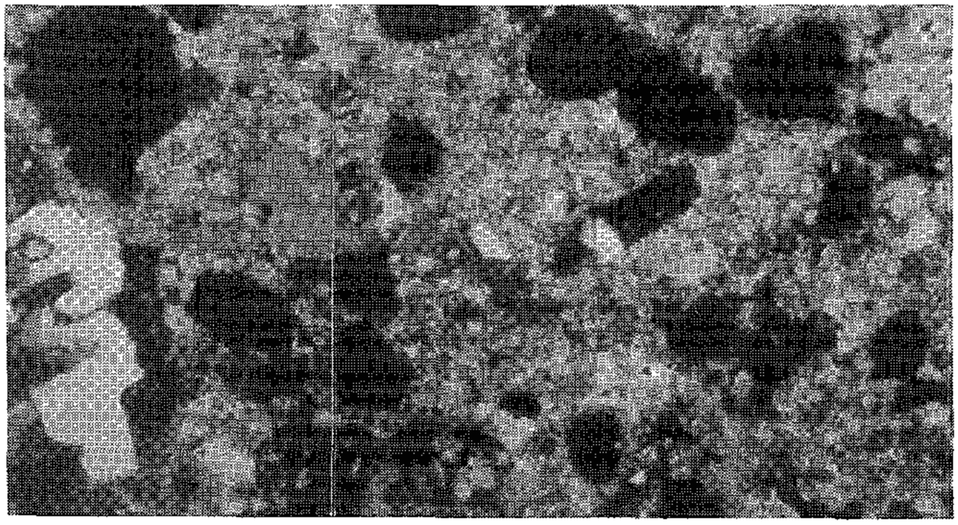


Photo 30. Photomicrograph (40x) of phosphatic limestone, Lemoray. Phosphate pellets (black) are dispersed in a carbonate-rich matrix. Some chert (lower left) and quartz are also present.

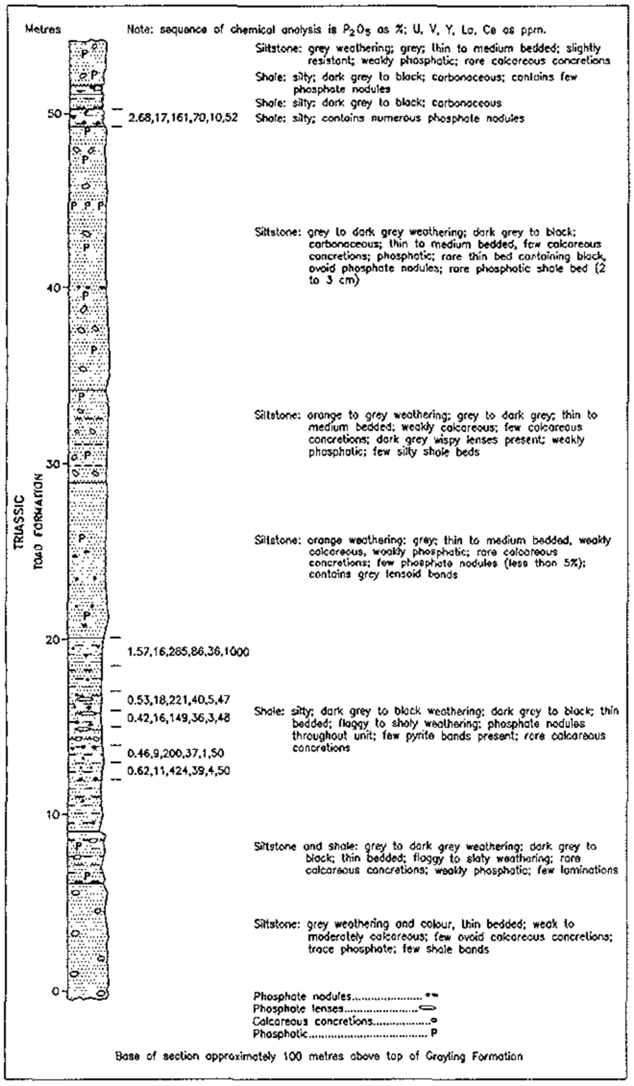


Figure 49. Section SB87-36, Laurier Pass north.

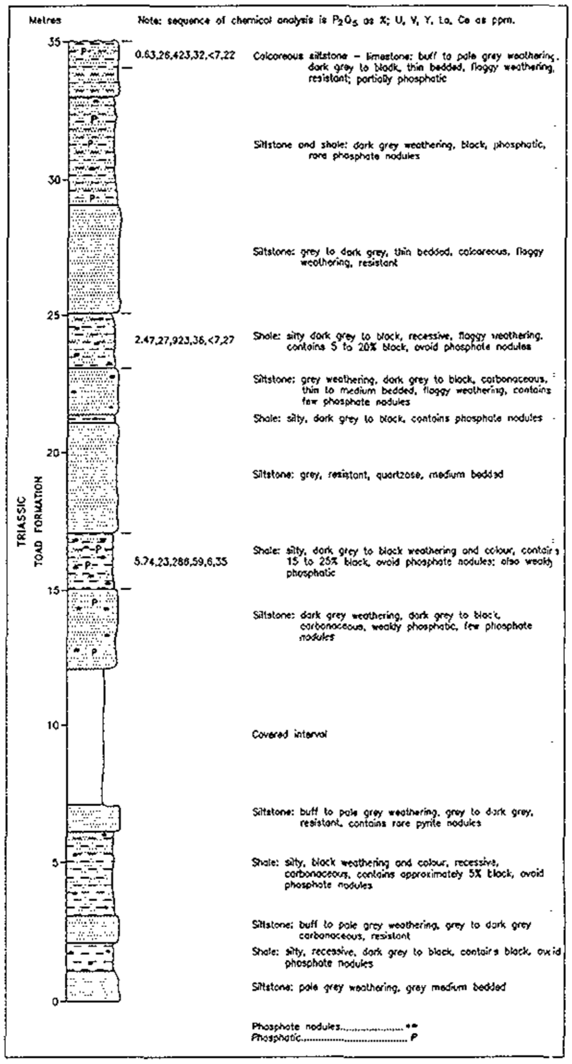


Figure 50. Section SB87-36(3), Laurier Pass north (measured on west limb of anticline approximately 60 metres upsection from Section SB87-36).

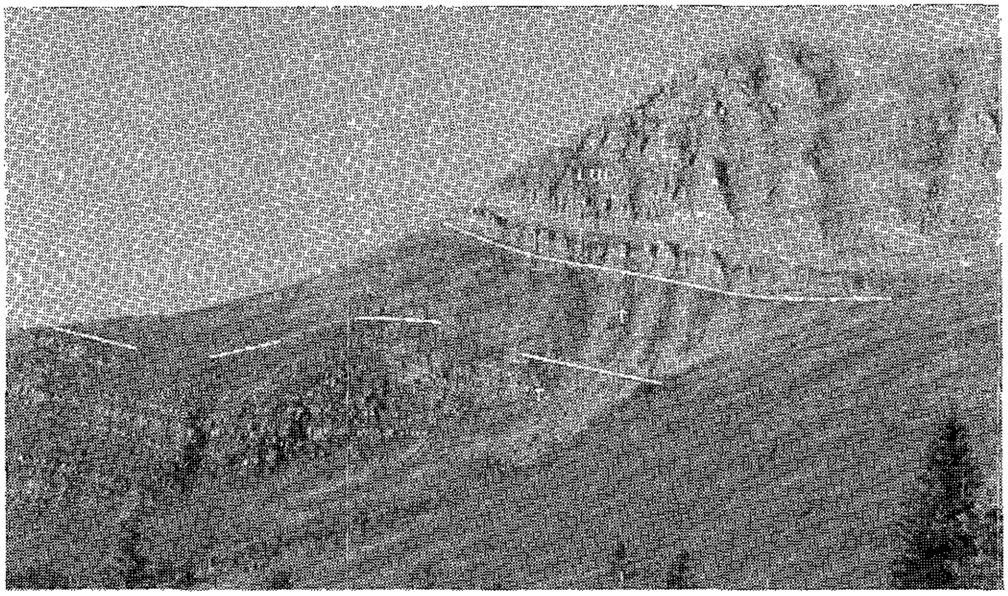


Photo 31. Section through the Toad Formation (T) and lower portion of the Ludington Formation (LUD). Hatched line marks the change from weakly carbonaceous - phosphat sediments to more calcareous - nonphosphatic sediments.

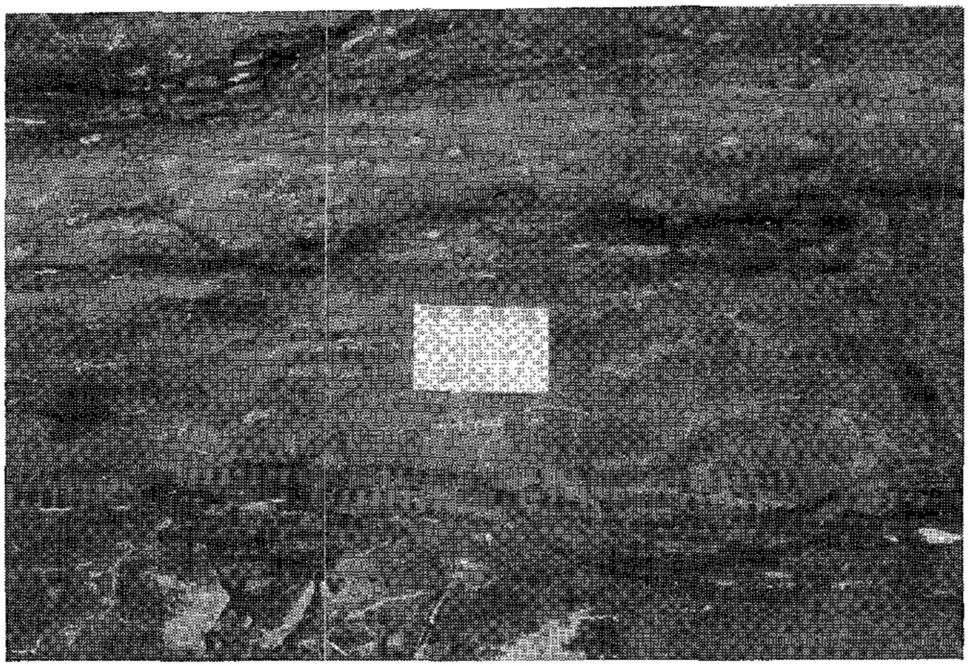


Photo 32. Phosphatic nodules and a solitary calcareous concretion in siltstone of the Toad Formation from a locality north of Laurier Pass.

RICHARDS CREEK (37) *NTS: 94G/12*

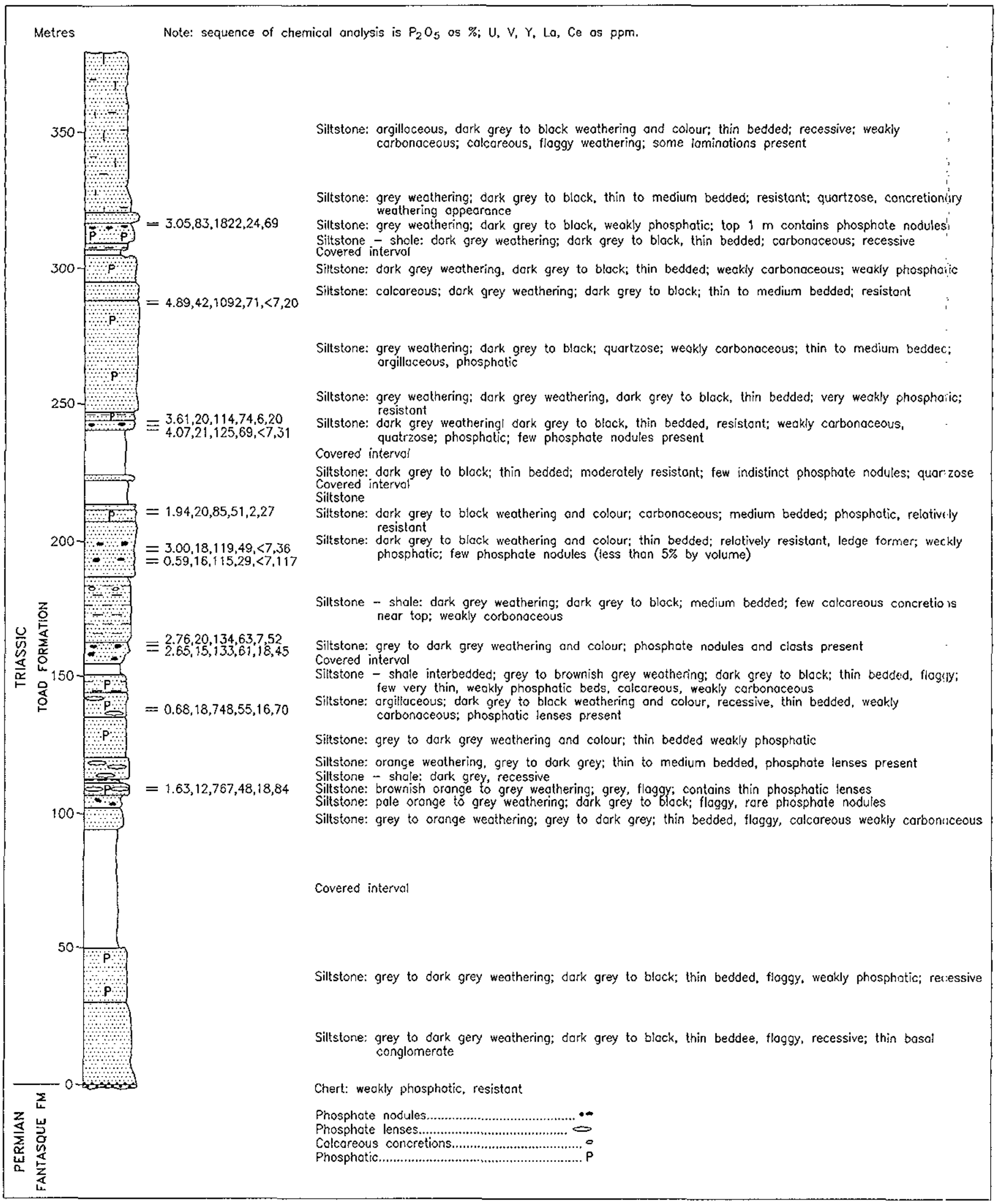
MINFILE: 094G022

Lat: 57°37′30″ Long: 123°40′00″

A thick phosphatic interval is exposed along a south-flowing tributary of Richards Creek west of Trutch on the Alaska Highway (Figure 18). Phosphate was first reported at this location by Pelletier (1964). A section from the top of the Permian Fantasque Formation to the Upper Triassic is exposed. Figure 51 is a section measured from the top of the Permian to the top of the phosphate-bearing interval.

Lithologies consist of very weakly phosphatic chert and siltstone of the Fantasque Formation. The contact with the overlying Toad Formation is unconformable, the Grayling Formation being absent at this location. Triassic strata consist of carbonaceous and calcareous siltstones and interbedded shales.

Phosphate-bearing rocks occur over a stratigraphic interval of 290 metres in the middle Toad Formation in strata of Anisian age. Phosphate nodules occur in several beds over an interval of 220 metres. Nodules are the dominant



Note: sequence of chemical analysis is P_2O_5 as %; U, V, Y, La, Ce as ppm.

Siltstone: argilloceous, dark grey to black weathering and colour; thin bedded; recessive; weakly carbonaceous; calcareous, flaggy weathering; some laminations present

Siltstone: grey weathering; dark grey to black, thin to medium bedded; resistant; quartzose, concretionary weathering appearance

Siltstone: grey weathering; dark grey to black, weakly phosphatic; top 1 m contains phosphate nodules

Siltstone – shale: dark grey weathering; dark grey to black, thin bedded; carbonaceous; recessive

Covered interval

Siltstone: dark grey weathering, dark grey to black; thin bedded; weakly carbonaceous; weakly phosphatic

Siltstone: calcareous; dark grey weathering; dark grey to black; thin to medium bedded; resistant

Siltstone: grey weathering; dark grey to black; quartzose; weakly carbonaceous; thin to medium beddec; argillaceous, phosphatic

Siltstone: grey weathering; dark grey weathering, dark grey to black, thin bedded; very weakly phosphatic; resistant

Siltstone: dark grey weatheringl dark grey to black, thin bedded, resistant; weakly carbonaceous, quatrzose; phosphatic; few phosphate nodules present

Covered interval

Siltstone: dark grey to black; thin bedded; moderately resistant; few indistinct phosphate nodules; quartzose

Covered interval

Siltstone

Siltstone: dark grey to black weathering and colour; carbonaceous; medium bedded; phosphatic, relatively resistant

Siltstone: dark grey to black weathering and colour; thin bedded; relatively resistant, ledge former; weakly phosphatic; few phosphate nodules (less than 5% by volume)

Siltstone – shale: dark grey weathering; dark grey to black; medium bedded; few calcareous concretions near top; weakly carbonaceous

Siltstone: grey to dark grey weathering and colour; phosphate nodules and clasts present

Covered interval

Siltstone – shale interbedded; grey to brownish grey weathering; dark grey to black; thin bedded, flaggy; few very thin, weakly phosphatic beds, calcareous, weakly carbonaceous

Siltstone: argillaceous; dark grey to black weathering and colour, recessive, thin bedded, weakly carbonaceous; phosphatic lenses present

Siltstone: grey to dark grey weathering and colour; thin bedded weakly phosphatic

Siltstone: orange weathering, grey to dark grey; thin to medium bedded, phosphate lenses present

Siltstone – shale: dark grey, recessive

Siltstone: brownish orange to grey weathering; grey, flaggy; contains thin phosphatic lenses

Siltstone: pale orange to grey weathering; dark grey to black; flaggy, rare phosphate nodules

Siltstone: grey to orange weathering; grey to dark grey; thin bedded, flaggy, calcareous weakly carbonaceous

Covered interval

Siltstone: grey to dark grey weathering; dark grey to black; thin bedded, flaggy, weakly phosphatic; recessive

Siltstone: grey to dark gery weathering; dark grey to black, thin beddee, flaggy, recessive; thin basal conglomerate

Chert: weakly phosphatic, resistant

Phosphate nodules.. ●●
Phosphate lenses.. ⬭
Calcareous concretions.................................... ○
Phosphatic.. P

Figure 51. Section SB87-37, Richards Creek.

form of phosphate comprising 5 to 40% of beds in which they occur. Nodules are typically black, ovoid to spherical and vary in diameter from 1 to 3 centimetres. Thin beds of pelletal phosphate are also present in the middle portion of the phosphatic sequence. Calcareous concretions similar to those at Mount Ludington and Laurier Pass North are present at approximately the same stratigraphic position.

TETSA RIVER - ALASKA HIGHWAY (38-40) *NTS: 94K/9*

MINFILE: 094K080, 081, 082, 083

Lat: 58°40'00" Long: 124°17'30" to 124°26'30"

Several phosphate occurrences are present in outcrops of Toad Formation in a folded sequence of Permian to Upper Triassic strata exposed along the Alaska Highway north of the Tetsa River (Figure 20).

Both pelletal and nodular phosphate occur in carbonaceous siltstone, shale and limestone of middle Triassic age. At the most easterly of these occurrences (Locality 38) a phosphorite bed 15 to 20 centimetres thick is present in a sequence of dark grey carbonaceous siltstone and limestone. This sequence is 3.3 metres thick and averages 4.30% P_2O_5. The phosphorite bed is pelletal with the pellets varying in size from 0.05 to 0.15 millimetre. The majority contain quartz nucleii or an occasional carbonate nucleus. The matrix consists of quartz with minor calcite and very minor feldspar. Also present are rare phosphatized shell fragments or nodules and some phosphate cement. There are a few nodules in the siltstone. Bedding at this locality is flat to very gently dipping to the west; beds vary in thickness from 50 to 100 centimetres.

Two kilometres to the west (Locality 39) another phosphorite bed, 15 centimetres thick, is exposed in a sequence of siltstone and dolomitic siltstone within the Toad Formation. It consists of 15 to 25% dispersed pellets in a matrix of quartz and minor carbonate. Pellets are subangular to rounded and 0.2 to 0.3 millimetre in diameter. The majority contain a quartz core or occasionally a carbonate core; a few have both quartz and carbonate nucleii. Some pellets have feathered contacts with internal carbonate grains suggesting that replacement of carbonate by phosphate has taken place. Within the phosphorite bed there is a layer 5 centimetres thick in which the volume of pellets increases to 50 or 60%.

Immediately to the west of this exposure, phosphate is present as disseminated pellets and nodules in outcrops of dark grey siltstone. Nodules and pellets are 0.5 to 1.0 centimetre in diameter and black in colour, in contrast to the dark grey colour of the siltstone. Some of the siltstone is very weakly phosphatic. Dessication cracks and ripple marks are seen at this locality but not elsewhere in the area. Deposition of the phosphate appears to have taken place in extremely shallow water during which there may have been short periods of subaerial exposure.

The most westerly of the phosphate occurrences outcrop at Kilometre 607.5 on the Alaska Highway (Locality 40). An interval of phosphatic siltstone and limestone 2.5 metres thick occurs in a sequence of dark grey to black argillaceous limestone and calcareous shale and averages 5.56% P_2O_5. Bedding strikes northwesterly with moderate dips to the southwest. A second bed, 70 centimetres thick, 55 metres higher in the section contains 10.12% P_2O_5.

Phosphate is present as disseminated pellets and a few black nodules. Pellets are 0.1 millimetre in diameter contrasting with a finer grained matrix. They may constitute as much as 40% of the rock but generally constitute less than 20% of the volume.

SUMMIT LAKE (41) *NTS: 94K/10*

MINFILE: 094K084

Lat: 58°40'00" Long: 124°36'00"

Shale and chert of the Permian Kindle Formation are exposed along the Alaska Highway approximately 2 kilometres east of Summit Lake (Figure 20). Within this sequence and overlying the chert is a 5-metre interval containing phosphatic laminations and lenses. The laminations are distinguished only by their black colour in contrast to the dark grey of the shale. Overlying the phosphatic sequence are brownish to brownish grey siltstones. A sample across 2.5 metres at this locality averaged 3.60% P_2O_5.

GREY PEAK (42) *NTS: 94F/14*

MINFILE: 094K019

Lat: 57°48'00" Long: 125°12'00"

Phosphate was first recognized in the Grey Peak area in the headwaters of the Kwadacha River (Figure 13) by Cecile and Norford (1979) while conducting stratigraphic studies of the Upper Cambrian - Lower Ordovician Kechika Formation. They observed that several thin phosphate horizons were present in the upper 100 metres of the formation. Phosphate also occurs at several horizons in the lower banded limestone unit; they describe these lower phosphate occurrences as "sea-floor pavements or lag deposits".

Thin phosphatic beds occur at five horizons in the upper 100 metres of the nodular limestone unit of the Kechika Formation. Phosphate is present as microcrystalline coatings, 1 to 10 millimetres thick, around limestone nodules, and as phosphatized fossil debris (trilobite) in beds 5 to 50 centimetres thick. Some pelletal and oolitic phosphate is also present. These phosphatic beds are easily recognized by their blue weathering surfaces and black colour contrasting with the pale grey of the host limestone (Photo 33). Also present, but not obvious, are thin phosphatic coatings, 1 millimetre or less thick, surrounding limestone nodules in beds 2 or more metres thick.

Cecile and Norford (1979) interpret the Kechika Formation in this area to represent an outer-shelf environment. Phosphate deposition was shallow enough that periodic turbulence caused some phoscrete beds to be broken up and redeposited, although the transport distance may have been very short.

CARBONATITES

Carbonatites and related alkaline intrusives are the second most important source of phosphate, accounting for ap-

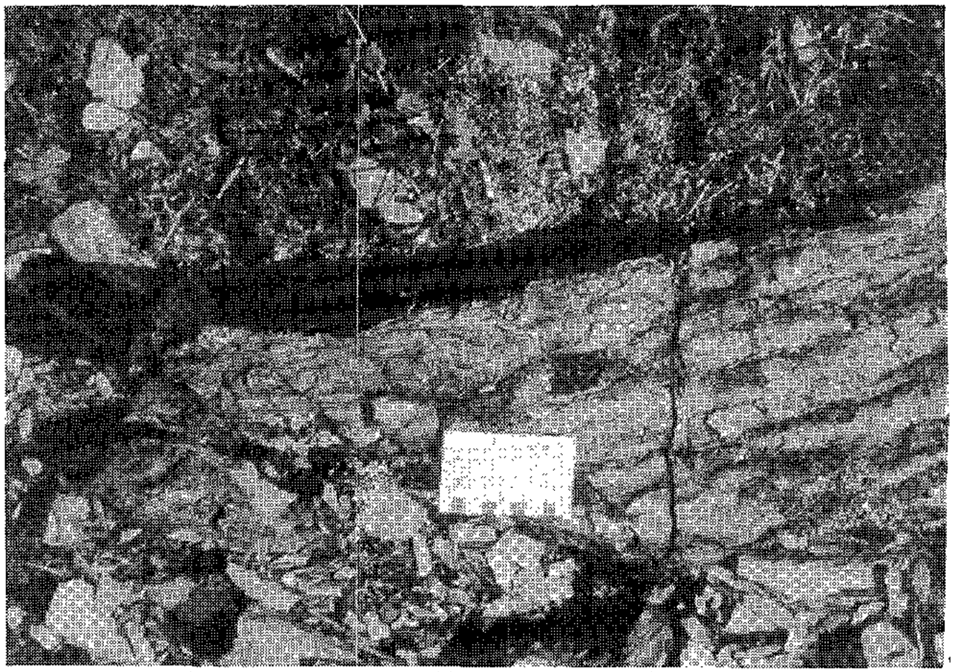


Photo 33. Microcrystalline coating of phosphate (blue) around nodular limestone of the Kechika Formation, Grey Peak area.

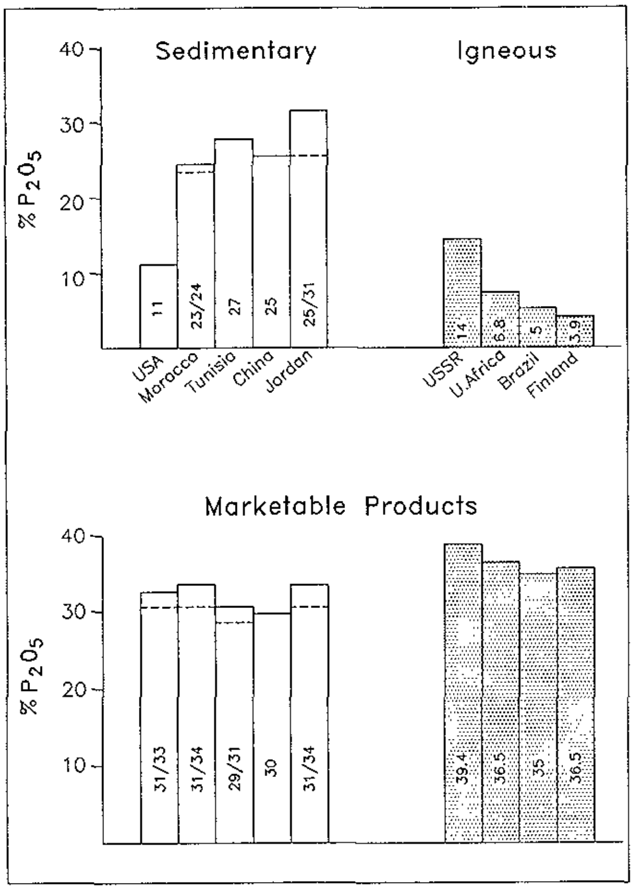


Figure 52. Comparative grades of sedimentary and igneous phosphate ores and marketable products (from Notholt and Highley, 1986).

proximately 20% of world reserves. Resources of igneous phosphate rock have been estimated at 9 billion tonnes averaging 4% P_2O_5 or more (Notholt and Highley, 1986). These deposits are expected to become more attractive as potential sources of phosphate, particularly in areas where sedimentary phosphate deposits are absent or of poor quality. Beneficiation technology is such that very low grade deposits can yield concentrates of very high grade. A comparison of marketable products from sedimentary and igneous phosphate deposits is shown in Figure 52.

Igneous phosphate deposits are generally associated with nepheline syenites stocks or carbonatite complexes; phosphate is normally present as apatite.

Production of phosphate from igneous rocks is limited to eight countries. Canada does not produce any igneous phosphate but does have substantial resources in Ontario; recent work indicates that significant resources of igneous phosphate may be present in British Columbia.

Emigh (1983) suggests that deposits containing 15% recoverable apatite (6% P_2O_5) may be of economic interest provided there are adequate reserves and that location and operating costs are favorable. Phosphate-bearing carbonatites have been recognized at several localities in British Columbia (Figure 53). At the present time none contain sufficient phosphate to be considered potentially economic based entirely on this single commodity. It is feasible, however, that phosphate could be produced as a byproduct in recovery of rare-earth elements.

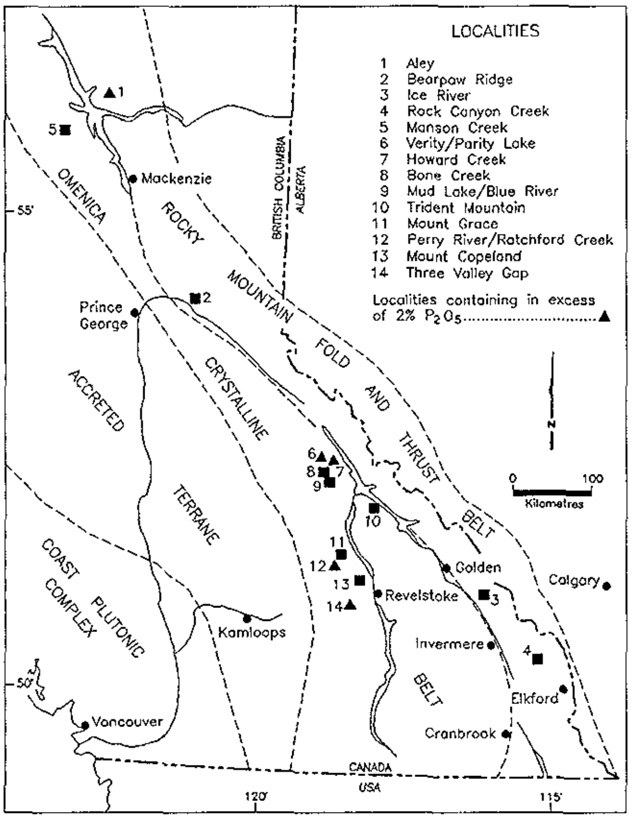


Figure 53. Map showing locations of phosphate-bearing carbonatites (modifed from Pell, 1987).

ALEY *NTS: 94B/5*

MINFILE: 094B027
Lat: 56°27′00″ Long: 123°44′50″

The Aley carbonatite complex (Figure 54) is described as an oval body, approximately 3 to 3.5 kilometres in diameter, consisting of a dolomite-calcite carbonatite core with an outer ring of metasomatically altered syenite (Mäder, 1987; Pell, 1987). Apatite is present as fine-grained crystals (Photo 34), averaging approximately 0.2 millimetre in length, and aggregates in both phases of the core but is more abundant in the calcite-carbonatite phase. K.R. Pride (oral communication, 1987) suggests that the average grade of the carbonatite is approximately 5% P_2O_5 representing approximately 10% apatite. Chemical analyses by the author and Pell (1987) indicate phosphate values of 1.44 to 6.07% P_2O_5.

VERITY *NTS:83D/6*

MINFILE: 083D005
Lat: 52°23′55″ Long: 119°09′25″

The Verity carbonatite is one of several carbonatites exposed east of the Yellowhead Highway in the Blue River area (Figure 55). Unlike the Aley complex the Verity carbonatite is a tabular body that has undergone intense structural deformation (J. Pell, oral communication, 1987). Descriptions of this locality is based on the work of Pell (1985, 1987) and Aaquist (1981) and on a brief examination by the author.

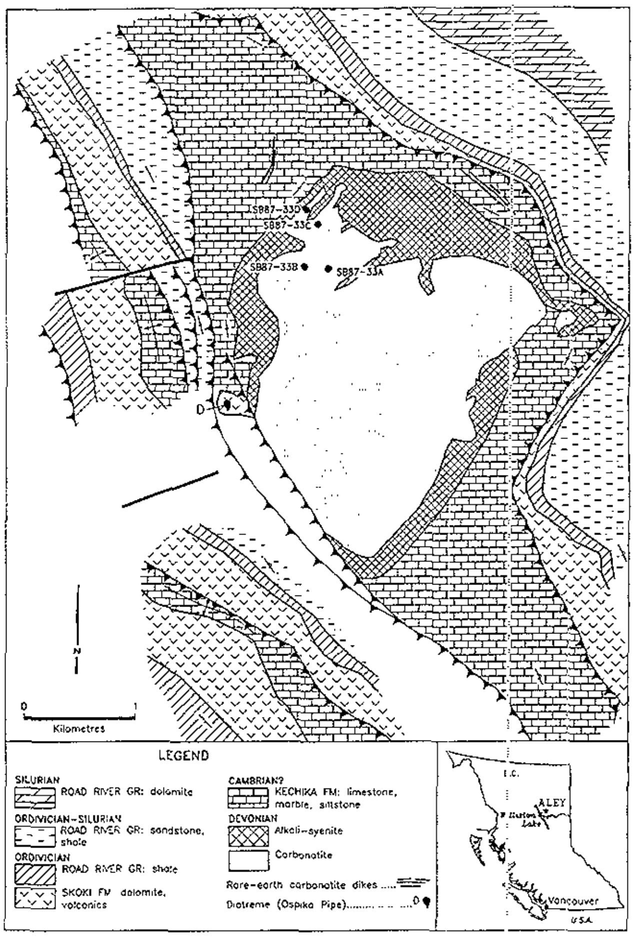


Figure 54. Geological map of the Aley carbonatite and sample locations (from Mäder, 1987).

Two types of carbonatite are present at the Verity locality: a white-weathering sovite containing predominantly calcite (60 to 85%), olivine (3 to 20%) and apatite (2 to 20%) and a buff-weathering dolomitic carbonatite (rauhaugite) containing amphibole (5 to 15%) and apatite (2 to 10%). The apatite occurs as subrounded grains 1 to 4 millimetres in diameter. Grades of 2 to 5% P_2O_5 have been recorded by Anschutz (Canada) Mining Limited (Aaquist, 1981). Sampling by the author and Pell (1987) obtained phosphate values ranging from 0.21 to 2.52% P_2O_5. Samples from the Paradise and Howard Creek carbonatites to the east contained 4.12 and 5.45% P_2O_5 respectively. The resource potential for the Verity carbonatite is only a few million tonnes.

REN (Ratchford Creek) *NTS: 82M/7*

MINFILE: 082M199
Lat: 51°21′30″ Long: 118°44′30″

The Ren carbonatite outcrops on the slopes south of Ratchford Creek in the core of the Mount Grace syncline

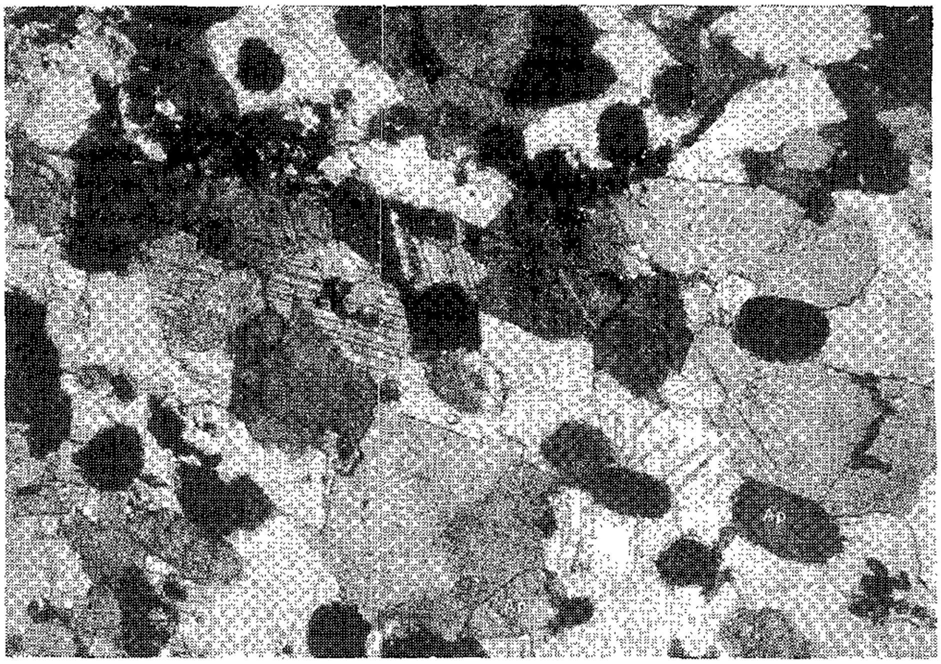


Photo 34. Photomicrograph under cross-nicols (40x) of subrounded apatite (Ap) crystals disseminated in a carbonate matrix, Aley carbonatite.

between the Seymour Arm of Shuswap Lake and the Columbia River. It is a concordant unit 3 kilometres long and 20 to 300 metres thick. The following description is summarized from Pilcher (1983), Pell (1987) and Höy (1987).

The Ren carbonatite is a massive to well-layered, orange- brown weathering body consisting of 60 to 80% calcite, 10 to 30% apatite and accessory biotite, amphibole, pyroxene and sphene. Minor amounts of pyrhotite, magnetite, pyrite, ilmenite, sphalerite, chalcopyrite, pyrochlore(?) and monazite(?) are also present. Mafic fenite occurs along the margin and within the carbonatite. It is enriched in light rare-earth elements and lanthanum. Grab samples collected by Höy (1987) across a 30-metre section of the carbonatite averaged 3.39% P_2O_5. The resource potential of this deposit is in the order of several million tonnes of very low grade material.

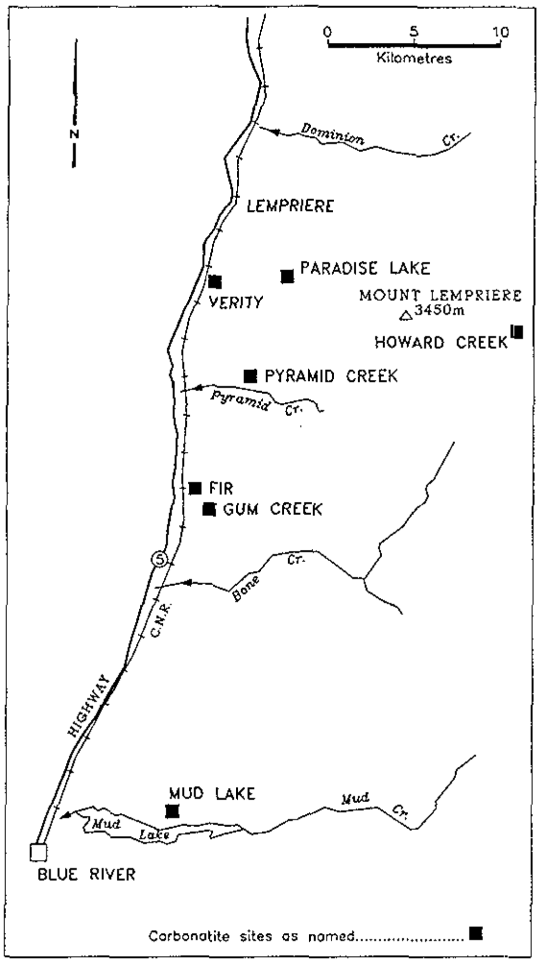


Figure 55. Blue River area. Map showing carbonatite and sample locations (from Pell, 1985).

THREE VALLEY GAP NTS: 82L/16

MINFILE: 082LNE44

Lat: 50°57′30″ Long: 118°29′00″

Discontinuous lenses of carbonatite, parallel to bedding in pelitic sedimentary rocks outcrop along the Victor Lake logging road which joins the Trans-Canada Highway from the south, approximately 3 kilometres east of Three Valley Gap (Pell, 1987). The carbonatites are composed of 45 to 50% calcite, 5 to 20% biotite, 5 to 15% apatite, up to 10% perthite, 5 to 30% hornblende and 1 to 10% augite. Traces of sphene are also present. Rare-earth element content are low. Three samples collected by Pell (1987) averaged 2.94% P_2O_5. The resource potential for phosphate at this location is very limited.

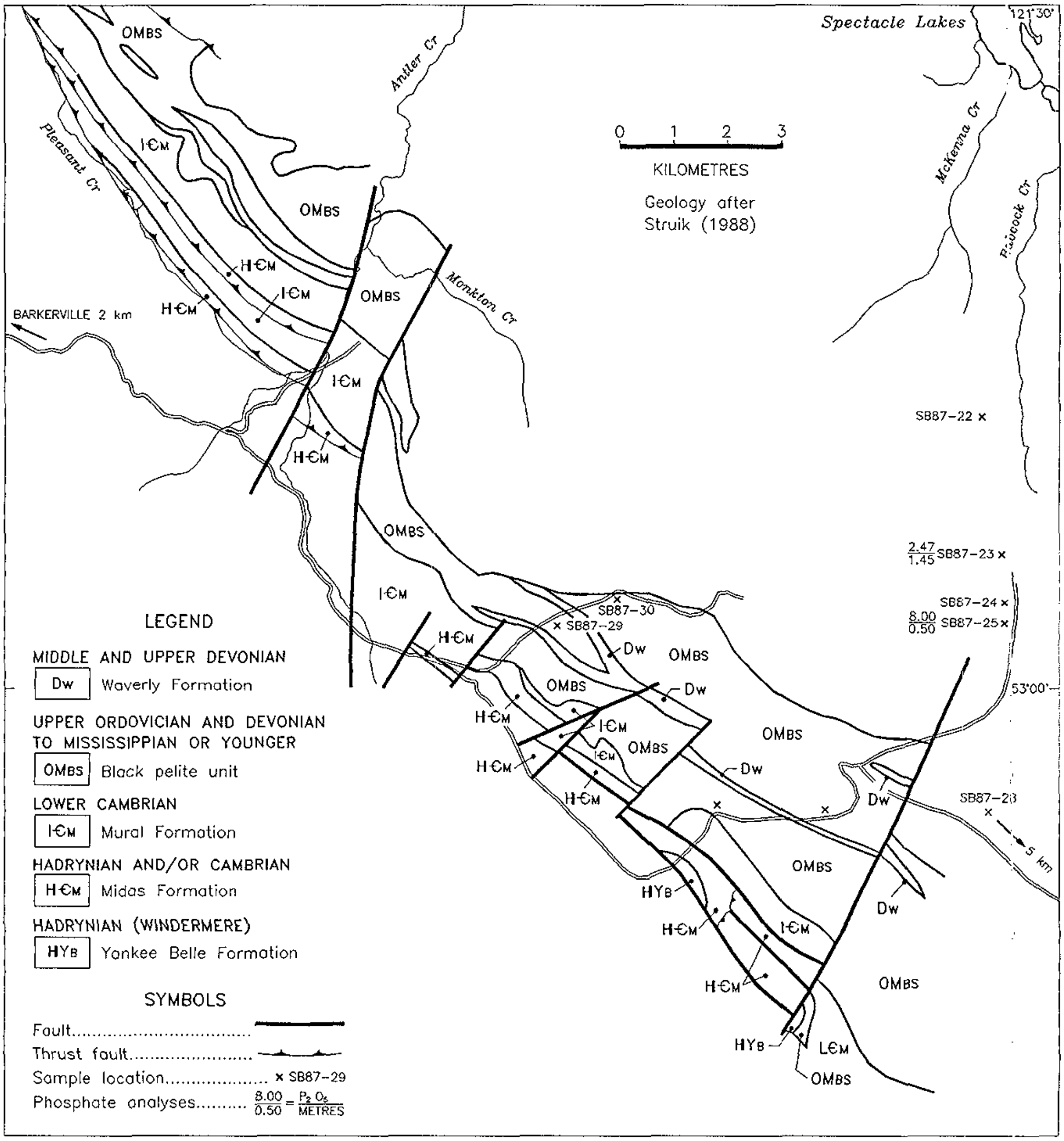


Figure 56. Geology and phosphate occurrences in the Cariboo Lake - Spectacle Lake area (9A/14 and 93H/3).

MISCELLANEOUS PHOSPHATE OCCURRENCES

Several other phosphate occurrences not covered earlier in this report, are present throughout British Columbia. While none of them show significant economic potential they illustrate a variety of forms in which phosphate may occur.

QUESNEL AREA

Campbell, *et al.* (1973) recognized the presence of phosphate in the Lower Cambrian Midas Formation while mapping in the McBride area. They reported that sandstones, containing up to 25% collophane grains, are present in the northern Caribou Mountains. These strata extend southward into the Wells - Barkerville area. Also in this area, marine sediments of the Black Stuart Group, interfingered with volcaniclastic rocks and pillow basalt of the Waverly Formation are locally phosphatic. This investigation concentrated on an area east of Wells and specifically in the Cunningham Creek area (Figure 56). Analytic results are presented in Appendices 17, 18 and 19.

The Black Stuart Group has been divided into three informal units (Struik, 1988). The lowermost unit consists of graptolitic shale and is overlain by a chert-carbonate unit. In the vicinity of Black Stuart Mountain this middle unit is 45 to 90 metres thick (Campbell *et al.*, 1973). The upper Black pelite unit is less than 500 metres thick and consists of siliceous shale, phyllite, greywacke and minor limestone and calcareous schists. Present within this unit are thin beds containing disseminated barite and phosphate. Sphalerite is also present locally but is not directly associated with phosphate. Grades of 3.55 to 8.00% P_2O_5 were obtained over thicknesses of 0.7 and 0.5 metre respectively at two separate localities.

The Black Stuart Group is interpreted to have been deposited on a gently undulating unconformable surface during the Orovician (Struik, 1988). Graptolitic shales were deposited in a quiet stagnant basin while the overlying chert-carbonate unit was deposited in shallower water. The upper Black pelite unit was deposited in a basin that was quiet and restricted with little clastic input.

GRANDUC TAILINGS

Grove (1986) reports that apatite up to 25% and averaging 10% occurs in calcsilicate rocks and limestones within the ore zone at the former producing Granduc mine. Analyses from some of these rocks returned values of 2.42% P_2O_5. Granduc tailings were sampled to determine if there had been any upgrading of the phosphate content during the concentration process. Results are uniformly low (0.22% P_2O_5) indicating that no upgrading has taken place and that the Granduc tailings have no potential for recovering phosphate.

IRON MASK BATHOLITH

Steeply dipping tabular magnetite-apatite lodes that vary in thickness from 1 centimetre to 3 metres and containing up to 3% P_2O_5 are reported in the Iron Mask Batholith (Young and Uglow, 1926). The maximum extent of these lodes is 200 metres (Cann and Godwin, 1983). Massive magnetite containing white or pale pink euhedral apatite crystals is present at the Magnet locality. Apatite and amphibole crystals frequently occur in layers adjacent to the walls of these lodes.

FRANCOIS LAKE ASPHALTUM *NTS: 93K/4*

MINFILE: 093K056
Lat: 54°04′55″ Long:125°45′00″

A small showing of botryoidal phosphate and asphaltum occurs 2 miles north of Francois Lake. An irregular vein 10 to 30 centimetres wide outcrops over a strike length of about 30 metres and cuts amygdaloidal and vesicular andesitic flows of Tertiary age. These flows overlie sandstone and shale. The phosphate minerals present have been identified as collinsite [$Ca_2(Mg,Fe)(PO_4)_2 2H_2O$] and quercyite ($3CaOP_2O_5CaOCO_2H_2OCaF2$) (Armstrong, 1949).

Phosphate occurs as nodules, 5 to 20 centimetres in diameter that consist of botryoidal masses of concentric layering of phosphate with an outer coating of black asphaltum. Most of the nodules enclose an angular fragment of andesite.

CHAPTER 7

BENEFICIATION AND PROCESSING OF PHOSPHATE ROCK

The purpose of beneficiation is to raise the P_2O_5 level to commercial standards (30 to 37% P_2O_5) and to reduce the proportion of carbonate, iron and alumina oxides, organic matter and such trace elements known to be poisons as cadmium, nickel and selenium. Canadian fertilizer plants are designed for feedstock containing 31.1 to 33.0% P_2O_5. Most phosphate rock requires some beneficiation prior to shipment to processing plants. Typical specifications for phosphate content and major impurities are summarized in Table 12. Only under humid and acidic soil conditions phosphate rock may be finely round and applied directly as fertilizer.

The first stage in the production of phosphate fertilizer is the conversion of phosphate rock to phosphoric acid. This is generally done by either a "dry" or "wet" process. These processes are outlined in Figure 57. Most commercial fertilizer plants use the wet acidulation method in the initial stage of fertilizer production. In the wet process phosphate rock is most commonly treated with sulphuric acid to produce phosphoric acid, and gypsum as a waste product. High calcium and magnesium carbonate contents in the phosphate rock are undesirable in the processing of phosphate rock as are high iron and aluminum contents. High carbonate content increases the consumption of sulphuric acid. Calcination is required if the organic content is too high as organic matter causes foaming during acidulation. It may also be required to remove excess carbonate.

While the phosphate specifications are designed primarily for Florida phosphate (Kouloheris, 1977), they also

TABLE 12
PHOSPHATE SPECIFICATIONS REQUIRED BY FERTILIZER PLANTS (from Kouloheris, 1977)

P_2O_5 content: 27 to 42%.

CaO/P_2O_5 ratio : 1.32 to 1.60.

$Al_2O_3 + Fe_2O_3 + MgO/P_2O_5$ .1 (optimum value).

MgO tolerance is approximatly 1.0%; less than 0.8% is necessary for the manufacture of triple super phosphate.

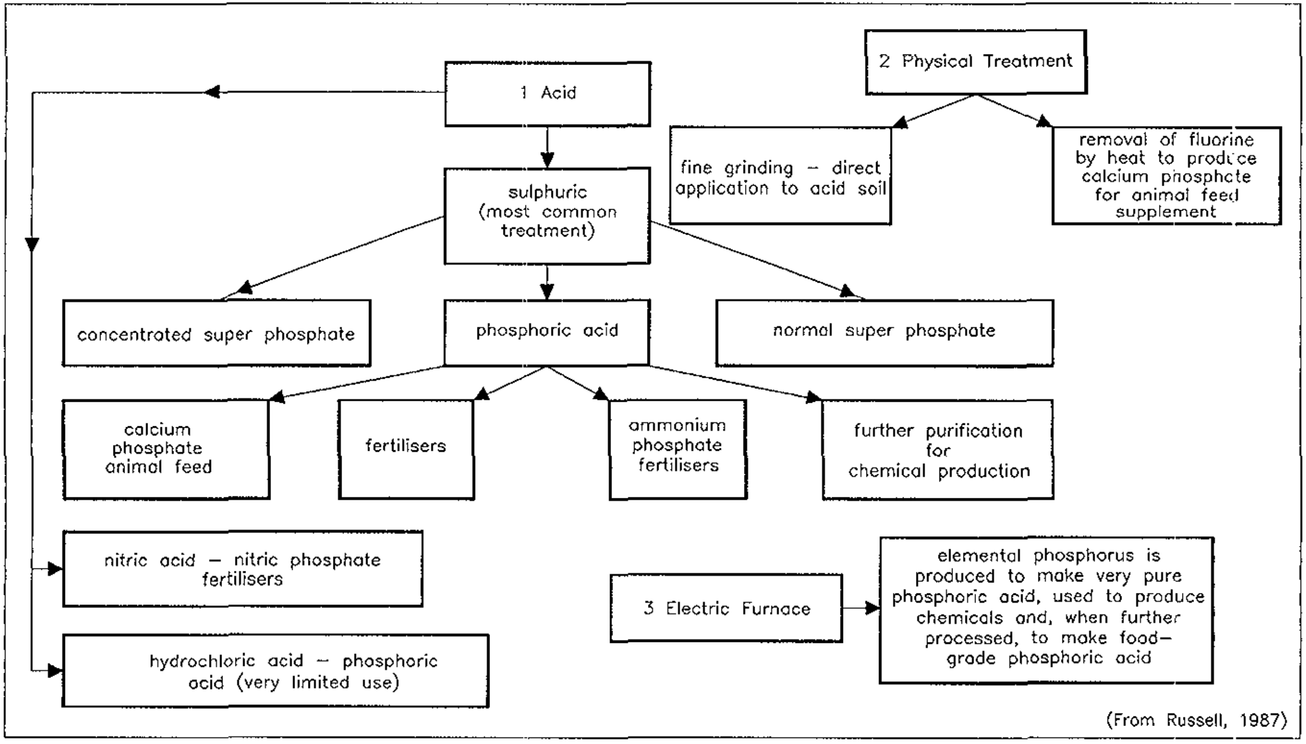
BPL/MgO ratio : 170 or higher.

$BPL/Al_2O_3 + Fe_2O_3$ ratio : > 20.

BPL/CaO ratio > 1.5.

Iron and aluminum as per cent Fe_2O_3 and Al_2O_3 should be less than 5%.

BPL = Bone phosphate of lime (2.1852 x per cent P_2O_5).



(From Russell, 1987)

Figure 57. The different methods of treating phosphate rock.

apply to other deposits (Table 12).

Rock with a high magnesia and alumina content produces acid of high surface tension and viscosity. Iron and alumina are believed to influence the development of gypsum which in turn affects the recovery of P_2O_5. Slimes, primarily colloidal clay material, tend to adhere to phosphate grains and also to float with the concentrate during the flotation process; clay coatings on phosphate particles impede the attack of sulphuric acid. Desliming is therefore used to remove clay from the phosphate rock.

In general, if the CaO/P_2O_5 ratio exceeds 1.6/1 sulphuric acid consumption by the calcite is too high for an economically viable process. The effects of the various impurities are summarized in Table 13.

All phosphorite deposits in British Columbia will require beneficiation prior to their use in fertilizer plants. The amount of beneficiation required is dependent upon the amount of gangue present; the higher the phosphate content the easier it should be to effect phosphate liberation. Factors affecting the processing, especially the grinding and flotation of phosphate rock include phosphate dispersion, grain

TABLE 13
EFFECTS OF IMPURITIES IN THE MANUFACTURE OF FILTER-GRADE WET-PROCESS PHOSPHORIC ACID

IMPURITY	PRACTICAL LEVELS FOUND IN FEEDSTOCK	DESIRABLE PROPERTIES	UNDESIRABLE PROPERTIES	AMOUNT OF IMPURITY PASSING INTO ACID
Aluminum	0.2-3% Al_2O_3	Reduces corrosion by fluoride ion	Forms complex phosphates which impair filtration, increase acid viscocity and precipitate.	70-90%
Iron	0.1-2% Fe_2O_3	May be recoverable as iron oxide	Forms complex phosphates. Strong influence on acid viscosity; forms sludge.	60-90%
Magnesium	0.2-0.6% MgO	May have nutrient value	Forms complex phosphates and fluosilicates; impedes filtration; affects downstream product quality.	
Fluorine	2-4%	Can be reacted and recovered as by-product	Liberated partly as HF; part held by filter; part may contribute to sludge formation. More fluorine generated during concentration. If H_2SiF_6 formed by reaction with SiO_2 may modify crystal formation.	25-75%
Silica	1-10% SiO_2	To convert HF to less aggressive fluosilicic acid (H_2SiF_6)	In high proportions causes erosion problems	5-40%
Strontium and lanthanides	0-3.0 SrO (for example)		Inhibits recrystallion of hemihydrate gypsum. Insoluble compounds formed in 40 wt-% P_2O_5 acid.	n.a.
Chlorine	0-0.05%		Above 0.03% can give severe corrosion with wrong materials.	100%
Carbonate	0.7-8.0%		Increases sulphuric acid consumption	n.a.
Organics	0.1-1.5% C		Stabilize foams during acidulation. Impair filtration by "blinding" cloth. Discolour product acid.	15-70%
Cadmium	0.8-255 ppm		Significant proportion passes through into acid and downstream products. Toxic metal.	70%
Uranium	35-400 ppm U_3O_8		Is recoverable and may be sold as by-product	75-80%

Source: Phosphorus & Potassium No. 146 (From Russell, 1987).

size of gangue minerals, pellet size, relative hardness of the minerals present, proportion of gangue material present in the pellets, strength of intergranular bonding agents and the nature of gangue replacement of phosphate (Mabie and Hess, 1964).

In their petrographic study of the Phosphoria Formation Mabie and Hess attempted to relate petrography and mineralogy to the metallurgical characteristics of the phosphate rock. They suggested that petrographic characteristics can be used to predict the behavior of phosphate rock in roasting, grinding, sizing, desliming and flotation processes.

Phosphate rock with a high carbonate or organic content may require roasting or calcining at temperatures varying from 500 to 900°C. Differences in size between gangue and phosphate pellets will affect the grinding of phosphate rock. In most British Columbia deposits the phosphate pellets are coarser than the gangue minerals. Coarse grinding will tend to concentrate the phosphate particles in the coarser fractions. In arenaceous ore the phosphate will tend to be concentrated in the finer fractions because the softer phosphate will be more easily broken up than the harder quartz. Mabie and Hess suggest that the effectiveness of concentration in the coarser fraction is dependent upon the tendency of the gangue to break down into fines and be freed from the fluorapatite. Clay and sericite can easily be separated by mechanical agitation whereas liberation from quartzose material is more difficult.

Pellet dispersion affects both the grade of the phosphate rock and the ease with which phosphate can be liberated from the gangue. In a study of flotation of phosphorite from a deposit in Idaho, pellet size and initial phosphate content were the principle factors controlling concentrate grade and recovery (Town, 1967). Liberation of dispersed pellets requires more grinding and therefore increases the proportion of phosphate recovered in finer fractions.

The amount of liberation of phosphate particles from the gangue will effect the flotation process. Excessive grinding increases the production of slimes. In deposits with well-compacted pellets, grinding to sizes coarser than the pellet size may be suitable for effective flotation but nucleated or encased pellets require grinding fine enough to liberate these very fine particles.

Mabie and Hess point out that replacement of pellets by gangue (clay, sericite, and carbonate) gives rise to textures that may affect the efficient flotation of the phosphate rock. Replacement usually follows pellet boundaries and internal structures that are lines of weakness along which the material will break upon grinding. As a result, the fluorapatite pellets will break down to particles that are coated with gangue and therefore will behave as gangue during flotation.

BENEFICIATION OF BRITISH COLUMBIA PHOSPHORITE ROCK

Although the criteria developed by Mabie and Hess (1964) relate to the Phosphoria Formation they may also be applied to British Columbia phosphate deposits, especially those in the Fernie Formation and Whistler member of the Sulphur Mountain Formation. Textural and mineralogical summaries for phosphate deposits in British Columbia are presented in Tables 14, 15, 16 and 17.

Phosphorite deposits in the Whistler member of the Sulphur Mountain Formation tend to be moderately to poorly sorted and contain numerous nucleated or encased pellets whereas phosphorite in the Fernie Formation tends to be well sorted with only a few encased or nucleated pellets. Both exhibit pellet sizes generally larger than the matrix. Whistler member phosphorites will probably require a finer grind to liberate the nucleii present in the pellets. There is no extensive replacement of pellets in either of these phosphorites. Oolites present in the Whistler member may pose grinding problems as they contain alternate carbonate and phosphate layers. Pellets will break along the oolite layers and carbonate may be floated away along with the enclosed phosphate if the grind is not fine enough.

Calcination will be required where the carbonate content is high. The Whistler member is invariably calcareous, especially in the Wapiti Lake area where CaO/P_2O_5 ratio exceeds 2/1 in the majority of samples. Calcination followed by slaking will probably be required to remove the carbonate. Locally, where dolomite is present some selective leaching may be required. The carbonate content of Fernie phosphorite is zoned (*see* Chapter 3); calcining will be necessary in high-carbonate areas. It is also anticipated that desliming will be required to remove excess clay material from Fernie phosphate.

In 1974 Energy, Mines and Resources Canada carried out a beneficiation test on a sample of Fernie phosphate from the Lodgepole Creek area south of Fernie. The sample was from a surface trench and averaged 10 to 11 % P_2O_5. It also contained approximately 20 % calcite with minor amounts of quartz, feldspar and traces of mica and mafic minerals (Hartman and Wyman, 1974). The results indicated recovery of 31.5 % with a maximum grade of 28.5 % P_2O_5 by attrition methods and recovery of 49 % with a maximum grade of 28.5 % P_2O_5 by hot conditioning and flotation with soda ash and oleic acid.

Hartman and Wyman also report: "The highest grade product was achieved using a chemical treatment: attrition and ultrasonics. This grade occurred in the 65 and 100-mesh (0.25 to 0.15 millimetre) fractions. Flotation results using hot conditioning with soda ash and oleic acid show the importance of screening and grinding to free and clean surfaces. Results are even better when ultrasonics are included. The approach to beneficiation using hot conditioning, although a costly step, appears promising. The results suggest that concentration by attrition and/or other mechanical means followed by heavy liquid separation should be considered". This investigation was not carried through to completion because of the low grade of the sample.

To the author's knowledge, Cominco Ltd. is the only company that has completed beneficiation tests on phosphate rock from southeastern British Columbia. Cominco has tested samples from the Lizard, Crow and Mount Lyne deposits. This work, now more than ten years old, was not totally satisfactory as the basal phosphate of the Fernie Formation has a strong hydrophyllic character and cannot be

TABLE 14
TEXTURAL AND COMPOSITIONAL FEATURES OF ISHBEL GROUP PHOSPHATES

Sample Number (mm)	Pellet/Nodule Size	Nature of Phosphate	Phosphate Dispersion	Gangue Size (mm)	Gangue	Phosphate Replacement	Organic Content	Iron Content	Carbonate Content	Composition	Grade (%P_2O_5)
SBB86-8J	2-5	Mainly nodules with some intra clasts; nodules contain quartz nucleii	Dispersed	0.05	Mainly quartz with some cherty sponge spicules		Slightly carbonaceous or bituminous	-	-	Phosphatic, quartzose siltstone	14.63
SBB86-57	0.1-0.5	Ovoid pellets with 5% nucleated and 5% encased; rare oolite;rare radial structure	Semi-compact to dispersed	0.1	Mainly fine grained calcite with minor clay	Minor carbonate	Slightly carbonaceous or bituminous	-	Calcareous	Quartzitic phosphorite	14.71
SBB86-58	0.3-0.5	Ovoid pellets with 5% nucleated rare oolite, intraclasts or nodules	Semi-compact to dispersed	0.1	Fine-grained quartz		Slightly carbonaceous or bituminous	-		Quartzitic phosphorite	24.59
SBB86-71	0.5 to 0.75	Nodular with few ovoid pellets and phosphatized bioclastic material	Dispersed	0.1	Mainly quartz	-	Slightly carbonaceous or bituminous	-	-	Phosphatic quartzose siltstone	14.41
SBB86-79(1)	0.1	Ovoid pellets with less than 1% containing nucleii; phosphate cement	Dispersed	0.1	Mainly clay with some quartz and very minor dolomite	-	Slightly carbonaceous or bituminous	-	-	Quartzitic phosphorite	24.59
SBB86-80	0.05-0.2	Ovoid pellets with 75% nucleated less than 5% oolites; few radial structures	Semi-compact	0.05-0.2	Mainly calcite with very minor quartz	Minor replacment by carbonate	Slightly carbonaceous or bituminous	Calcareous	Phosphatic limestone	5.93	

TABLE 15
TEXTURAL AND COMPOSITIONAL FEATURES OF THE WHISTLER MEMBER PHOSPHATES

Sample Number	Pellet Size (mm)	Nature of Phosphate	Phosphate Dispersion	Gangue Size (mm)	Gangue	Phosphate Replacement	Organic Content	Iron Content	Carbonate Content	Composition	Grade (% P_2O_5)
SB87-6	0.05-1.00	Ovoid pellets with 10-15% nucleated or encased;rare nodule	Semi-compact to dispersed	0.10-0.30	Dominantly calcite with minor quartz, quart, clay and dolomite	Minor carbonate and very minor clay	Highly carbonaceous or bituminous	–	Calcareous	Phosphorite	23.64
SB87-11	0.05-0.25	Ovoid pellets with 25% nucleated; 5-10% are oolitic	Dispersed to semi-compact	0.05-0.10	Quartz with lesser calcite;minor dolomite, feldspar and clay		Moderately carbonaceous or bituminous	–	Calcareous	Phosphorite	26.39
SB87-12	0.10-0.25	Ovoid pellets with 30-40% nucleated or encased;10-15% are oolitic;some nodules and clasts and phosphatized bioclastic debris	Semi-compact	0.05-0.10	Calcite with lesser quartz and trace dolomite	Minor to moderate carbonate and and lesser clay	Moderately carbonaceous or bituminous	–	Calcareous	Phosphorite	28.3
SB87-15	0.10-0.30	Ovoid pellets with 10-15% nucleated;rare nodules	Compact to semi-compact	0.05-0.10	Quartz with calcite, minor dolomite and trace clay and feldspar		Slightly carbonaceous or bituminous	–	Weakly calcareous	Phosphorite	28.02
85-23/3B	0.10-0.30	Ovoid pellets with 25 30% nucleated; 5-10% oolites;phosphate cement	Compact	0.05-0.10	Quartz and calcite and very minor clay		Slightly carbonaceous or bituminous	–	Calcareous	Argillaceous to quartzitic phosphorite	20.3

TABLE 15 CONTINUED

Sample Number	Pellet Size (mm)	Nature of Phosphate	Phosphate Dispersion	Gangue Size (mm)	Gangue	Phosphate Replacement	Organic Content	Iron Content	Carbonate Content	Classification	Grade (% P_2O_5)
97	0.10–0.20	Ovoid and oolitic pellets with 50 60% nucleated some phosphatized bioclastic debris	Dispersed	0.10–0.20	Mainly calcite with quartz and minor clay	Very minor carbonate and lesser clay	Slightly carbonaceious or bituminous		Calcareous	Phosphorite	20
90 1/4	0.20–0.30	Ovoid pellets with 30 40% nucleated or encased;rare nodules;some phosphatized bioclastic debris	Compact	0.10–0.20	Mainly calcite with lesser quartz and minor clay		Slightly carbonaceous or bituminous		Calcareous	Phosphorite	20.29
85 23/3A	0.10–0.30	Ovoid pellets with 60% nucleated;few oolites; rare compound pellets	Dispersed	0.05; some 0.10	Mainly calcite with lesser quartz and minor clay and feldspar	Very minor carbonate	Slightly carbonaceous or bituminous		Calcareous	Argillaceous to quartzitic phosphorite	20.3

TABLE 16
TEXTURAL AND COMPOSITIONAL FEATURES OF THE FERNIE PHOSPHATE

Sample Number	Pellet Size (mm)	Nature of Phosphate	Phosphate Dispersion	Gangue Size	Gangue	Phosphate Replacement	Organic Content	Iron Content	Carbonate	Composition	Grade (%P_2O_5)
LIZ	0.2-0.3	Mainly ovoid pellets with 50% nucleated; less than 5% oolitic pellets.	Semi-compact to dispersed	0.2-0.3	Calcite with minor quartz; very minor albite and clay	Very minor carbonate	Slightly carbonaceous or bituminous	-	Calcareous: mostly calcite	Phosphorite	24.71
SBB86-3	0.1-0.3	Generally ovoid pellets with 5% nucleated	Compact to semi-dispersed	0.05-0.1	Fine quartz with lesser calcite, dolomite, feldspar, mica and clay	Minor carbonate	Moderately carbonaceous or bituminous	-	Slightly calcareous: calcite with minor dolomite	Quartzitic to argillaceous phosphorite	27.28
SBB86-4	0.1-0.3	Ovoid pellets with 5-10% nucleated; rare oolitic pellets	Compact to semi-compact	0.05-0.1	Fine quartz with calcite and very minor feldspar and clay	Minor sericite and clay	Slightly carbonaceous or bituminous	-	Calcareous: mainly calcite	Quartzitic phosphorite	22.33
SBB86-6	0.3-0.5	Ovoid pellets with 25% nucleated	Semi-compact to dispersed	0.1	Very fine-grained calcite and minor sericite and clay	Minor calcite with lesser sericite and clay	Moderately carbonaceous or bituminous	-	Calcareous: mostly calcite	Quartzitic phosphorite	13.41
SBB86-13	0.1-0.2	Ovoid pellets with less than 5% nucleated; rare oolitic pellet	Semi-compact to dispersed	0.05-0.1	Mainly fine-grained quartz		Slightly carbonaceous or bituminous	-	-	Quartzitic phosphorite	23.19
SBB86-38	0.1-0.3; Rare 0.5	Ovoid pellets with less than 2% nucleated	Semi-compact to dispersed	0.05-0.1	Fine-grained quartz and calcite; minor feldspar and clay	Weak carbonate	Slightly carbonaceous or bituminous	-	Very weakly calcareous: mainly calcite	Phosphorite	25.27
SBB86-40	0.1-0.3	Ovoid pellets, intraclasts and nodules; 5% nucleated	Semi-compact to dispersed	0.05	Very fine-grained quartz		Slightly carbonaceous or bituminous	Slightly ferruginous	-	Phosphatic quartzose siltstone	7.29
SBB86-70	0.1-0.4	Ovoid pellets with 5% nucleated	Compact to semi-compact	0.05-0.1	Very fine-grained quartz with minor feldspar and clay	Little or none	Moderately carbonaceous or bituminous	-	-	Quartzitic to argillaceous phosphate	28.43

TABLE 17
TEXTURAL AND COMPOSITIONAL FEATURES OF THE TOAD FORMATION PHOSPHATES

Sample Number	Pellet Size (mm)	Nature of Phosphate	Phosphate Dispersion	Gangue Size (mm)	Gangue	Phosphate Replacement	Organic Content	Iron Content	Carbonate Content	Classification	Grade
SB87-16(3)	0.10-0.30	Ovoid pellets with 50% nucleated	Dispersed to semi-compact	0.05-0.10	Dolomite and quartz with lesser clay	-	Slightly carbonaceous or bituminous	-	Calcareous	Phosphorite	33.34
SB87-37(4)	0.05-0.10	Ovoid pellets with 50% nucleated	Dispersed to semi-compact	0.05-0.10	Calcite with lesser quartz and minor dolomite; trace feldspar and clay	-	Highly	carbonaceous or bituminous	Calcareous		5.31
SB87-40	0.05-0.15	Ovoid pellets with 50-60% nucleated orencased; rare nodule; phosphatized bioclastic debris	Semi-compact	0.05-0.10	Calcite and quartz with minor dolomite and trace feldspar	-	Moderately carbonaceous or bituminous	-	Calcareous		12.12
SB87-43	0.20-0.30	Ovoid pellets with 50-60% nucleated or encased	Dispersed	0.10	Quartz with lesser calcite;minor dolomite	Minor to moderate carbonate	Slightly carbonaceous or bituminous	Calcareous			10.4

floated effectively with fatty acid or anionic collectors. This is believed to be due to the presence of montmorillonite in the matrix. Recoveries from the Lizard deposits were seriously affected by its high carbonate content. A process of careful grinding, attrition-scrubbing and elutriation, generally produced the best results at all three sites (J.M. Hamilton, personal communication, 1986; Christie and Kenny, in preparation); the best results were obtained for the Mount Lyne deposits.

Recent research has resulted in the replacement of traditional fatty acids by new collectors such as amphoteric alkyl amino propionic acids. These do not require phosphate depressants (Notholt and Highley, 1986) and offer some encouragement for processing ores from areas where montmorillonite is a problem.

In the mid-Sixties the United States Bureau of Mines undertook a study of the Meade Peak member of the Phosphoria Formation (Town, 1967). This study is discussed here in some detail as there are a number of similarities between pelletal phosphorites of the Phosphoria Formation and those of the Fernie Formation, the Whistler member of the Sulphur Mountain Formation and the Ishbel Group.

Samples with initial phosphate grades ranging from 21.6 to 27.1% P_2O_5 were upgraded to over 31% P_2O_5. A sample initially containing 15.3 % P_2O_5 and 17.4 % P_2O_5 after roasting was also upgraded to over 31 % P_2O_5 but recoveries were substantially lower. Samples in the 10 to 11% P_2O_5 range were upgraded to 23% P_2O_5 with recoveries of only 71 %.

This study showed that the initial phosphate content is the single most important factor affecting concentration. Calcite and dolomite started to decompose at approximately 700°C during roasting. A pH between 8.5 and 9.5 provided the best conditions for flotation. Grinding finer than -65 or -100-mesh had little effect; grinds finer than -150-mesh caused lower recoveries because of slime losses while improving the concentrate grade only slightly. The amount of emulsion required depended on the pellet size, percentage of clay and sericite and the number of cleaning steps necessary to obtain acid grade (31% P_2O_5). Flotation of silica from phosphate resulted in higher phosphate losses and lower grade concentrates.

Research on the beneficiation of phosphorite from the Phosphoria Formation is ongoing. Recent work by Judd *et al.* (1986) has achieved 98% recovery of phosphate by leaching of unbeneficiated phosphate ores, but did not evaluate the cost effectiveness of the procedure. Rule *et al.* (1982) also completed a study of flotation techniques on the Phosphoria phosphates. Their work involved depression of the phosphate minerals with fluosilicic acid and anionic flotation of carbonate minerals, followed immediately by cationic flotation of silica. Results demonstrated the potential for an increase of 12 to 15% in total phosphate recovery if the flotation process is incorporated into an existing washing-sizing plant. Pilot plant tests achieved recoveries from flotation feed in the range of 73 to 96%.

Studies on the beneficiation of Brazilian phosphate ores at The University of British Columiba (de Araujo *et al.*, 1986) have indicated that desliming, using selective flocculation followed by a conventional single-stage anionic flotation of phosphate, give the best results.

Exploitation of phosphate deposits in British Columbia will require beneficiation techniques that will produce a concentrate grade of 30% P_2O_5 with acceptable recoveries. All test work completed to date was done on the Fernie phosphate more than 10 years ago; new methods being developed may be more effective. Processes that have recently been tried or seriously considered include dense-medium cyclone preconcentration, high-intensity magnetic separation and selective leaching of dolomite from high-grade phosphorites (Hollick and Wright, 1986). This later process may be critical to the beneficiation of the Whistler member phosphorite.

Recent work by Wilemon and Scheiner (1987) on phosphate ores in Florida suggest that the direct leaching of phosphate rock using sulphuric acid and alcohol mixtures may be an alternative to beneficiation procedures previously tested. Phosphate recoveries as high as 90% were obtained in their studies. However, other investigations involving the same mixture had recoveries of only 60 to 65% (Wilson and Radan, 1978). The main problem with this process is obtaining a product low enough in iron and alumina to meet feedstock specifications for fertilizer manufacture.

In the dry process, metallic phosphorus is produced by the thermal reduction of phosphate rock in an electric furnace charged with calcined phosphate rock, silica and coke. The phosphorus is then oxidized to form P_2O_5 and reacted with water to form a high-purity phosphoric acid. Much of the phosphate rock produced from the Phosphoria Formation is processed this way. The major drawback is the high energy consumption in the initial reduction stage and therefore higher cost. Phosphate rock used in this process generally has a grade of 24 to 3% P_2O_5 (52 to 70% BPL) and an iron content less than 1.5% Fe_2O_3. It should also have a water content less than 4%. In British Columbia, phosphate deposits occur close to large deposits of coking coal and sources of hydro-electric power. Phosphate deposits in the Fernie Formation appear to meet the required criteria for the dry process and it can be considered a possible alternative for processing British Columbia phosphate ores.

CHAPTER 8

RESOURCE POTENTIAL OF SEDIMENTARY PHOSPHATE DEPOSITS IN BRITISH COLUMBIA

The economic viability of any mineral deposit is dependent upon many factors, including the size, grade and geometry of the deposit; mining and processing costs; the capital cost of development; and the cost of transportation to market. Flat-lying phosphate deposits in Florida are mined by low-cost open-pit methods and the ore is readily concentrated, allowing Florida producers to exploit deposits with grades of less than 15% P_2O_5. The more geologically complex deposits in Idaho and Montana require grades as high as 30% P_2O_5 to be economically viable as they are mined both by open-pit and more expensive underground methods and beneficiation costs are also higher (*see* Chapter 7).

Substantial phosphate deposits are present in British Columbia but none currently are economically viable. This chapter will attempt to outline the phosphate resource potential throughout the province. A similar study of phosphate deposits in Alberta has been completed by MacDonald (1987). MacDonald's parameters for estimating resource potential are largely adopted here; estimates are for *in situ* phosphate and economically recoverability is not implied unless specifically stated. Detailed phosphate inventories have been calculated for some deposits, for the most part, these estimates remain confidential.

Phosphate resource potential has been calculated for phosphate-bearing formations where practicable. The calculations are based on broadly spaced sample sites and assume continuity of grade and thickness along strike and down dip. As in MacDonalds's study, structural complications were not considered. A specific gravity of 2.8 was used for deposits with a grade greater than or equal to 12% P_2O_5 and 2.7 for lower grade deposits. These specific gravities are average values and may vary from the actual specific gravity at any given location. Summaries of the calculated resource potentials are presented in Tables 18 to 20. Phosphate deposits are discussed in order from oldest to youngest. Deposits with the best potential occur within the Whistler member of the Sulphur Mountain Formation and at the base of the Fernie Formation.

CAMBRIAN OCCURRENCES

The only recorded occurrences of phosphate in Cambrian rocks in British Columbia are at Mount Sheffield and in the Upper Cambrian Kechika Formation in the vicinity of Grey Peak. The resource potential for Cambrian strata is considered to be low.

TABLE 18
RESOURCE POTENTIAL FOR PERMIAN PHOSPHATES

Area	Formation (km)	Outcrop Length	Thickness (m)	Gross Tonnes (x 10^6)		Grade (%P_2O_5)
				300 m	50 m	
I	Johnston Canyon	40	3	97.2	16.2	3-5
II	Johnston Canyon	19	1	15.4	2.6	16.4
III	Ranger Canyon	25	1	20.3	3.4	8
IV	Ranger Canyon	38	1	30.8	5.1	4
V	Condensed Permian	120	1	97.2	16.2	8.3
VI	Mowitch	125	1	101.2	16.9	12.5
VII	Mowitch	15	1	12.2	2	11.7
TOTALS		382	1.29*	373.3	62.4	8.4**

Specific Gravity: 2.7
*Arithmetic Average
**Weighted Average

TABLE 19
RESOURCE POTENTIAL FOR TRIASSIC PHOSPHATES

Area	Formation/ member ($\%P_2O_5$)	Outcrop Length (km)	Thickness (m)	Gross Tonnes (x 10^6) 300 m	50 m	Grade
I	Whistler member	140	1	113.4	19	15-20
II	Toad Fm	300	10	2430	405	5
II	Subsurface:					

Area 200 x 50 = 100 000 km^2
Thickness: Average 20 m
Sp. Gr. 2.7
Resource Potential: 54 x 10^9 tonnes of unknown grade

TABLE 20
RESOURCE POTENTIAL FOR THE BASAL FERNIE PHOSPHATE

Area	Outcrop Length (km)	Thickness (m)	Gross Tonnes (x 10^6) 300 m	50 m	Grade ($\%P_2O_5$)
I	28	1.5	35.3	5.9	19
II	6.5	1.5	8.2	1.4	20
III	12	1.5	15.1	2.5	17.5
IV	24	1	20.2	3.4	15
V	20	3.4	57.1	9.5	12
VI	27	1.5	34	5.7	20
VII	22	1	18.5	3.1	17.3
VIII	25.5	1	21.4	3.6	25
IX	10.7	1.5	13.5	2.3	17.5
X	8	1.6	10.7	1.8	15.2
XI	20	1.5	25.2	4.2	15
XII	56	1.5	70.6	11.8	17
XIII	15	1	12.6	2.1	15
Total	124.2	1.5*	342.4	57.3	16.92**

*Arithmetic average
**Weighted average

EXSHAW FORMATION

The Devono-Mississippian Exshaw Formation, although phosphate bearing, does not represent a significant phosphate resource in British Columbia but does have some potential in Alberta (MacDonald, 1987). The best phosphate exposures are restricted to the High Rock Range immediately north and south of Crowsnest Pass. Many of the better grade exposures are in Alberta. Grades of 1 to 9% P_2O_5 across 10 to 30 centimetres have been reported from the basal sandstone between Phillipps Pass and Racehorse Pass. Grades of 6 to 10% across widths of 1 metre have been documented from the middle phosphate horizons and grades of 15% or more across widths of 10 centimetres or less are recorded from the uppermost phosphate horizon (MacDonald, 1985).

Exshaw exposures on Morrissey Ridge and in the Flathead River area of British Columbia are restricted and were not examined during this study. MacDonald (1985) recorded values of 0.28% P_2O_5 across a width of 1.5 metres and 0.16% P_2O_5 across 0.8 metre at Mount Broadwood. West of the Elk Valley the Exshaw Formation is not exposed. MacDonald (1987) has calculated a resource potential of 10.4 million tonnes (down-dip 300 metres) or 1.7 million tonnes (50 metres downdip) for the Exshaw Formation in Alberta. However, this phosphate occurs in areas alienated from exploration or development.

PERMIAN DEPOSITS

JOHNSTON CANYON FORMATION

Probably the best potential for Permian phosphate in southeastern British Columbia is in the Johnston Canyon Formation. De Schmid (1917) suggests that a continuous phosphate sheet may have been deposited at the base of the Johnston Canyon Formation and although much of it has been removed by erosion, much has been preserved. Both nodular and pelletal varieties are present. The resource potential of the Johnston Canyon Formation is estimated at approximately 370 million tonnes grading somewhat less than 10% P_2O_5, to a depth of 300 metres down-dip. Estimates are summarized in Table 18 and distribution of the resource is shown in Figure 58.

Along the MacDonald thrust fault in the Bighorn - Cabin Creek area at the southeastern limit of deposition of the Johnston Canyon Formation, phosphate occurs almost continuously. The thickness of phosphatic intervals varies considerably, from less than 5 metres in the southeast to 22 metres at Mount Broadwood. Northwesterly along the same trend, in the vicinity of the Fernie ski-hill, phosphatic intervals vary from 1 centimetre to 1 metre thick. Along this trend, a basal conglomerate 25 to 30 centimetres thick contains chert and phosphate pebbles and has a phosphate content averaging 4.3% P_2O_5. At the Fernie ski-hill this conglomerate is only 1 to 2 centimetres thick.

Pelletal phosphorite in the Johnson Canyon Formation was recognized only in the Nordstrum - Brulé - Weigert Creeks area. Work by the author and MacDonald (1985) indicates the presence of at least one pelletal phosphorite bed, ranging in thickness from 0.5 to 2 metres with the phosphate content ranging from 12.7 to 22.7% P_2O_5.

Nodular phosphorite occurs along a strike length of 120 kilometres on the eastern margin of Permian exposures. A sample of nodules from an outcrop in the Crowsnest area assayed 24.0% P_2O_5 while a sample of sandstone from the same locality assayed 12.3% P_2O_5. This phosphate horizon, which is approximately 1 metre thick, can be traced as far south as Flathead Pass and as far north as Banff, where grades of 27.63% P_2O_5 have been reported (de Schmid, 1917).

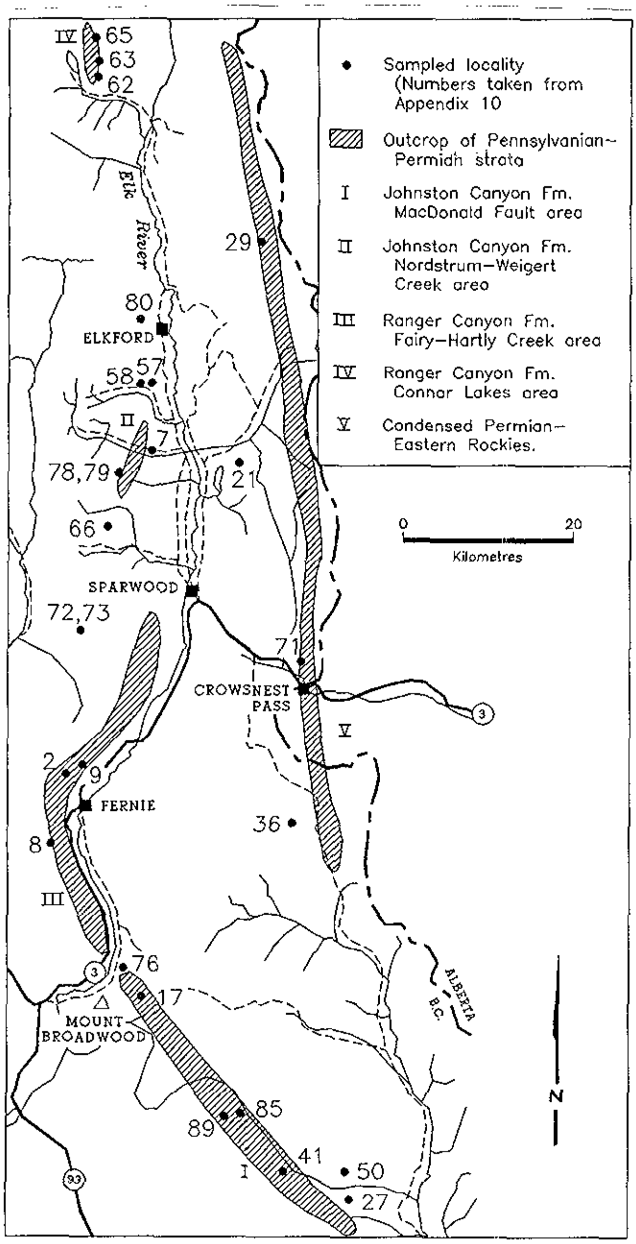


Figure 58. Resource potential for Permian phosphates, southeastern British Columbia.

The best potential in the Johnston Canyon Formation appears to be in the Nordstrum - Weigert Creek area (Area II) and along the MacDonald thrust (Area I), but estimating tonnage and grade is difficult. While grades in excess of 12% P_2O_5 are present, continuity along strike is almost impossible to ascertain as the structure in this area is relatively complex.

ROSS CREEK FORMATION

The Ross Creek Formation is restricted in its distribution and phosphate is known at only a few localities. Phosphatic intervals tend to be low grade (less than 5% P_2O_5) and are generally less than 1 metre thick. MacRae and McGugan (1977) report that samples collected from phosphate horizons have yielded values up to 20% P_2O_5. Thicknesses over which these grades were obtained were only a fraction of a metre. There is also little continuity of these phosphate beds over significant distances. The potential for economic deposits is considered to be low.

RANGER CANYON FORMATION

The Ranger Canyon Formation is widely distributed. It is estimated to outcrop over an area of 150 000 square kilometres in British Columbia and Alberta (Rapson-McGugan, 1970). In southeastern British Columbia phosphatic exposures are thickest along the western and southwestern margins of the Fernie basin where phosphate is present in a basal conglomerate and more commonly as nodules, although other forms are also present. Resource potential for the Ranger Canyon Formation in British Columbia is summarized in Table 18 and its distribution outlined in Figure 58. The best potential occurs in Alberta where MacDonald (1987) has estimated a potential for 230 million tonnes calculated downdip for 300 metres, with grades in the range 6 to 18% P_2O_5.

A phosphatic interval varying in thickness from 0.4 to 4 metres outcrops in the Mutz Creek (12) - Fairy Creek (13) (Figure 14) area north of Fernie. Phosphate content is low and is not considered economically significant. This horizon is believed to extend into the Hartley Creek (15) (Figure 14) area. Norris (1965) also reports the presence of phosphate nodules in the uppermost Ishbel Group from a locality 5 kilometres east of Mount Proctor. Because of sparse data, no resource potential was calculated for this area.

To the west, near the Fernie ski-hill, a phosphate bed assays 13.3% P_2O_5 across 0.5 metre and is the best occurrence in this area.

A well-defined phosphatic bed is present in the upper part of the Ranger Canyon Formation in the Connor Lakes area. A sandstone bed, 1 metre thick and containing phosphate nodules averaging 6 centimetres in diameter, occurs on the limbs of a series of anticlinal and synclinal folds. Although this bed has an extensive strike length and the phosphate nodules contain in excess of 25% P_2O_5, the bed as a whole (including the nodules) averages less than 5% P_2O_5.

The phosphate resource potential of the Ranger Canyon Formation in southeastern British Columbia appears to be limited, approximately 20 million tonnes with a grade of 8% P_2O_5 or less. Most of the areas examined contain extensive occurrences of low-grade phosphate (less than 2% P_2O_5 across thicknesses of 1 to 10 metres).

In northeastern British Columbia phosphate is restricted to a bed 1 metre thick at the top of the Mowitch Formation or stratigraphically equivalent Fantasque Formation, extending from Meosin Mountain to south of Lemoray (Areas VI and VII, Figure 59). Phosphate is nodular and grades are in the order of 12% P_2O_5.

Phosphate is present in the subsurface in the Belloy Formation of the Peace River district (roughly equivalent to the Ishbel Group of southeastern British Columbia) but at depths that preclude its inclusion in estimates of resource potential. This horizon extends eastward into Alberta.

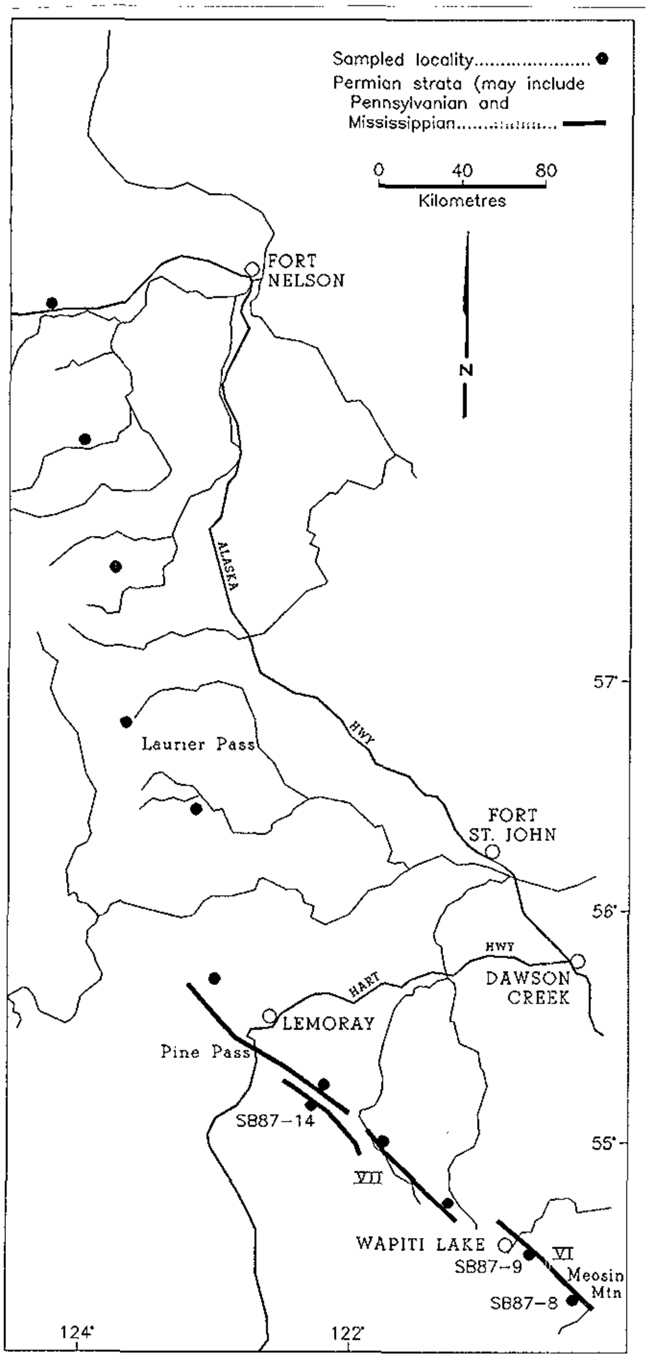


Figure 59. Resource potential for Permian phosphates, northeastern British Columbia.

TRIASSIC DEPOSITS

Phosphate occurrences in Triassic strata extend from the Alberta - British Columbia boundary near Kakwa Lake to north of the Alaska Highway west of Fort Nelson. Areas of resource potential are shown in Figure 60 and resource estimates summarized in Table 19.

A phosphorite bed, occurring at or near the base of the Whistler member of the Sulphur Mountain Formation and extending from Meosin Mountain to Watson Peak (Figure 16) represents a potential source of sedimentary phosphate second only to the Fernie Formation in the East Kootenay district. At Meosin Mountain this bed is 1.3 metres thick and consists of both pelletal and nodular phosphate. South of Meosin Mountain this bed passes into phosphatic, bioclastic and silty limestone and phosphatic calcareous siltstone. A phosphorite bed 1 to 2 centimetres is present at Lemoray, north of Watson Peak. However, its exact stratigraphic position is uncertain. The resource potential for the Whistler member phosphorite is estimated to be 113 million tonnes containing 15 to 20% P_2O_5.

Within this belt the best potential is southeast of Wapiti Lake where the host stratigraphy has been folded into series of plunging synclines and anticlines (Heffernan, 1980; Legun and Elkins, 1986). Here the phosphorite ranges in

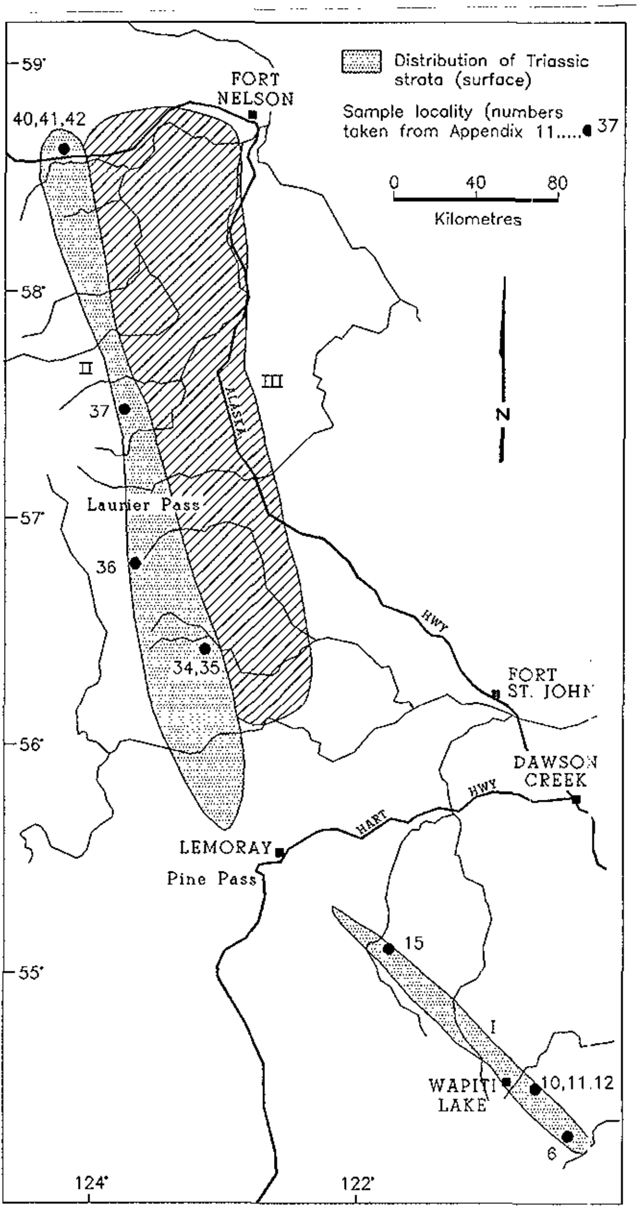


Figure 60. Resource potential for Triassic phosphates, northeastern British Columbia.

thickness from 0.8 to 3.2 metres with assays varying 11.9 to 23.7 P_2O_5 (Heffernan, 1980; A. Legun, personal communication, 1987). Phosphorite is exposed on a dip slope on the eastern limb of the Wapiti syncline, placing large tonnages potentially within reach of surface mining. The base of the phosphorite bed is marked by a thin phosphatic conglomerate that varies in thickness from 5 to 20 centimetres.

SUBSURFACE TRIASSIC DEPOSITS

Subsurface phosphate of Triassic age can be traced as far north as Fort Nelson. Near Fort Nelson the Triassic thins and the phosphatic sequence pinches out. Depths to the top of the phosphatic unit vary from 547 to 2015 metres with the greater depths generally occurring in the most easterly of the holes examined. The phosphate interval varies from a few metres to in excess of 300 metres thick. Correlation with surface phosphate occurrences shows a general thickening in the vicinity of Richards Creek and extending southeasterly in the subsurface. This thickened interval covers only a small area as it quickly thins in every direction, most noticeably easterly where the Triassic section as a whole decreases in thickness.

Although these deep deposits represent a significant resource, the possibility of exploiting them in the foreseeable future is extremely remote.

FERNIE FORMATION

Phosphate occurring at the base of the Fernie Formation represents the best potential for developing an economic deposit in the foreseeable future. It can be traced along strike for approximately 300 kilometres in southeastern British Columbia.

Phosphate is present as a single bed, or as two beds separated by phosphatic shale, throughout the Fernie basin and is consistently at least 1 to 2 metres thick (Figure 61), locally attaining thicknesses of 2 to 3 metres. As much as 8.4 billion tonnes of phosphate rock may have been deposited, but less than 5% of this can be considered a potential resource. The gross resource potential is estimated to be 342 million tonnes with a grade between 11 and 29% P_2O_5 and averaging 17% P_2O_5. A down-dip extension of 300 metres has been used in this calculation. Resource potential for specific areas outlined in Figure 62 is summarized in Table 20.

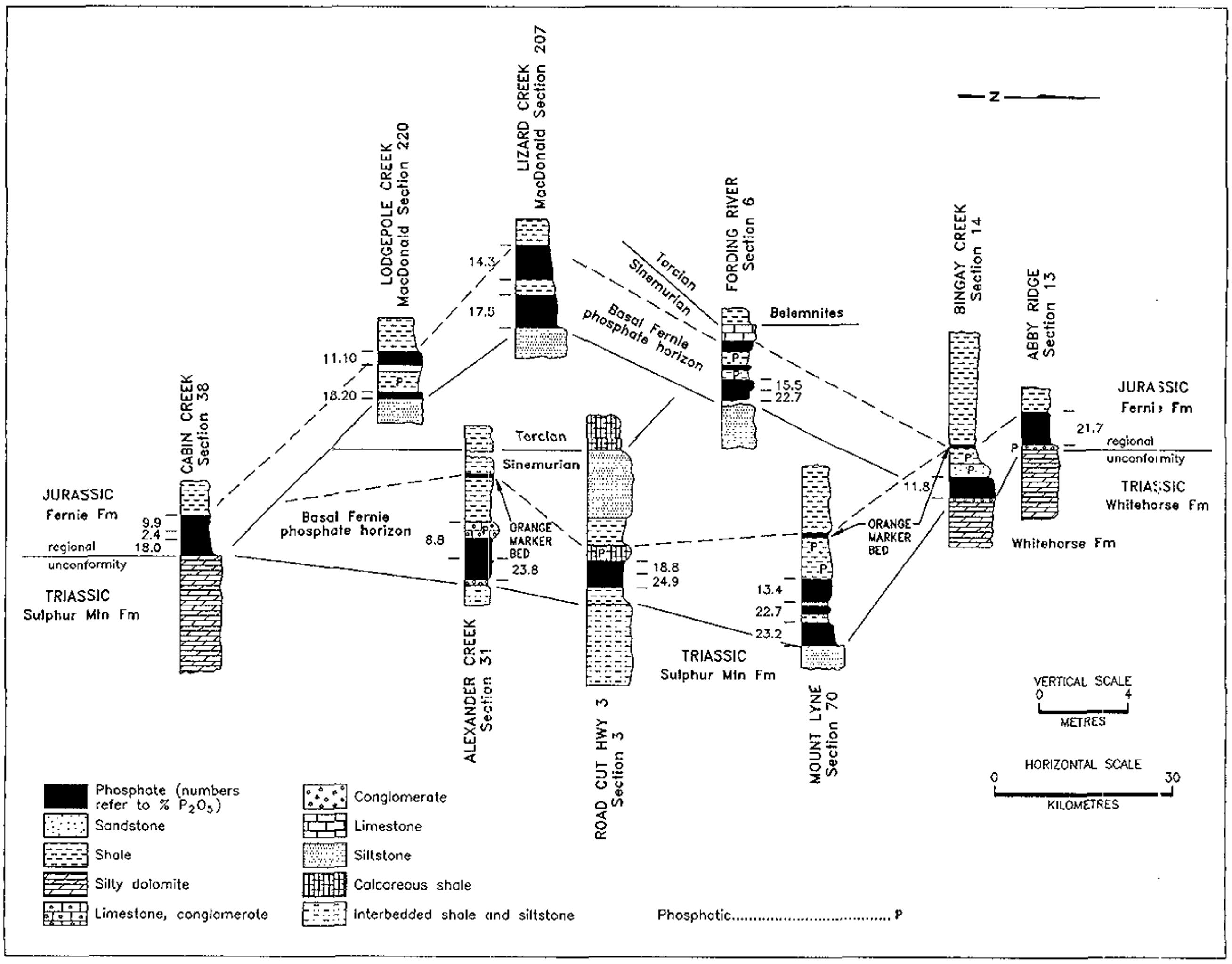


Figure 61. Stratigraphic correlation of the basal Fernie phosphate in Southeastern British Columbia.

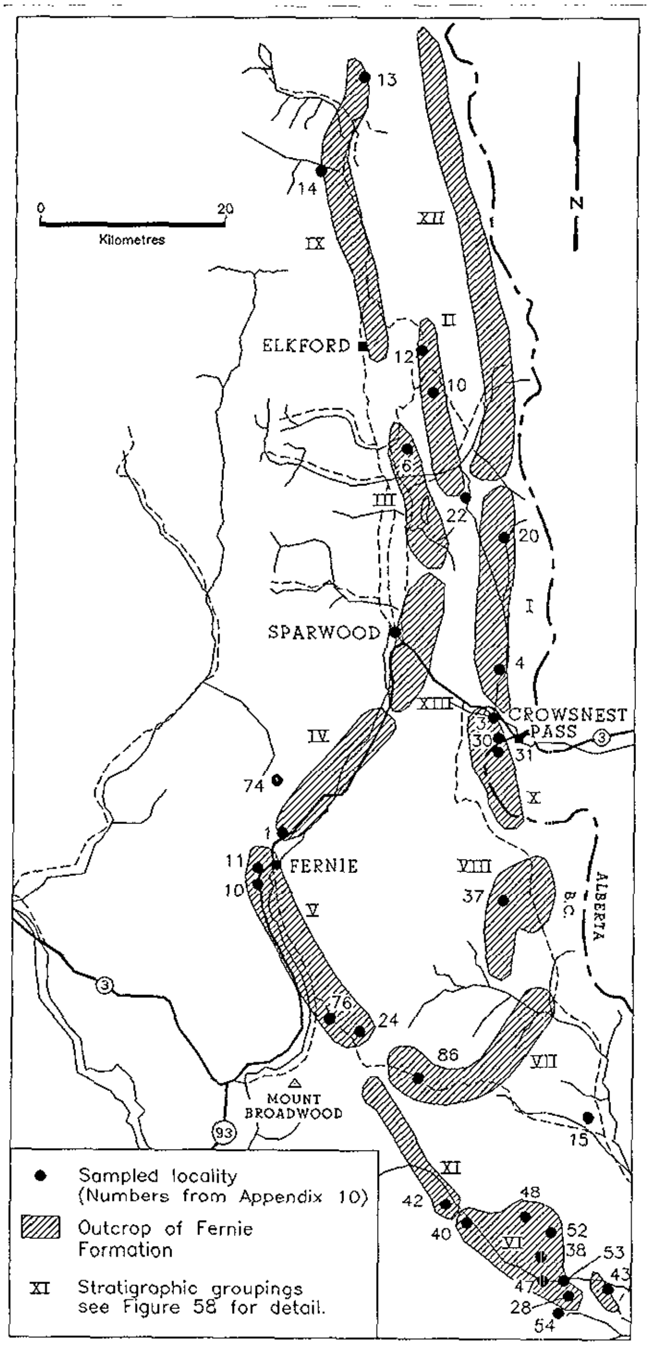


Figure 62. Resource potential for the Fernie phosphate, southeastern British Columbia.

The southeastern and eastern exposures of the basal phosphate appear to offer the best economic potential. The southeasternmost exposures of the basal phosphate occur in the Cabin Creek area. Exploration by First Nuclear Corporation Ltd. (Hartley, 1982), Imperial Oil Ltd. (Van Fraassen, 1978) and the author has demonstrated continuity of a phosphate bed averaging 1.5 metres in thickness along a strike length of 27 kilometres. Phosphate is present in a broad synclinal structure modified by thrust faults and minor folds. Thrust faulting has thickened the phosphate bed at some localities and at others, the phosphate has been remobilized into the noses of folds (Hartley, 1982). Phosphate content is in the range of 13 to 20% P_2O_5; less silty varieties contain more than 20% P_2O_5 (Hartley, 1982).

The Cabin Creek area is estimated to have a resource potential of 34 million tonnes, calculated to a depth of 300 metres, with an average grade of approximately 20% P_2O_5. There is some untested potential immediately west of the Flathead River in the vicinity of Cabin Creek.

North of Crowsnest Pass, the Crow deposit has been the subject of extensive underground work and metallurgical testing by Cominco Ltd. It has an estimated resource potential in excess of 2 million tonnes with an average grade of approximately 25% P_2O_5. This same phosphate bed is interpreted to extend to the headwaters of Alexander Creek where grades averaging 28.4% P_2O_5 across widths of 0.3 metre or less have been sampled.

In the west Line Creek area the basal phosphate can be traced for a strike length of 15 kilometres, in strata that dip 40 to 75 degrees easterly. It varies in thickness from less than 1 metre south of Line Creek, to more than 3 metres at Mount Lyne. Phosphate content ranges from a low of 3.7% P_2O_5 in a diamond-drill hole, to a high of 23.7% P_2O_5 across 1.6 metres in a backhoe trench (Hannah, 1980). At Mount Lyne the phosphorite averages 22.9% P_2O_5 across 2 metres or 19.8% P_2O_5 across 3 metres.

Crows Nest Resources Ltd. calculated a reserve of 972 800 tonnes to a depth of 30 metres in the west Line Creek area, based on a strike length of 5850 metres and an average thickness of 2 metres (Hannah, 1980). The resource potential of the Line Creek area is estimated to be in excess of 25 million tonnes with a grade of approximately 20% P_2O_5, assuming a strike length of 15 kilometres, an average thickness of 2 metres and a depth of 300 metres. The estimated grade is based on surface samples and therefore could be lower, depending on how much weathering of the phosphate has taken place.

In the Barnes Lake area phosphorite is exposed along the limbs of a sequence of folds. The phosphate resource potential for the Fernie Formation in this area is estimated to be 7 million tonnes to a depth of 100 metres, based on a 25.5-kilometre strike length and an average thickness of 1 metre. An additional 4.2 million tonnes may be available to the east of the Corbin logging road.

Christie (1981; in preparation) has suggested that "normative apatite" or "bone phosphate of lime" could be called "total formational apatite" (TFA) and expressed in centimetres by the formula:

TFA = thickness (metres) x assay (% P_2O_5) x 2.18.

Under ideal conditions, "total formational apatite" can be used to indicate where apatite formed, that is, which parts of the basin are most phosphogenic. This procedure, although it will not show where the phosphate is economic, can be useful in locating target areas within a phosphogenic region that may contain economic phosphate.

Total formational apatite (TFA) has been calculated for several localities in the Fernie basin; the results are shown in Figure 63. Their distribution confirms that the eastern margin of the basin is the most phosphogenic, and that there are two centres of more intense phosphogenesis, the Cabin Creek and Crowsnest Pass areas. A single value at Mount Lyne southeast of Elkford suggests that phosphogenesis was also active in this area. It should be noted that for those localities where the section is incomplete, the calculated value is a minimum. These results tend to confirm the hypothesis that the eastern margin of the Fernie basin offers the best potential for economic phosphate deposits.

Carbonatite deposits also represent a significant source of phosphate in the province, with the Aley deposit accounting for virtually all of the resource potential. Its resource potential is estimated in excess of 30 billion tonnes. Phosphate could conceivably be produced as a byproduct should this property be brought into production for niobium.

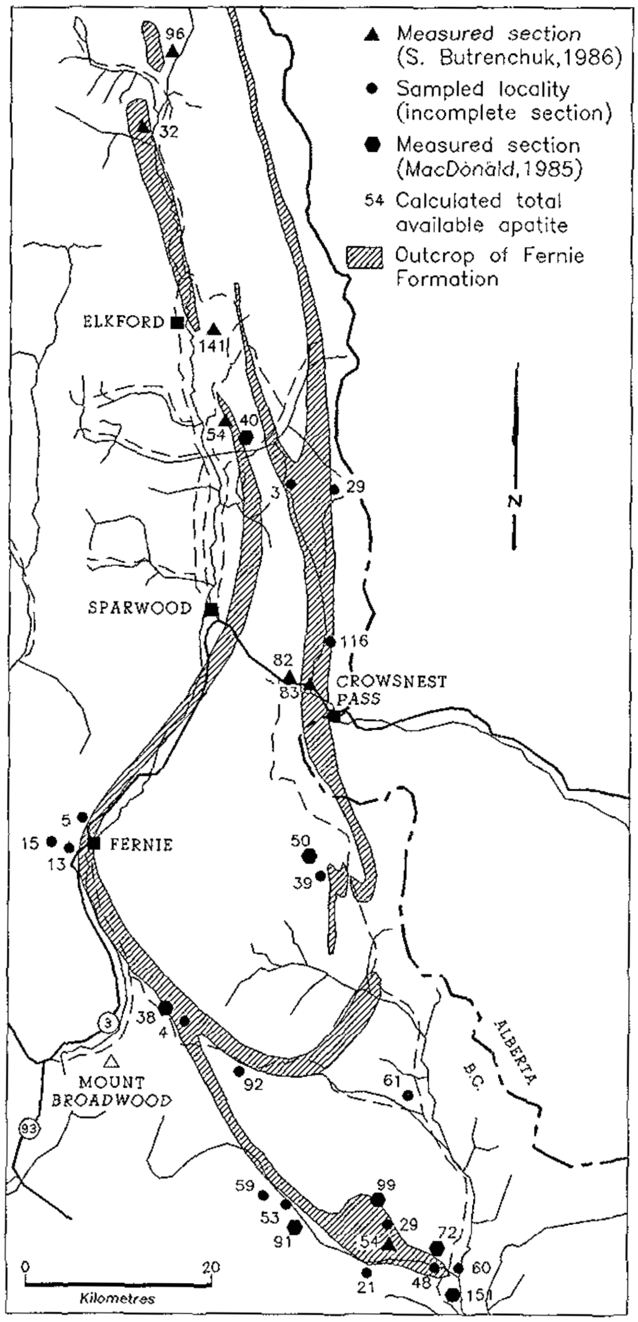


Figure 63. Total formational apatite, basal phosphate horizon, Fernie Formation.

CHAPTER 9

SUMMARY AND CONCLUSIONS

British Columbia is well endowed with phosphate deposits, both sedimentary and igneous. Sedimentary phosphate deposits have been identified in 14 stratigrpahic units ranging in age from Upper Cambrian to Lower Jurassic. These deposits are all located in the Rocky Mountains east of the Rocky Mountain Trench. Some isolated occurrences occur west of the trench but none are of economic significance. Sedimentary phosphate occurs in a variety of forms but only pelletal varieties offer potential for future development. Grades greater than 15% P_2O_5, the threshold of economic interest, occur only in the Whistler member of the Sulphur Mountain Formation, in the Fernie Formation and locally in Permian strata. At present these phosphate deposits cannot compete with production from the western United States where beds grading 30% P_2O_5 are selectively mined. In the future, as production in Florida decreases and mining of lower grade phosphate from the Phosphoria Formation becomes necessary, phosphate deposits in British Columbia may become economically viable.

Presently known deposits in British Columbia present practical difficulties with respect to their mining and beneficiation. Phosphate beds are narrow and their structural attitude precludes open-pit mining in most locations. The low grade of these deposits requires that they be beneficiated to meet fertilizer industry standards. While past research on beneficiation of these deposits has not been particularly rewarding, more recent work offers some encouragement.

Cambrian:

Phosphate deposits of Cambrian age occur primarily in the Kechika Formation as thin beds of limited areal extent. They do not represent a significant resource potential. Presently known phosphate occurrences are located in Kwadacha Provincial Park and are precluded from exploration.

Mississippian:

Phosphate deposits of Mississippian age are present in the Exshaw Formation. The best resource potential for these deposits is in Alberta immediately adjacent to British Columbia, north of Crowsnest Pass. These deposits too are precluded from development as they occur in an Alberta Protection Area.

Permian:

Phosphate deposits are present in several stratigraphic units of Permian age. These deposits are best developed in southeastern British Columbia, in strata the Johnston Canyon and Ranger Canyon formations.

The phosphate potential of Permian strata is difficult to assess because of the predominantly nodular nature of the phosphate. While the nodules may contain in excess of 25% P_2O_5 and can occur over stratigraphic thicknesses of several metres, the host beds have phosphate values generally less than 2 to 4% P_2O_5.

Two areas of pelletal phosphorite, Weigert and Nordstrum Creek appear to have limited areal extent although phosphate grades are in excess of 12 and 24% respectively. These deposits cannot be considered as having a large resource potential. The Ranger Canyon Formation in British Columbia is estimated to have a resource potential of 51 million tonnes with grades between 4 and 8% P_2O_5.

In northeastern British Columbia the best potential for Permian phosphate is in the Mowitch Formation where there is an estimated potential for 113 million tonnes with a phosphate grade averaging approximately 12% P_2O_5.

Triassic:

Phosphate deposits of Triassic age include predominantly nodular varieties in the Toad Formation and pelletal phosphorite in the Whistler member of the Sulphur Mountain Formation. The Toad Formation may have a resource potential in excess of 2 billion tonnes with grades of 3 to 5% P_2O_5. The Whistler member is estimated to have a resource potential of 113 million tonnes with grades of 15 to 20% P_2O_5, assuming the best possible parameters. Included in this resource is the potential for approximately 11 000 tonnes of lanthanum and 4500 tonnes of cerium. These deposits, because of their high carbonate content, present beneficiation problems in addition to difficult mining conditions. Although most of these deposits would have to be mined underground there appears to be some open-pit potential in the Wapiti Lake area.

A large phosphate resource of undetermined grade and dubious exploitability is present in Triassic strata in the subsurface.

Jurassic:

The best potential for an economic sedimentary phosphate deposit occurs at the base of the Jurassic Fernie Formation. This phosphorite bed is estimated to have a maximum resource potential of 340 million tonnes grading 15 to 20% P_2O_5. It is also estimated to contain approximately 66 000 tonnes of lanthanum, 44 000 tonnes of cerium, 163 000 tonnes of yttrium and 11 000 tonnes of uranium and represents a significant source of these metals.

Beneficiation of the Fernie phosphate will require grinding to either 65- or 100-mesh depending on grain size, desliming to remove the clay fraction and flotation. Calcining will be required in areas where the carbonate or organic content is high. Exploration of these deposits should concentrate on the eastern and southeastern margin of the Fernie Basin. Phosphate grades and, to some extent, trace element contents are generally higher in these areas while the carbonate content tends to be much lower.

Carbonatites also represent a significant source of phosphate in the province. At present only the Aley carbonatite has significant phosphate potential. Other phosphate-bearing carbonatites do occur and the potential for locating more of these deposits is excellent.

REFERENCES

Aaquist. B. (1981): Blue River Carbonatites, British Columbia, Final Report 1981, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 10274, 30 pages.

Altschuler, Z.S., Clarke, R.S. and Young, E.J. (1958): Geochemistry of Uranium in Phosphorite, *United States Geological Survey*, Professional Paper 314D, pages 45-90.

Altschuler, Z.S. (1980): The Geochemistry of Trace Elements in Marine Phosphorites. Part 1. Characteristic Abundances and Enrichment, *The Society of Economic Paleontologists and Mineralogists*, Special Publication No. 29, pages 19-30.

Armstrong, J.E. (1949): Fort St. James Map-area, Cassiar and Coast Districts, British Columbia, *Geological Survey of Canada*, Memoir 252, 210 pages.

Bamber, E.W., Taylor, G.C. and Proctor, R.M. (1968): Carboniferous and Permian Stratigraphy of Northeastern British Columbia, *Geological Survey of Canada*, Paper 68-15, 25 pages.

Barry, G.S. (1986): Phosphate, Canadian Minerals Yearbook, 1987, pages 46.1-46.8; *Energy, Mines and Resources Canada*.

Barry, G.S. (1987): Phosphate, *Canadian Mining Journal*, February 1987, pages 65-66.

Benvenuto, G.L. and Price, R.A. (1979): Structural Evolution of the Hosmer Thrust Sheet, Southeastern British Columbia, *Canadian Petroleum Geologists*, Bulletin, Volume 27, Number 3, pages 360-394.

Burnett, W.C., Beers, M.J. and Roek, K. (1982): Growth Rates of Phosphate Nodules from the Continental Margin off Peru, *Science*, Volume 215, Number 26, pages 1616-1617.

Butrenchuk, S.B. (1987a): Phosphate Inventory (82G and J), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 289-302.

Butrenchuk, S.B. (1987b): Phosphate Deposits of Southeastern British Columbia. *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-16, 103 pages.

Butrenchuk, S.B. (1988): Phosphate Inventory: Northeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 396-410.

Campbell, R.B., Mountjoy, E.W. and Young, F.G. (1973): Geology of McBride Map-area, British Columbia, *Geological Survey of Canada*, Paper 72-35, 104 pages.

Cann, R.M. and Godwin, C.I. (1983): Genesis of Magmatic Magnetite-apatite Lodes, Iron Mask Batholith, Southcentral British Columbia (92I), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1982, Paper 1983-1, pages 267-276.

Cathcart, J.B. (1983): Sedimentary Phosphate Deposits of the World - Present Status and Outlook for the Future, paper presented at Industrial Minerals Meeting, Phosphates: What Prospects for Growth, Orlando, Florida, December 11-14, 1983; *Metal Bulletin Journals Ltd.*, pages 6-42.

Cecile, M.P. and Norford, B.S. (1979): Basin to Platform Transition, Lower Paleozoic Strata of Ware and Trutch Map Areas, Northeastern British Columbia, *Geological Survey of Canada*, Paper 79-1A, pages 219-226.

Cheney, T.M. (1957): Phosphate in Utah and on Analysis of the Stratigraphy of the Park City and Phosphoria Formations, Utah, *Utah Geological and Mineralogical Survey*, Bulletin 59, 54 pages.

Christie, R.L. (1978): Sedimentary Phosphate Deposits - An Interim Review, *Geological Survey of Canada*, Paper 78-20, 9 pages.

Christie, R.L. (1980): Paleolatitudes and Potential for Phosphorite Deposition in Canada, *Geological Survey of Canada*, Paper 80-1B, pages 241-248.

Christie, R.L. (1981): Phosphorite in Western Canada, *Canadian Institute of Mining and Metallurgy*, Reprint Number 55, 83rd Annual General Meeting, Calgary, May 4-7, 1981.

Christie, R.L. (in preparation): Phosphogenic Basins and Phosphate Economics in the Cordilleran Region of Western Canada, *Geological Survey of Canada*.

Christie, R.L. and Kenny, R.L. (in preparation): Phosphate Exploration in the Southern Canadian Rockies, *Canadian Institute of Mining and Metallurgy*.

Cook, P.J. (1976): Sedimentary Phosphate Deposits, *in* Handbook of Stratabound and Stratiform Ore Deposits, Volume 7, K.H. Wolf, Editor, *Elsevier*, pages 505-535.

Cook, P.J. and McElhinney, M.W. (1979): A Reevaluation of the Spatial and Temporal Distribution of Sedimentary Phosphate Deposits in the Light of Plate Tectonics, *Economic Geology*, Volume 74, pages 315-330.

Dales, G.D. (1978): Report on Diamond Core Drilling - FH and WW Group Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 6859.

de Araujo, A.C., Poling, G.W. and Coelho, E.M. (1986): Selective Desliming of Sedimentary Phosphate Ores, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 79, Number 895, pages 52-59.

de Schmid, H.S. (1917): A Reconnaissance for Phosphate in the Rocky Mountains; and for Graphite near Cranbrook, British Columbia, *Department of Mines*, Mines Branch, Ottawa, Summary Report, 1916, pages 22-35.

Dorian, N. (1975): Refraction Seismic Survey on the Flathead Phosphate Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 5556.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F. and Belyea, H.R. (1970): Geology of Western Canada, *in* Geology and Economic Minerals of Canada, Chapter VIII, *Geological Survey of Canada*, Economic Geology Report 1, 5th Edition, pages 367-488.

Emigh, G.D. (1983): Phosphate Rock, *in* Industrial Minerals and Rocks, 5th Edition, S.J. Lefond, Editor, *Society of Mining Engineers*, pages 1017-1047.

Freebold, H. (1957): The Jurassic Fernie Group in the Canadian Rocky Mountains and Foothills, Geological Survey of Canada, Memoir 287, 197 pages.

Freebold, H. (1969): Subdivisions and Facies of Lower Jurassic Rocks in the Southern Canadian Rocky Mountains and Foothills, Geological Association of Canada, Proceedings, Volume 20, pages 76-87.

Gabrielse, H., Dodds, C.J., Mansy, J.L. and Eisbacher, G.H. (1977): Geological Map of Ware West Half and Toodoggone River Map-areas, *Geological Survey of Canada*, Open File Report 483.

Gibson, D.W. (1969): Triassic Stratigraphy of the Bow River - Crowsnest Pass Region, Rocky Mountains of Alberta and British Columbia, *Geological Survey of Canada*, Paper 68-29, 49 pages.

Gibson, D.W. (1971): Triassic Stratigraphy of the Sikanni Chief River - Pine Pass Region, Rocky Mountain Foothills, Northeastern British Columbia, *Geological Survey of Canada*, Paper 70-31, 105 pages.

Gibson, D.W. (1972): Triassic Stratigraphy of the Pine Pass - Smoky River Area, Rocky Mountain Foothillls and Front Ranges of British Columbia and Alberta, *Geological Survey of Canada*, Paper 71-30, 108 pages.

Gibson, D.W. (1974): Triassic Rocks of the Southern Canadian Rocky Mountains, *Geological Survey of Canada*, Bulletin 230, 65 pages.

Gibson, D.W. (1975): Triassic Rocks of the Rocky Mountain Foothills and Front Ranges of Northeastern British Columbia and West-central Alberta, *Geological Survey of Canada*, Bulletin 247, 42 pages.

Goodfellow, W.D. and Jonasson, I.R. (1983): Environment of Formation of the Howards Pass (XY) Zn-Pb Deposit, Selwyn Basin, Yukon, *in* Mineral Deposits of Northern Cordillera, J.A. Morin, Editor; *Canadian Institute of Mining and Metallurgy*, Special Volume 37, pages 19-50.

Grove, E.W. (1986): Geology and Mineral Deposits of the Unuk River - Salmon River - Anyox Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 63, 152 pages.

Gulbrandsen, R.A. (1966): Chemical Composition of Phosphorites of the Phosphoria Formation, *Geochimica and Cosmochimica Acta*, Volume 30, pages 769-778.

Halbertsma, H.L. (1959): Nomenclature of Upper Carboniferous and Permian Strata in the Subsurface of the Peace River Area, *Journal of Alberta Society of Petroleum Geologists*, Volume 7, Number 5, pages 109-118.

Hannah, T.W. (1980): Phospahtic Beds in the Fernie Formation of West Line Creek, Southeast British Columbia, *Crows Nest Resources Ltd.*, Unpublished Company Report.

Hartley, G.S. (1981): Physical Work and Investigation of Mineralization on the Zip 1 Claim, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 9142.

Hartley, G.S. (1982): Investigation of Phosphate Mineralization on the Cabin Creek Claims 1-45 and on the Zip 1 Claim, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 10135.

Hartman, F.H. and Wyman, R.A. (1974): Beneficiation of Phosphate Rock from Fernie, British Columbia, *Energy, Mines and Resources Canada*, Investigation Report IR74-37, 22 pages.

Heffernan, K.J. (1978): 1977 Drilling Report for Lodge 1 Claim in the Fort Steele Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 7616.

Heffernan, K.J. (1980): Report on Geological Mapping, Sampling and Drilling, Wapiti 1-25 Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 8407, 17 pages.

Henderson, G.G.L. and Dahlstrom, C.D.A. (1959): First-order Nappe in Canadian Rockies, *Bulletin of American Association of Petroleum Geologists*, Volume 43, Number 3, pages 641-653.

Hollick, C.T. and Wright, R. (1986): Recent Trends in Phosphate Mineral Beneficiation, *The Institution of Mining and Metallurgy*, Transactions, Section A, Mining Industry, Volume 95, July 1986, pages A150-A154.

Höy, T. (1987): Geology of the Cottenbelt Lead-zinc-magnetite Layer, Carbonatites and Alkalic Rocks in the Mount Grace Area, Frenchman Cap Dome, Southeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 80, 99 pages.

Irish, E.J.W. (1970): Halfway River Map-area, British Columbia, *Geological Survey of Canada*, Paper 69-11, 154 pages.

Irving, E. (1979): Paleopoles and Paleolatitudes of North America and Speculations about Displaced Terrains, *Canadian Journal of Earth Sciences*, Volume 16, pages 669-694.

Judd, J.C., Sandberg, R.G. and Huiatt, J.L. (1986): Recovery of Vanadium, Uranium and Phosphate from Idaho Phosphorite Ores, *United States Bureau of Mines*, Report of Investigations 9025, 15 pages.

Kazakov, A.V. (1937): The Phosphorite Facies and the Genesis of Phosphorites, *in* Geological Investigations of Agricultural Ores of the U.S.S.R., *Science Institute, Fertilizers and Insecto-Fungicides*, Transactions, Volume 142, pages 95-113 (published for the 17th International Geological Congress, Leningrad).

Kenny, R.L. (1977): Phosphate Exploration in Southeastern British Columbia, Cominco Ltd., talk presented at Meeting, *Canadian Institute of Mining and Metallurgy*, Ottawa, Ontario.

King, D.E.C. (1986): Rare Earths, *Canadian Minerals Yearbook 1986, Review and Outlook*, Mineral Report 35, pages 50.1-50.10.

Kouloheris, A.P. (1977): Solving Problems in Chemical Processing of Low Quality Phosphate Rock: *Engineering and Mining Journal*, pages 104-108.

Krauskopf, K.B. (1955): Sedimentary Deposits of Rare Metals, *Economic Geology*, 50th Anniversary Volume, pages 411-463.

Kuck, P.H. (1983): Vanadium Mineral Commodity Profile, *United States Bureau of Mines*, 18 pages.

Lavers, W. (1986): Phosphate Rock: Regional Supply and Changing Pattern of World Trade, *The Institution of Mining and Metallurgy*, Transactions, Section A, Mining Industry, Volume 95, July 1986, pages A119-A125.

Leech, G.B. (1960): Fernie (West-half), *Geological Survey of Canada*, Map 11-1960 (1:126 720).

Leech, G.B. (1979): Kananaskis Lakes, West Half, British Columbia and Alberta (82J/W 1/2), *Geological Survey of Canada*, Open File Map 634 (1:125 000).

Legun, A. aand Elkins, P. (1986): Wapiti Syncline Phosphate Potential, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 151-153.

Mabie, C.P. and Hess, H.C. (1964): Petrographic Study and Classification of Western Phosphate Ores, *United States Department of the Interior*, Report of Investigations 6468, 95 pages.

Mäder, U.K. (1987): The Aley Carbonatite Complex, Northern Rocky Mountains, British Columbia (94B/5), *B.C. Ministry* *of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 283-288.

McCrossan, R.G. and Glaister, R.P. (1964): Geological History of Western Canada, *Alberta Society of Petroleum Geologists*, 232 pages.

MacDonald, D.E. (1985): Geology and Resource Potential of Phosphates in Alberta and Portions of Southeastern British Columbia, Unpublished M.Sc. Thesis, *University of Alberta*, 238 pages.

MacDonald, D.E. (1987): Geology and Resource Potential of Phosphates in Alberta, *Alberta Research Council*, Earth Sciences Report 87-2, 65 pages.

McGugan, A. (1967): Permian Stratigraphy, Peace River Area, Northeast British Columbia, *Canadian Petroleum Geology*, Bulletin Volume 15, Number 1, pages 82-90.

McGugan, A. and Rapson, J.E. (1962): Permo-Carboniferous Stratigraphy, Crowsnest Area, Alberta and British Columbia, *Alberta Society of Petroleum Geologists*, Journal, Volume 10, pages 352-368.

McGugan, A. and Rapson, J.E. (1964a): Permian and Carboniferous Stratigraphy, Crowsnest Area, Alberta and British Columbia, *Canadian Petroleum Geologists*, Bulletin, Volume 12, Field Conference Guidebook, pages 494-499.

McGugan, A. and Rapson, J.E. (1964b): Permo-Carboniferous Stratigraphy, Wapiti Lake area, Northeast British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 1155 (Petroleum Resources Division).

MacIntyre, D.G. (1980): Geological Compilation and Mineral Occurrence Map, Driftpile Creek - Aikie River, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 38.

MacIntyre, D.G. (1981): Akie River Project (94F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1980, Paper 1981-1, pages 33-47.

MacIntyre, D.G. (1982): Akie River Project (94F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1982-1, pages 142-148.

McMechan, M.E. (1987): Stratigraphy and Structure of the Mount Selwyn Area, Rocky Mountains, Northeastern British Columbia, *Geological Survey of Canada*, Paper 85-28, 34 pages.

MacRae, J. and McGugan, A. (1977): Permian Stratigraphy and Sedimentology - Southwestern Alberta and Southeastern British Columbia, *Canadian Petroleum Geologists*, Bulletin, Volume 25, Number 4, pages 752-766.

Newmarch, C.B. (1953): Geology of the Crowsnest Coal Basin with Special Reference to the Fernie Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 33, 107 pages.

Norris, D.K. (1965): Stratigraphy of the Rocky Mountain Group in the Southeastern Cordillera of Canada, *Geological Survey of Canada*, Bulletin 125, 82 pages.

Notholt, A.J.G. and Highley, D.E. (1986): World Phosphate Resources, with particular reference to Potential Low-grade Ores: *The Institution of Mining and Metallurgy*, Transactions, Section A, Mining Industry, Volume 95, July 1986, pages 125-132.

Patton, W.W. and Matzko, J.J. (1959): Phosphate Deposits in Northern Alaska, *United States Department of the Interior*, Geological Survey Professional Paper 302-A, 16 pages.

Pell, J. (1985): Carbonatites and Related Rocks in British Columbia; *in* Geological Fieldwork 1984, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1985-1, pages 84-94.

Pell, J. (1987): Alkaline Ultrabasic Rocks in British Columbia: Carbonatites, Nepheline Syenites, Kimberlites, Ultramafic Lamprophyres and Related Rocks; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-17, 109 pages.

Pelletier, B.R. (1961): Triassic Stratigraphy of the Rocky Mountains and Foothills, Northeastern British Columbia [94K and N (parts of)]; *Geological Survey of Canada*, Paper 61-8, 32 pages.

Pelletier, B.R. (1963): Triassic Stratigraphy of the Rocky Mountains and Foothills, Peace River District, British Columbia, *Geological Survey of Canada*, Paper 62-26, 43 pages.

Pelletier, B.R. (1964): Triassic Stratigraphy of the Rocky Mountain Foothills Between Peace and Muskwa Rivers, Northeastern British Columbia, *Geological Survey of Canada*, Paper 63-33, 89 pages.

Pelzer, M.A. (1977): Geological and Drilling Report, 1977 Field Work, Phosphate Properties, Flathead Area, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 6365.

Pettijohn, F.J. (1957): Sedimentary Rocks, Second Edition: New York; *Harper and Row*, 718 pages.

Pilcher, S.H. (1983): Report on the Geology and Geochemical Surveys and Physical Work Conducted on the Ren I, II, III and IV Claims, Kamloops Mining Division; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 11639, 17 pages.

Price, R.A. (1961): Fernie (East-half), *Geological Survey of Canada*, Map 35-1961 (1:126 720).

Price, R.A. (1964): Flathead (Upper Flathead, East Half), British Columbia - Alberta, *Geological Survey of Canada*, Map 1154A, (1:50 000).

Price, R.A. and Grieve, D. (in preparation): Tornado Mountain, British Columbia and Alberta, (1:50 000), *Geological Survey of Canada.*

Price, R.A. and Grieve, D. (in preparation): Fording River, British Columbia and Alberta (1:50 000), *Geological Survey of Canada.*

Prud'homme, M. and Francis, D. (1987): The Fertilizer Industry, *Energy, Mines and Resources Canada*, Mineral Policy Sector, Internal Report MRI 87/3, 15 pages.

Rapson-McGugan, J.E. (1970): The Diagenesis and Depositional Environment of the Permian Ranger Canyon and Mowitch Formations, Ishbel Group, from the Southern Canadian Rocky Mountains, *Sedimentology*, Volume 15, pages 363-417.

Rule, A.R., Larson, D.E. and Dallenbach, C.B. (1982): Application of Carbonate-silica Flotation Techniques to Western Phosphate Material, *United States Bureau of Mines*, Report of Investigations 8782, 13 pages.

Russell, A. (1987): Phosphate Rock: Trends in Processing and Production, *Industrial Minerals*, Number 240, September 1987, pages 25-52.

Savanick, G.A. (1983): New Developments in Hydraulic Borehole Mining of Phosphate, *in* Phosphates: What Prospects for Growth?, P.W. Harben, Editor, *Metal Bulletin Inc.*, New York.

Sheldon, R.P. (1981): Ancient Marine Phosphorites, *Annual Review of Earth Planetary Science*, Volume 9, pages 251-284.

Sheldon, R.P. (1987): Association of Phosphatic and Siliceous Marine Sedimentary Deposits, in Siliceous Sedimentary Rock-hosted Ores and Petroleum, J.R. Hein, Editor, pages 58-80.

Slansky, M. (1980):

Slansky, M. (1986): Geology of Sedimentary Phosphates, *Elsevier*, 210 pages.

Struik, L.C. (1988): Structural Geology of the Cariboo Gold Mining District, East-central British Columbia, *Geological Survey of Canada*, Memoir 421, 100 pages.

Taplin, A.C. (1967): Internal Company Report, *Cominco Ltd.*

Taylor, G.C. and Stott, D.F. (1973): Tuchodi Lakes Map-area, *Geological Survey of Canada*, Memoir 373, 37 pages.

Telfer, L. (1933): Phosphate in the Canadian Rockies, *Canadian Institute of Mining and Metallurgy*, Transactions, Volume 36, pages 566-605.

Thompson, R.I. (1986a): Mount Brewster and Jones Peak, *Geological Survey of Canada*, Map 1-1986.

Thompson, R.I. (1986b): Wicked River, *Geological Survey of Canada*, Map 2-1986.

Thompson, R.I. (1986c): Gauvreau Creek, *Geological Survey of Canada*, Map 3-1986.

Thompson, R.I. (1986d): Emerslund Lakes and Hackney Hills, *Geological Survey of Canada*, Map 4-1986.

Thompson, R.I. (1986e): Christina Falls, *Geological Survey of Canada*, Map 5-1986.

Thompson, R.I. (1986f): Mount Lady Laurier, *Geological Survey of Canada*, Map 6-1986.

Thompson, R.I. (1986g): Mount Robb, *Geological Survey of Canada*, Map 7-1986.

Thompson, R.I. (1986h): Mount Laurier, *Geological Survey of Canada*, Map 8-1986.

Town, J.W. (1967): Petrographic and Flotation Studies on the Meade Peak, Idaho, Phosphate Samples, *United States Department of the Interior*, Bureau of Mines, Report of Investigations 6751, 15 pages.

Van Fraassen, M.A. (1978): 1978 Drilling and Geology Report, Cabin 1, 2, 3, and Ram 1 and 2 Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 7617.

Webber, G.L. (1975): Geological Report on Grave Lake Groups No. 1 and No. 2, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 5545.

Webber, G.L. (1976): Diamond Drilling Report on Grave Lake Group No. 1, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 5545.

Werner, A.B.T. (1982): Phosphate Rock: an Imported Mineral Commodity, *Energy, Mines and Resources Canada*, Mineral Bulletin, MR193, 61 pages.

Wilemon, G.M. and Scheiner, B.J. (1987): Leaching of Phosphate Values from two Central Florida Ores using H_2SO_4-methanal Mixtures, *United States Department of the Interior*, Report of Investigations 9094, 9 pages.

Wilson, R.A. and Radan, D.J. (1978): Phosphoric Acid Manufacture from Phosphate Matrix, Unites States Patent 4,105,749, August 8, 1978.

Young, G.A. and Uglow, W.L. (1926): The Iron Ores of Canada; *Geological Survey of Canada*, Economic Geology Series, Number 3, pages 109-128.

GLOSSARY OF TERMINOLOGY USED IN THIS REPORT

Pellet:	*Phosphate grain no greater than 4.0 millimetres in* longest dimension.
Nodule:	Phosphate grain 4.0 millimetres or more in longest dimension.
Ovoid Pellet:	Pellet with no discernible internal structure.
Oolite:	Pellet with concentric internal structures.
Nucleated Pellet:	Pellet hat has a centre of non-phosphatic material with a diameter of less than one-half the minimum diameter of the pellet.
Polynucleated Pellet:	Pellets containing two or more detrital grains or fossil fragments.
Encased Pellet:	Pellet with core-diameter equal to or greater than half of the minimum diameter of the pellet.
Intraclasts:	Reworked fragment of a contemporary sediment from the same depositional basin.
Compacted Texture:	Texture in which more than one-half of the fluorapatite occurs as pellets that are mostly adjoining.
Semidispersed Texture:	Texture in which one-half of the fluorapatite occurs as pellets that are only partially adjoining.
Dispersed Texture:	Texture in which gangue is dominant or where greater than one-half of the fluorapatite occurs interstitially as pellets.
Phosphate Rock:	*Term applied to phosphate-bearing rock that is* mined and used as a raw material in the manufacture of phosphate fertilizers.
Phosphorite:	A deposit of phosphate rock of sedimentary origin, which is of economic interest. It is generally assumed that the rock contains a minimum of 18% P_2O_5 or 50% apatite by volume. For purposes of this report the term phosphorite is applied to those rocks having a pelletal texture and containing greater than 7% P_2O_5.
Bone Phosphate *of Lime (BPL):*	Phosphate Expression of the calcium phosphate content of phosphate rock (equivalent to 2.1852 x *%* P_2O_5*).*
Phosphatic Sandstone:	Rock with arenite grain size that contains 1 to 5% P_2O_5.
Phosphatic Shale:	Rock with rudite grain size that contains 1 to 5% P_2O_5.
Phosphatic Siltstone:	Rock with silt grain size that contains 1 to 5% P_2O_5.
Desliming:	The process of removing clay material from the rock.
Flotation:	Process used to produce a product ranging from 70 to 72% BPL.

APPENDICES

APPENDIX 1
CALCULATIONS USED TO DETERMINE MINERALOGICAL COMPOSITION USED IN THE CLASSIFICATION OF PHOSPHATE ROCKS

In Mabie and Hess's (1964) classification the following assumptions were made:

(1) All the P_2O_5 was assumed to be in the form of collo phane obtaining 38 per cent P_2O_5 by weight.
(2) Alumina was assumed to be in the form of muscovite-sericite-clay containing 38.5 per cent Al_2O_3 by weight.
(3) All SiO_2 not in muscovite-sericite-clay was assumed to be in quartz.

Mineralogical components were calculated as follows:

(1) Fluorapatite (collophane) = 2.63 x wt. % P_2O_5.
(2) Muscovite-sericite-clay = 2.60 x wt. % Al_2O_3.
(3) Quartz = wt. % SiO_2 - (1.17 x wt. % Al_2O_3).

In our classification we make the same basic assumptions except that we assume that the fluorapatite contains 40 per cent P_2O_5 by weight. In addition we add a carbonate and an organic component. Calculations are based on the following formula:

(1) Quartz and muscovite-sericite-clay were calculated in a similar manner to that of Mabie and Hess.
(2) Fluorapatite = 2.5 x wt. % P_2O_5.
(3) Organic matter = 1.2 x wt. % C_{org} (from Gibson, 1975).
(4) Carbonate = 1.78 x [wt. % CaO_{Total} - (1.32 x wt. % P_2O_5)].

As with Mabie and Hess our classification does not account for minor amounts of feldspar or dolomite that may be present. Many of the phosphorites in the western United States contained fluorapatite with 39 to 40 per cent P_2O_5 by weight. For fluorapatite the ratio of 1.32/1 for CaO/P_2O_5 was used in calculating the amount of CaO required for fluorapatite.

APPENDIX 2
MAJOR OXIDES - KECHIKA AND ROAD RIVER FORMATIONS

Sample Number	Lab Number	Location	P_20_5	$Si0_2$	Ca0	Al_20_3	Fe_20_3	Na_20	Mg0	K_20	$Ti0_2$	Mn0	$C0_2$	Corg	F	H_20	S	L0I	Fe0	$\frac{Ca0}{P_20_5}$	$\frac{R_20_3^*}{P_20_5}$
(1)SB87 38(1)	34265	Mount Sheffield	0.31	68.6	11.24	3.94	1.55	0.09	1.6	0.99	0.29	0.01	11.15	1.02	0.97	0.25	0.16	10.78	1.07	–	–
(1)SB87 39	34266	Grey Peak	18.61	16.91	42.17	2.49	1.74	0.07	2.16	0.17	0.06	0.1	14	1.82	1.5	0.27	0.09	15	1.28	2.26	0.34
(2)SB87 39(1)	34267	Grey Peak	0.29	66.27	5.13	8.04	4.62	0.2	3.97	2.74	0.24	0.06	6.39	0.53	0.06	0.27	0.16	7.76	2.56	–	
(1)SB87 39(2)	34268	Grey Peak.18	50.77	14.6	10.45	3.5	1.18	2.63	2.19	0.35	0.08	11.65	0.3	0.06	0.22	0.04	13.86	2.71			
(2)SB87 39(4)	34269	Grey Peak	0.28	62.17	5.51	8.71	5.02	0.19	5.2	3.07	0.34	0.04	7.21	0.28	0.08	0.34	0.57	8.97	3.14	–	–
(2)SB87 39(5)	34270	Grey Peak	0.85	66.07	8.08	4.24	1.14	<0.10	5.27	1.9	0.22	0.01	12.1	0.52	0.15	0.39	0.03	12.64	0.64	–	–

(1) Kechika Formation

(2) Road River Formation

* $R_20_3 = Fe_20_3 + Al_20_3 + Mg0$

APPENDIX 3
MAJOR OXIDES - PERMIAN PHOSPHATES

Sample Number	Lab Number	Location	P_20_5	$Si0_2$	Ca0	Al_20_3	Fe_20_3	Na_20	Mg0	K_20	$Ti0_2$	Mn0	$C0_2$	Corg	F	H_20	S	L0I	Fe0	$\frac{Ca0}{P_20_5}$	$\frac{R_20_3^*}{P_20_5}$
(1)SBB86-8J	32980	Fernie Ski Hill	14.63	59.59	20.47	1.62	0.31	0.15	0.27	0.57	0.13	0.01	2.11	0.68	0.83	0.25	0.2	1.69	0.291	0.4	0.15
(1)SBB86 17	32982	Mt. Broadwood	1.65	79.14	5.57	1.99	0.55	0.17	2.63	0.7	0.18	0.02	7.96	0.74	0.16	0.23	0.18	6.7	0.293	0.38	3.13
(1)SBB86 41	32984	Cabin Creek	2.7	66.16	8.95	3.64	0.72	0.06	4.44	1.47	0.31	0.04	10.19	0.56	0.28	0.19	0.05	10.38	0.433	0.31	3.26
(1)SBB86 57	32985	Weigert Creek	14.71	16.88	43.65	1.57	0.25	0.31	0.66	0.15	0.06	0.04	27.35	1.2	1.11	0.24	0.28	21.26	0.292	0.96	0.17
(1)SBB86 62	32986	Forsyth Creek	3.21	61.92	12.85	1.48	0.69	0.05	5.83	0.47	0.11	0.13	14.05	1.18	0.29	0.32	0.16	13.07	0.254	0	2.49
(1)SBB86 71	32988	Crowsnest Pass	14.41	64.18	20.49	0.66	0.33	0.14	0.23	0.19	0.07	0.02	1.79	0.89	1.06	0.17	0.08	1.44	0.211	0.42	0.08
(1)SBB86 79(1)	32989	Nordstrom Creek	24.59	37.41	33.9	1.5	0.76	0.35	0.34	0.48	0.11	0.01	2.42	1.28	1.43	0.21	0.35	1.77	0.501	0.38	0.11
(1)SBB86 84	32990	MacDonald Fault	0.44	30.83	28.48	4.8	1.41	0.45	1.16	0.84	0.18	0.03	39.84	5.15	0.1	0.39	1.41	26.13	0.5	–	–
(2)SB87 G(1)	33510	Montana	34.3	9.05	44.9	0.52	0.05	0.05	0.28	0.1	0.02	0.02	1.44	0.39	>2.00	0.35	0.12	12.02	0.06	1.31	0.02
(2)SB87 G(2)	33511	Montana	33.7	8.74	47.41	2.03	1.1	0.1	0.35	0.39	0.07	0.02	2.2	0.6	>2.00	0.73	0.74	4.54	0.18	1.41	0.1
(3)SB87 37	34261	Richards Creek	0.04	95.62	0.12	1.48	0.5	<0.10	0.07	0.54	0.06	0	1.36	0.26	0.04	0.32	0.09	1.38	0.4	–	–
(4)SB87 45	34356	Alaska Highway	4.5	29.88	28.71	4.94	1.17	0.27	2.06	1.3	0.21	0.03	32.85	4.64	0.37	0.77	0.22	26.59	0.38	6.38	1.81

(1) Ishbel Group

(2) Phosphoria Formation

(3) Fantasque Formation (sample of chert) *$R_2O_3 = Al_2O_3 + Fe_2O_3 + MgO$

(4) Kindle Formation

APPENDIX 4

MAJOR OXIDES - TRIASSIC PHOSPHATES

(values in per cent)

Sample	Lab	Location	P_2O_5	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	TiO_2	MnO	CO_2	Corg	F	H_2O	S	LOI	FeO	CaO	R_2O_3*
SB87 6	33503	Meosin Mountain	23.64	2.49	48.94	0.37	0.12	0.27	0.54	0.13	0.02	0.03	32.7	5.85	72	0.47	0.54	20.04	0.3	1.71	0.03
SB87 7(4)	33504	Meosin Mountain	5.01	18.74	42.68	0.46	0.17	0.06	0.81	0.19	0.02	0.02	34.5	3.41	0.34	0.22	0.38	31.64	0.28	8.52	0.29
SB87 11(2)	33505	Wapiti Lake	26.39	15.98	44.54	1.15	0.33	0.34	0.65	0.35	0.07	0.03	11.1	2.22	72	0.53	0.33	9.81	0.28	1.69	0.08
SB87 12	33506	Wapiti Lake	28.3	11.63	47.13	0.66	0.16	0.19	0.66	0.18	0.04	0.03	12.2	2.74	72	0.48	0.35	9.83	0.22	1.66	0.05
SB87 15	33507	Mount Palsson	28.02	10.74	44.87	1.74	0.54	0.15	0.98	0.7	0.08	0.02	13.5	1.91	72	0.65	0.25	9.98	0.07	1.6	0.12
SB87 16(3)	33508	Lemoray	33.34	4.91	47.73	1.98	1.04	0.59	0.69	0.45	0.18	0.01	5.57	1.17	72	0.53	0.8	5.21	0.23	1.43	0.11
SB87 19	35502	Lemoray	0.38	86.96	4.07	1.49	0.48	0.02	0.5	0.3	0.07	0	7.66	1.23	0.06	0.32	0.28	5.87	0.24	–	–
SB87 19(1)	33509	Lemoray	1.11	68.91	11.64	2.55	0.72	0.32	0.39	0.46	0.11	0.01	15.1	2.03	0.18	0.45	0.39	12.09	0.24	10.49	3.3
SB87 32	34252	West Burnt River	0.51	25.15	30.79	3.69	0.94	0.45	2.94	1.23	0.18	0.03	45.7	7.01	0.07	0.22	0.91	33.4	0.64	–	–
SB87 32(1)	34253	West Burnt River	1.14	77.15	6.82	1.63	1.15	0.01	2.71	0.51	0.1	0.01	7.1	0.68	0.19	0.35	0.06	8.38	0.33	5.98	4.82
SB87 34	34255	Mount Ludington	0.31	50.39	16.47	6.99	1.75	1.11	2.82	1.84	0.42	0.03	20.06	2.01	0.06	0.26	0.27	17.67	0.86	–	–
SB87 34(2)	34256	Mount Ludington	8.37	29.32	30.1	4.18	0.81	0.49	2.04	1.03	0.2	0.03	27	6.16	0.49	0.3	0.13	23.3	0.57	3.6	0.84
SB87 35	34257	Mount Ludington	14.4	11.58	46.6	1.25	0.62	0.41	0.81	0.21	0.05	0.04	23.74	2.94	1.35	0.35	0.1	22.36	0.29	3.24	0.19
*SB87 36***	*34258*	*Laurier Pass North*	*0.08*	*59.49*	*10.02*	*9.35*	*1.84*	*1.03*	*1.34*	*2.44*	*0.53*	*0.03*	*18.16*	*2.9*	*0.07*	*0.6*	*0.11*	*13.21*	*0.96*	–	–
SB87 36(1)	34259	Laurier Pass North	7.26	29.25	30.75	4.86	0.77	0.49	1.47	1.29	0.23	0.02	31.3	4.46	0.62	0.8	0.05	23.95	0.43	4.23	0.43
SB87 36(2)	34260	Laurier Pass North	29.52	9.17	47.36	0.82	0.24	0.21	0.55	0.12	0.03	0.03	0.14	4.69	72	0.68	0.3	11.39	0.29	1.6	0.05
SB87 37(1)	34262	Richards Creek	0.87	47.35	12.75	8.09	6.14	0.84	3.94	1.96	0.49	0.09	18.69	1.29	0.11	0.32	1.17	16.35	2.92	–	–
SB87 37(2)	34263	Richards Creek	4.62	46.53	19.55	6.05	1.31	0.62	2.24	1.52	0.34	0.02	20.87	3.55	0.41	0.5	0.46	16.6	0.57	4.23	2.07
SB87 37(4)	34264	Richards Creek	5.31	19.2	38.53	2.06	0.37	0.08	1.15	0.54	0.08	0.02	38.32	7.64	0.49	0.66	0.55	32.81	0.21	7.26	0.67
SB87 40	34271	Alaska Highway	12.12	26.63	39.48	0.91	0.26	0.05	0.96	0.4	0.05	0.02	22.15	2.1	1.02	0.21	0.24	20.14	0.4	–	–
SB87 43	34272	Alaska Highway	10.4	15.77	45.07	0.75	0.53	0.09	0.88	0.23	0.03	0.02	23.26	2.36	0.96	0.25	0.32	26.19	0.16	4.33	0.2
SB87 43(1)	34273	Alaska Highway	9.98	39.85	31.16	1.77	0.41	0.12	1.43	0.45	0.08	0.01	17.39	0.8	0.83	0.18	0.36	16.3	0.24	–	–

* $R_2O_3 = Al_2O_3 + Fe_2O_3 = MgO$

** Phosphate nodules

APPENDIX 5

MAJOR OXIDES - FERNIE PHOSPHATE (JURASSIC)

Sample Number	Lab Number	Location	P_2O_5	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	TiO_2	MnO	CO_2	Corg	F	H_2O	S	LOI	FeO	$\frac{CaO}{P_2O_5}$	$\frac{R_2O_3}{P_2O_5}$
Liz	32976	Lizard	24.71	10.16	47.78	1.04	0.25	0.62	0.65	0.05	0.04	0.02	21.22	1.88	1.44	0.29	0.54	14.09	0.43	1.93	0.08
SBB86 3	32977	Highway 3	27.28	16.49	43.13	1.91	0.29	0.43	1.38	0.34	0.09	0.02	15.81	2.22	2.09	0.29	0.38	8.68	0.36	1.58	0.13
SBB86 4	32978	Crow	22.33	19.64	41.07	1.9	0.34	0.4	1.47	0.33	0.09	0.03	16.45	1.63	1.23	0.44	0.16	11.97	0.29	1.83	0.17
SBB86 6	32979	Fording River	13.41	16.66	39.29	1.99	0.44	0.44	0.94	0.2	0.08	0.03	30.27	2.91	0.85	0.3	0.57	21.15	0.36	2.92	0.25
SBB86 11	33276	Island Lake	12.16	23.71	38.01	1.11	0.43	0.26	0.67	0.12	0.07	0.07	24.29	1.62	1.1	0.21	0.49	20.87	0.24	3.12	0.18
SBB86 13D	32981	Abby	23.19	35.06	34.11	1.69	0.42	0.39	0.43	0.38	0.07	0.02	7.64	1.53	1.38	0.42	0.31	4.71	0.33	1.47	0.11
SBB86 15	33277	Zip	31.08	14.03	40.94	3.12	0.83	0.17	0.58	1.31	0.17	0.04	5.06	1.04	2	0.63	0.16	3.93	0.22	1.32	0.15
SBB86 22	33282	Harriet Lake	3.89	70.23	5.69	8.62	2.29	2.4	0.58	0.54	0.36	0.03	2.38	0.56	0.38	0.5	0.24	3.39	0.8	1.46	2.95
SBB86 37	33278	Cabin Creek	32.01	12.26	41.38	1.9	1.03	0.09	0.43	0.79	0.12	0.05	10.76	2.67	2	0.45	0.59	5.52	0.5	1.29	0.1
SBB86 38	33279	Cabin Creek	25.27	20.76	36.75	2.62	1.01	0.12	0.78	0.95	0.16	0.04	13.45	2.59	1.95	0.4	0.59	7.57	0.28	1.45	0.17
SBB86 40	32983	Cabin Creek	7.29	74.65	10.22	2.49	1.18	0.22	0.32	0.87	0.41	0.03	2.36	0.5	0.6	0.2	0.19	2.04	0.29	1.4	0.55
SBB86 42	33280	Bighorn	18.79	45.4	26.44	2.82	1.21	0.09	0.35	1.19	0.35	0.03	3.67	0.68	1.75	0.27	0.41	2.85	0.36	1.41	0.23
SBB86 52	33283	Storm Creek	26.96	14.34	40.29	2.96	1.01	0.06	0.66	0.9	0.12	0.05	13.65	2.13	2	0.25	0.88	8.19	0.26	1.49	0.17
SBB86 54	33284	Cabin Creek	3.49	81.9	5.13	3.48	1.27	0.26	0.49	1.16	0.41	0.04	2.17	0.52	0.43	0.23	0.28	2.26	0.19	1.47	1.5
SBB86 70	32987	Line Creek	28.43	20.51	38.33	3.59	0.88	0.31	0.58	1.3	0.19	0.02	8.03	2.4	1.69	0.8	0.32	5.37	0.36	1.35	0.18
SBB86 86	33281	Lodge	27.34	21.55	36.89	4.13	1.19	0.1	0.65	1.38	0.2	0.04	6.11	1.17	2	0.62	0.18	4.59	0.28	1.35	0.22
Average			*20.48*	*31.08*	*32.67*	*2.63*	*0.88*	*0.4*	*0.68*	*0.74*	*0.16*	*0.04*	11.46	1.63	1.43	*0.39*	*0.39*	*7.95*	*0.35*	*1.67*	*0.44*

*$R_2O_3 = Al_2O_3 + Fe_2O_3 + MgO$

APPENDIX 6
TRACE ELEMENTS - KECHIKA AND ROAD RIVER FORMATIONS

Sample	C1	Ni	Cr	Sr	Rb	Y	As	Ba	Au	Ag	Zn	Cu	Pb	Mo	Cd	U	Th	Se	La	Ce	V	Sc
Number	%	(		ppm				)	(ppb)	(					ppm							)
(1)SB87 38(1)	<0.01	12	35	221	26	14	5	1486	<20	1	59	35	5	47	<1	24	<5	2	26	35	57	10.4
(1)SB87 39	<0.01	36	21	1087	18	82	21.2	200	<20	<0.5	200	14	13	8	19	65	27	<1	66	155	64	36.0
(2)SB87 39(1)	<0.01	20	31	137	59	19	4.5	805	<20	<0.5	87	11	10	<8	<1	28	<5	<1	38	72	42	06.1
(1)SB87 39(2)	<0.01	16	49	425	74	20	2.3	415	<20	<0.5	47	16	13	<8	<1	37	47	<1	357	92	46	16.3
(2)SB87 39(4)	<0.01	27	44	150	66	18	8.1	1120	<20	0.8	69	13	12	<8	<1	28	13	2	49	73	37	07.7
(2)SB87 39(5)	<0.01	24	N/A	N/A	N/A	N/A	5.9	237	<20	<0.5	8	49	5	<8	1	N/A	N/A	4	356	81	321	08.2
(1)Average	<0.01	21	35	578	39	39	9.5	700	<20	<0.5	102	22	10	20	<1	42	26	1	150	94	56	20.9
(2)Average	<0.01	24	38	144	19	19	6.2	721	<20	<0.5	55	24	9	<8	<1	28	9	2	148	75	135	07.3

(1) Kechika Fm.
(2) Road River Fm.
N/A - Not analyzed

APPENDIX 7
TRACE ELEMENTS - PERMIAN PHOSPHATES

Sample	C1	Ni	Cr	Sr	Rb	Y	As	Ba	Au	Ag	Zn	Cu	Pb	Mo	Cd	U	Th	Se	La	Ce	V	Ti	Sc
Number	%	(		ppm				)	(ppb)	(					ppm								)
SBB86 8J		35	120	199	<7	136	<1.0	155	<20	<0.5	17	13	8	7	<1	23	<6	3.1	113	60	93	946	16.3
SBB86 17		28	17	78	<7	46	1.5	133	<20	<0.5	273	11	5	<5	3	4	<6	3.7	28	27	20	1238	3.2
SBB86 41		27	82	107	<7	66	5.4	211	<20	<0.5	117	10	7	<5	1	4	7	<1.0	84	65	84	2197	7.2
SBB86 57		41	21	1084	<7	646	1	157	<20	<0.5	85	28	12	<5	1	39	<6	2.1	235	160	38	551	39
SBB86 62		23	93	104	<7	77	6.3	164	<20	<0.5	150	12	4	<5	1	23	8	3.1	38	23	87	741	10.5
SBB86 71		35	58	170	<7	250	<1.0	<56	<20	<0.5	21	13	10	<5	<1	88	8	1.5	64	90	80	478	14
SBB86 79(1)		27	132	458	<7	215	1.5	121	<20	<0.5	53	20	14	<5	<1	103	9	4.7	133	90	210	860	25.5
SBB86 84		100	21	1169	27	39	10.2	326	44	<0.5	120	68	13	46	1	8	11	6.1	33	27	171	1510	28.2
Average		40	53	396	4	184	3	165	6	<0.5	104	22	9	7	1.5	37	6.5	3.1	91	68	98	1065	18
*SB87 G(1)		3	NA	641	NA	236	<40	204	<20	0.5	51	11	153	<5	1	24	78	1	131	<13	181	187	43.6
*SB87 G(2)		14	NA	1259	NA	895	<40	582	<20	1.2	216	21	26	23	2	155	14	23	476	78	279	603	46.6
SB87 37		14	50	40	3	2	42	375	<20	<0.5	35	10	7	<8	NA	27	25	9	18	23	17	NA	0.4
SB87 45		NA	NA	1343	NA	45	NA	2718	<20	1	2.7	39	15	10	13	33	20	27	<10	<10	940	NA	NA

* Sample from the Phosphoria Formation at Warm Springs, Montana
NA - Not analyzed

APPENDIX 8
TRACE ELEMENTS - TRIASSIC PHOSPHATES

Sample	C1	Ni	Cr	Sr	Rb	Y	As	Ba	Au	Ag	Zn	Cu	Pb	Mo	Cd	U	Th	Se	La	Ce	V	Ti	Sb	Sc
Number	%	(			ppm			)	ppb	(		ppm			)									
(1)SB87 6	<0.01	42	ND	655		138	<40	310	<20	0.6	1300	13	11	<5	42	116	12	6	13	<13	469	-	24	42.7
(1)SB87-7(4)	0.02	70	ND	357		71	<40	544	<20	0.7	758	25	15	<5	16	55	9	13	5	<13	532	212	<10	37.2
(1)SB87 11(2)	<0.01	25	ND	435		329	<40	94	<20	<0.5	280	14	14	<5	17	145	2	7	94	47	317	597	<10	37.5
(1)SB87 12	<0.01	15	ND	516		462	<40	52	<20	<0.5	552	15	14	<5	28	193	26	5	167	69	287	333	<10	40.8
(1)SB87 15	<0.01	36	ND	636		248	<40	141	<20	0.7	2900	48	14	10	91	98	9	16	82	44	445	693	14	38.9
(3)SB87 16(3)	<0.01	61	ND	2601		498	<40	339	<20	1.2	333	27	17	10	7	139	26	9	84	17	114	1535	<10	42.4
(2)SB87 19	<0.01	30	74	168	2	24	6	328	<20	<0.5	83	20	11	<5	3	22	7	16	33	23	80	NA	NA	3.2
(2)SB87 19(1)	<0.01	40	84	385	8	5	<40	576	<20	0.5	191	60	10	7	2	N/D	N/D	20	<7	12	198	756	<10	12.3
(2)SB87-32	<0.01	130	167	382	41	41	20	152	<20	<0.5	1500	56	12	7	26	51	39	22	22	31	1620	NA	NA	26.9
(2)SB87 32(1)	<0.01	22	128	106	6	49	4.5	176	<20	<0.5	98	9	7	4	2	29	<5	10	59	44	41	NA	NA	5
(2)SB87 34	<0.01	45	115	220	46	18	17.6	342	<20	<0.5	48	32	15	9	1	29	20	55	31	37	438	NA	NA	16.9
(2)SB87 34(2)	<0.01	76	220	663	41	42	8.1	2929	<20	3	92	49	12	7	1	54	36	32	33	26	474	NA	NA	27.2
(2)SB87 35	<0.01	17	59	676	19	17	5	61	<20	<0.5	27	10	5	3	<1	42	42	5	3	N/D	52	NA	NA	36.1
(2)SB87 36	<0.01	48	128	399	79	16	28.4	1393	<20	2	4700	62	13	34	67	30	34	24	38	218	2448	NA	NA	39.2
(2)SB87 36(1)	<0.01	72	225	778	41	42	7.1	1460	<20	2	30	45	12	30	3	35	14	30	25	129	1026	NA	NA	72
(2)SB87 36(2)	0.02	50	47	1709	27	108	4	746	<20	<0.5	627	26	3	8	10	26	N/D	11	31	52	215	NA	NA	43.3
(2)SB87 37(1)	<0.01	29	84	165	49	31	20	418	<20	2	29	35	13	<8	<1	23	<5	21	40	61	199	NA	NA	15
(2)SB87 37(2)	<0.01	52	81	427	43	64	9	870	<20	1	253	39	12	<8	<1	32	12	6	61	64	107	NA	NA	19
(2)SB87 37(4)	<0.01	54	178	1284	43	90	10.2	600	<20	1	277	24	7	8	19	57	57	12	255	16	1819	NA	NA	33.6
(2)SB87 40	<0.01	24	32	664	14	88	5.4	910	<20	<0.5	172	15	<3	<8	5	52	28	2	<10	<10	63	NA	NA	NA
(2)SB87 43	<0.01	35	46	1653	34	142	11.9	400	<20	<0.5	255	18	5	21	3	61	46	12	304	3	405	NA	NA	37.8
(2)SB87 43(1)	<0.01	19	88	1323	19	133	9.3	564	<20	1	182	19	10	<8	6	49	23	9	<10	<10	257	NA	NA	NA
Average	<0.01	45	110	736	32	121	13.9	609	<20	0.9	667	30	11	9	15	64	23	16	64	42	528			31.4

(1)Whistler Member: Sulphur Mountain Formation
(2)Toad Formation
(3)Triassic - Formation Uncertain
NA - Not Analyzed
N/D - Not Detected

APPENDIX 9
TRACE ELEMENTS - FERNIE PHOSPHATE (JURASSIC)

Sample	Ni	Cr	Sr	Rb	Y	As	Ba	Au	Ag	Zn	Cu	Pb	Mo	Cd	U	Th	Se	La	Ce	V	Ti	Sc
Number	(			ppm			)	ppb	(						ppm							)
Liz	29	22	843	<7	516	1.3	119	<20	<0.5	75	31	4	7	1	42	15	2.3	216	122	35	461	46
SBB86 3	51	31	1534	<7	351	1	676	<20	<0.5	58	43	6	7	1	33	<6	1.3	108	91	45	912	47
SBB86 4	35	40	1270	<7	326	3.9	747	<20	<0.5	55	43	10	10	1	28	<6	1.5	141	100	49	895	46
SBB86 6	50	23	1354	9	320	4.4	911	<20	<0.5	75	28	8	5	1	35	<6	1.9	143	91	70	733	50.4
SBB86 11	18	N/A	893	N/A	240	<30	394	<20	0.4	12	24	13	<5	<0.2	7	2	4	110	61	40	611	N/A
SBB86 13D	31	29	914	<7	312	1.5	706	<20	<0.5	70	47	2	5	<1	37	8	1.1	118	67	27	554	38
SBB86 15	30	N/A	645	N/A	946	<30	292	46	0.5	120	49	19	<5	1.8	48	<6	4	383	233	127	1394	N/A
SBB86 22	20	N/A	321	N/A	106	<30	1063	<20	0.4	48	17	33	<5	<0.2	1	14	3	91	156	44	2270	N/A
SBB86 37	38	N/A	878	N/A	590	<30	179	<20	0.5	63	51	14	<5	<0.2	37	<6	4	201	115	58	977	N/A
SBB86 38	67	N/A	829	N/A	767	<30	336	<20	0.5	115	40	10	<5	1.3	38	<6	6	303	168	94	1289	N/A
SBB86 40	83	124	184	<7	232	19.8	342	<20	<0.5	84	25	10	16	1	27	<6	1.5	84	65	100	2881	13.7
SBB86 42	45	N/A	490	N/A	592	<30	959	<20	0.3	86	33	18	<5	1	37	5	5	247	161	97	2502	N/A
SBB86 52	95	N/A	822	N/A	856	<30	423	<20	0.4	193	46	19	<5	2.2	75	3	7	372	235	24	986	N/A
SBB86 54	39	N/A	107	N/A	178	<30	303	<20	<0.3	38	12	11	<5	0.7	3	6	3	87	91	43	2678	N/A
SBB86 70	18	77	581	20	515	3.9	154	<20	<0.5	190	66	13	<5	<1	29	<6	1	180	105	60	1619	48
SBB86 86	19	N/A	897	N/A	840	<30	344	<20	0.6	86	29	18	<5	1.7	51	15	4	335	222	101	1384	N/A
Average		42	--	785	480	<30	497	<20	<0.5	86	37	13	<5	0.9	33	6	3.2	195	130	63	1384	--

N/A - Not Analyzed

APPENDIX 10
SAMPLE LOCATIONS AND RESULTS FROM SOUTHEASTERN BRITISH COLUMBIA

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86 1A	31768	49°30'40"	115°05'30"	Jurassic	Fernie	0.7	0.59	12	6	48
SBB86 1B	31769	49°30'40"	115°05'30"	Jurassic	Fernie	1.0	0.75	10	5	51
SBB86 1C	31770	49°30'40"	115°05'30"	Jurassic	Fernie	0.7	0.7	9	8	39
SBB86 1D	31771	49°30'40"	115°05'30"	Jurassic	Fernie	0.7	0.66	8	9	135
SBB86 2A	31772	49°31'02"	115°06'00"	Permian	Ranger Canyon	0.4	0.53	6	4	69
SBB86 3A	31773	49°39'15"	114°44'10"	Triassic	Sulphur Mountain	0.7	0.33	14	18	150
SBB86 3B	31774	49°39'15"	114°44'10"	Jurassic	Fernie	0.5	21.3	38	22	639
SBB86 3C	31775	49°39'15"	114°44'10"	Jurassic	Fernie	0.7	9.05	41	19	118
SBB86 3D	31776	49°39'15"	114°44'10"	Jurassic	Fernie	0.7	2.07	12	12	24
SBB86 3E	31777	49°39'15"	114°44'10"	Jurassic	Fernie	1.2	4.13	59	22	252
SBB86 4A	31778	49°39'45"	114°42'30"	Jurassic	Fernie	1	26.6	44	20	126
SBB86 4B	31779	49°39'45"	114°42'30"	Jurassic	Fernie	1	26.6	41	22	180
SBB86 4C	31780	49°39'45"	114°42'30"	Jurassic	Fernie	1	25.7	40	27	241
SBB86 4D	31781	49°39'45"	114°42'30"	Jurassic	Fernie	1	25.1	40	25	175
SBB86 4E	31782	49°39'45"	114°42'30"	Jurassic	Fernie	0.7	27	40	22	108
SBB86 6A	31783	49°54'20"	114°50'55"	Jurassic	Fernie	0.4	22.7	41	17	75
SBB86 6B	31784	49°54'20"	114°50'55"	Jurassic	Fernie	0.4	15.5	37	26	105
SBB86 6C	31785	49°54'20"	114°50'55"	Jurassic	Fernie	0.5	6.05	44	14	91
SBB86 6D	31786	49°54'20"	114°50'55"	Jurassic	Fernie	0.24	7.88	38	12	156
SBB86 6E	31787	49°54'20"	114°50'55"	Jurassic	Fernie	0.6	4.18	36	12	141
SBB86 6F	31788	49°54'20"	114°50'55"	Jurassic	Fernie	0.4	1.92	24	8	57
SBB86 6G	31789	49°54'20"	114°50'55"	Jurassic	Fernie	0.6	1.3	16	9	84
SBB86 6H	31790	49°54'20'	114°50'55"	Jurassic	Fernie	1	0.61	67	22	208
SBB86 7B	31921	49°53'20"	114°57'00"	Permian	Ranger Canyon	grab	0.69	8	8	18

*P_2O_5 Analyses done by XRF
Error ± 1% Absolute for values
Remaining P_2O_5 samples analyzed by volumetric method

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SB86 8A	31922	49°27'40"	115°06'30"	Permian	Johnston Canyon	0.9	1.53	6	12	159
SB86 8B	31923	49°27'40"	115°06'30"	Permian	Johnston Canyon	0.5	1.65	13	25	300
SB86 8C	31924	49°27'40"	115°06'30"	Permian	Johnston Canyon	0.6	1.04	11	64	330
SB86 8E	31925	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.5	0.64	43	14	366
SB86 8F	31926	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.5	0.19	17	14	186
SB86 8H	31927	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.3	0.08	6	12	133
SB86 8K	31928	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.5	13.3	12	11	24
SB86 8L	31929	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.7	2.38	5	8	24
SB86 9A	31930	49°32'02"	115°04'55"	Permian	Ranger Canyon	1	1.77	9	24	59
SB86 9B	31931	49°32'02"	115°04'55"	Permian	Ranger Canyon	1	0.92	6	11	54
SB86 9C	31932	49°32'02"	115°04'55"	Permian	Ranger Canyon	1	0.29	11	13	108
SB86 9D	31933	49°32'02"	115°04'55"	Permian	Ranger Canyon	1	0.35	10	9	120
SB86 10A	31934	49°31'40"	115°10'40"	Jurassic	Fernie	grab	13.2	28	17	117
SB86 11A	31935	49°31'50"	115°10'45"	Jurassic	Fernie	grab	15.4	25	20	69
SB86 12	31936	49°58'50"	114°48'40"	Jurassic	Fernie	grab	0.1	36	20	24
SB86 13A	31937	50°18'25"	114°56'05"	Jurassic	Fernie	0.35	7.43	26	14	39
SB86 13B	31938	50°18'25"	114°56'05"	Jurassic	Fernie	1.5	21.7	46	19	60
SB86 13C	31939	50°18'25"	114°56'05"	Jurassic	Fernie	1	29.4	35	20	72
SB86 14A	31940	50°12'00"	115°00'00"	Jurassic	Fernie	1.04	11.8	31	14	77
SB86 14B	31941	50°12'00"	115°00'00"	Jurassic	Fernie	0.65	1.48	28	15	66
SB86 14C	31942	50°12'00"	115°00'00"	Jurassic	Fernie	0.85	1.79	28	10	60
SB86 14D	31943	50°12'00"	115°00'00"	Jurassic	Fernie	1	0.16	54	17	78
SB86 15A	31944	49°16'05"	114°36'00"	Jurassic	Fernie	0.7	23.9	43	23	108
SB86 15B	31945	49°16'05"	114°36'00"	Jurassic	Fernie	0.7	27.1	40	27	121
SB86 15C	31946	49°16'05"	114°36'00"	Jurassic	Fernie	1.3	8.46	31	13	103
SB86 15D	31947	49°16'05"	114°36'00"	Jurassic	Fernie	0.7	27.1	40	27	121

*P_20_5 Analyses done by XRF

Error ± 1% Absolute for values

Remaining P_20_5 samples analyzed by volumetric method

Sample Number	Lab No.	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86 17A	31948	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.3	0.52	13	10	15
SBB86 17B	31949	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	0.2*	11	16	60
SBB86 17C	31950	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	0.66	13	11	105
SBB86 17D	31951	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	0.35	23	14	216
SBB86 17E	31952	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	1.72	15	12	360
SBB86 17F	31953	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	1.49	18	17	204
SBB86 17G	31954	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	0.67	19	17	264
SBB86 17H	31955	49°18'00"	114°56'55"	Permian	Johnson Canyon	1.4	1.11	16	10	132
SBB86 17I	31956	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.6	2.66	13	11	96
SBB86 17J	31957	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.8	0.67	12	15	84
SBB86 17K	31958	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	2.38	11	12	138
SBB86 17L	31959	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.4	1.33	21	14	312
SBB86 17M	31960	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	0.58	13	13	48
SBB86 17N	31961	49°18'00"	114°56'55"	Permian	Johnson Cnyon	1	1.56	15	13	201
SBB86 17O	31962	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.8	1.19	18	13	186
SBB86 17P	31963	49°18'00"	114°56'55"	Permian	Johnson Canyon	1	2.52	12	17	57
SBB86 17Q	31964	49°18'00"	114°56'55"	Permian	Johnson Canyon	2	0.49	20	14	336
SBB86 17R	31965	49°18'00"	114°56'55"	Permian	Johnson Canyon	3	0.28	20	15	258
SBB86 17S	31966	49°18'00"	114°56'55"	Permian	Johnson Canyon	0.2	4.58	9	22	80
SBB86 20	31967	49°51'00"	114°43'40"	Jurassic	Fernie	grab	27.4	30	23	48
SBB86 20A	31968	49°51'00"	114°43'40"	Jurassic	Fernie	0.3	29.4	29	28	45
SBB86 21A	31969	49°51'55"	114°47'10"	Permian	Johnson Canyon	grab	13.8	10	15	183
SBB86 21B	31970	49°51'55"	114°47'10"	Permian	Johnson Canyon	0.7	0.7*	8	8	19
SBB86 22A	31971	49°52'20"	114°46'40"	Jurassic	Fernie	0.55	2.7*	13	32	42
SBB86 24	31972	49°18'50	114°55'30"	Jurassic	Fernie	0.12	14.3	19	24	222

*P_20_5 Analyses done by XRF
Error ±+A118 1% Absolute for values
Remaining P_20_5 samples analyzed by volumetric method

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86 27A	31973	49°06'20"	114°40'45"	Permian	Ranger Canyon	1	1.1*	10	8	18
SBB86 27B	31974	49°06'20"	114°40'45"	Permian	Ranger Canyon	1	1.3*	14	7	33
SBB86 28	31975	49°05'03"	114°39'30"	Jurassic	Fernie	2	13.7	64	22	195
SBB86 29A	31976	50°07'00"	114°45'30"	Permian	?	grab	2.1*	7	15	24
SBB86 30	31977	49°39'05"	114°44'00"	Jurassic	Fernie	grab	0.4*	13	31	525
SBB86 31A	31978	49°39'10"	114°44'00"	Jurassic	Fernie	1	23.8	38	20	714
SBB86 31B	31979	49°39'10"	114°44'00"	Jurassic	Fernie	1	8.8	35	15	140
SBB86 31C	31980	49°39'10"	114°44'00"	Jurassic	Fernie	0.6	7.9	32	20	80
SBB86 31D	31981	49°39'10"	114°44'00"	Jurassic	Fernie	2	0.4*	46	26	246
SBB86 36A	31982	49°27'30"	114°41'40"	Permian	Johnston Canyon	grab	1.7*	5	8	24
SBB86 37A	31983	49°27'10"	114°41'50"	Jurassic	Fernie	0.8	22.4	45	22	144
SBB86 38A	31984	49°06'40"	114°40'45"	Jurassic	Fernie	1	18	37	25	204
SBB86 38B	31985	49°06'40"	114°40'45"	Jurassic	Fernie	0.2	2.4*	65	20	585
SBB86 38C	31986	49°06'40"	114°40'45"	Jurassic	Fernie	0.6	9.99	250	41	1500
SBB86 38D	31987	49°06'40"	114°40'45"	Jurassic	Fernie	1.5	0.3*	73	23	204
SBB86 40A	32346	49°09'30"	114°46'00"	Jurassic	Fernie	1.2	15.7	28	13	134
SBB86 41A	32347	49°09'00"	114°46'20"	Permian	Johnston Canyon	1	1.6*	4	10	47
SBB86 41B	32348	49°09'00"	114°46'20"	Permian	Johnston Canyon	1	0.3*	5	109	65
SBB86 41C	32349	49°09'00"	114°46'20"	Permian	Johnston Canyon	1.5	1.1*	6	9	114
SBB86 41D	32350	49°09'00"	114°46'20"	Permian	Johnston Canyon	1.5	1.8*	4	10	140
SBB86 42A	32351	49°09'30"	114°46'15"	Jurassic	Fernie	1	18.4	28	11	91
SBB86 42B	32352	49°09'30"	114°46'15"	Jurassic	Fernie	1	18.6	25	23	62
SBB86 43A	32353	49°05'20"	114°36'05"	Jurassic	Fernie	1	22.2	40	20	175
SBB86 44A	32354	49°05'05"	114°39'20"	Jurassic	Fernie	1	27.5	31	16	110
SBB86 47A	32355	49°06'20"	114°42'45"	Jurassic	Fernie	1	9.51	46	14	141
SBB86 47B	32356	49°06'20"	114°42'45"	Jurassic	Fernie	1	0.4*	61	16	91
SBB86 47C	32357	49°06'20"	114°42'45"	Jurassic	Fernie	1	0.4*	62	34	167
SBB86 47D	32358	49°06'20"	114°42'45"	Jurassic	Fernie	1	0.2*	54	16	189
SBB86 47E	32359	49°06'20"	114°42'45"	Jurassic	Fernie	1	0.4*	59	14	257

*P_2O_5 Analyses done by XRF
Error ± Absolute for values
Remaining P_2O_5 samples analyzed by volumetric method

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86 48A	32360	49°09'50"	114°40'45"	Jurassic	Fernie	grab	29.2	41	14	128
SBB86 50A	32361	49°06'45"	114°40'50"	Permian	Ranger Canyon	1	0.8*	3	8	45
SBB86 52A	32362	49°06'55"	114°40'10"	Jurassic	Fernie	1.0	14	30	15	115
SBB86 53	32363	49°05'40"	114°41'00"	Jurassic	Fernie	0.7	0.2*	72	17	138
SBB86 54A	32364	49°05'45"	114°41'00"	Jurassic	Fernie	grab	17.6	37	13	160
SBB86 57A	32365	49°57'45"	114°56'25"	Permian	Johnston Canyon	grab	15.8	27	10	94
SBB86 58A	32366	49°57'40"	114°56'35"	Permian	Johnston Canyon	1	15.4	28	10	118
SBB86 58B	32367	49°57'40"	114°56'35"	Permian	Johnston Canyon	1	13.1	30	11	118
SBB86 61A	32368	49°41'40"	114°56'10"	Permian	grab	4.2*	3	8	102	
SBB86 62A	32370	50°17'50"	115°02'45"	Permian	Ranger Canyon	1	1.6*	6	7	216
SBB86 62B	32371	50°17'50"	115°02'45"	Permian	Ross Creek	1	0.8*	5	6	75
SBB86 62C	32372	50°17'50"	115°02'45"	Permian	Ross Creek	1	0.8*	5	5	50
SBB86 62D	32373	50°17'50"	115°02'45"	Permian	Ross Creek	1	0.4*	5	7	54
SBB86 62E	32374	50°17'50"	115°02'45"	Permian	Ross Creek	1	2*	12	12	261
SBB86 62F	32375	50°17'50"	115°02'45"	Permian	Ross Creek	1	1.7*	8	10	187
SBB86 62G	32376	50°17'50"	115°02'45"	Permian	Ross Creek	1	0.8*	9	10	65
SBB86 62I	32369	50°17'50"	115°02'45"	Permian	Ranger Canyon	grab	25.8	12	9	106
SBB86 63A	32377	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.5	18.6	9	7	159
SBB86 63B	32378	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.3	0.2*	9	5	35
SBB86 63C	32379	50°18'10"	115°02'45"	Permian	Ranger Canyon	1.3	3.8*	10	23	160
SBB86 63D	32380	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.9	3.1*	7	10	30
SBB86 63E	32381	50°18'10"	115°02'45"	Permian	Ranger Canyon	1.25	0.2*	8	10	77
SBB86 63F	32382	50°18'10"	115°02'45"	Permian	Ranger Canyon	1.25	<0.1*	5	6	75
SBB86 63G	32383	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.9	<0.1*	2	7	50
SBB86 63H	32384	50°18'10"	115°02'45"	Permian	Ranger Canyon	1.3	0.3*	5	9	120
SBB86 63I	32385	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.9	<0.1*	4	5	86
SBB86 63J	32386	50°18'10"	115°02'45"	Permian	Ranger Canyon	0.7	<0.1*	11	8	183
SBB86 63K	32387	50°18'10"	115°02'45"	Permian	Ranger Canyon	1	<0.1*	9	8	102
SBB86 63L	32388	50°18'10"	115°02'45"	Permian	Ranger Canyon	1.3	<0.1*	10	9	112

*P_20_5 Analyses done by XRF
Error ±+A192 1% Absolute for values
Remaining P_20_5 samples analyzed by volumetric method

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86 65A	32389	50°19'20"	115°02'50"	Permian	Ranger Canyon	1	3*	8	9	55
SBB86 66A	32390	49°48'05"	115°03'00"	Permian	Telford	grab	11.4	6	9	19
SBB86 70A	32391	49°58'00"	114°48'10"	Jurassic	Fernie	1	23.2	73	16	272
SBB86 70B	32392	49°58'00"	114°48'10"	Jurassic	Fernie	1	22.7	50	17	165
SBB86 70C	32393	49°58'00"	114°48'10"	Jurassic	Fernie	0.9	13.4	53	11	137
SBB86 70D	32394	49°58'00"	114°48'10"	Jurassic	Fernie	1	5.45	61	14	141
SBB86 70E	32395	49°58°00"	114°48'10"	Jurassic	Fernie	1	3.56	38	8	144
SBB86 71A	32396	49°39'10"	114°42'30"	Permian		grab	14.5	6	7	54
SBB86 71B	32397	49°39'10"	114°42'30"	Permian		grab	25.7	5	11	132
SBB86 72A	32398	49°44'25"	115°02'50"	Permian	Ross Creek	0.9	0.9*	16	10	195
SBB86 73A	32399	49°44'20"	115°03'00"	Permian	Ross Creek	grab	0.5*	34	11	428
SBB86 74A	32400	49°36'05"	115°04'30"	Jurassic	Fernie	0.5	21.5	40	11	136
SBB86 76A	32401	49°19'50"	114°57'00"	Jurassic	Fernie	1	<0.1*	10	20	58
SBB86 76B	32402	49°19'50"	114°57'00"	Jurassic	Fernie	1	<0.1*	10	20	56
SBB86 76C	32403	49°19'50"	114°57'00"	Jurassic	Fernie	0.3	<0.1*	14	22	59
SBB86 76D	32404	49°19'50"	114°57'00"	Jurassic	Fernie	1	<0.1*	13	22	60
SBB86 76E	32405	49°19'50"	114°57'00"	Jurassic	Fernie	1	<0.1*	11	20	60
SBB86 76F	32406	49°19'50"	114°57'00"	Jurassic	Fernie	0.8	0.5*	9	20	55
SBB86 77A	32407	49°37'20"	114°39'30"	Mississippian	Exshaw	0.5	0.7*	85	22	533
SBB86 77B	32408	49°37'20"	114°39'30	Mississippian	Exshaw	0.9	0.2*	50	18	340
SBB86 77C	32409	49°37'20"	114°39'30"	Mississippian	Exshaw	0.7	0.9*	24	10	59
SBB86 77D	32410	49°37'20"	114°39'30"	Mississippian	Exshaw	0.5	0.8*	30	10	78
SBB86 77E	32411	49°37'20"	114°39'30"	Mississippian	Exshaw	1.5	3.6*	58	12	236
SBB86 78A	32412	49°51'45"	114°59'50"	Permian	Ross Creek	grab	0.1*	24	12	43
SBB86 79A	32413	49°51'50"	114°59'55"	Permian	Johnston Canyon	1.0	21.2	9	12	54
SBB86 79B	32414	49°51'50"	114°59'55"	Permian	Johnston Canyon	0.5	1.5*	6	12	31
SBB86 80A	32415	50°01'30"	114°57'30"	Permian	Ross Creek	0.5	2.9*	41	7	152
SBB86 80B	32416	50°01'30"	114°57'30"	Permian	Ross Creek	0.4	5.93	13	16	78
SBB86 83A	32417	49°10'30"	114°49'10"	Pennsylvanian	Kananaskis	grab	1.3*	10	10	20
SBB86 84A	32418	49°10'30"	114°49'05"	Permian	Johnston Canyon	0.25	40*	6	13	28
SBB86 84B	32419	49°10'30"	114°49'05"	Permian	Johnston Canyon	1	3.2*	50	11	133
SBB86 84C	32420	49°10"30"	114°49'05"	Permian	Johnston Canyon	0.4	11.7	43	14	465
SBB86 84D	32421	49°10'30"	114°49'05"	Permian	Johnston Canyon	1	1.1*	103	23	1300
SBB86 85A	32422	49°10'00"	114°47'00"	Permian	Ranger Canyon	0.6	9.58	8	10	56
SBB86 86A	32423	49°16'50"	114°47'40"	Jurassic	Fernie	grab	29.5	32	19	66

*P_20_5 Analyses done by XRF

Error ± 1% Absolute for values

Remaining P_20_5 samples analyzaby volumetric method

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Sr (ppm)	Y (ppm)	U (ppm)	Th (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Ti (ppm)	Ba (ppm)
SBB86 1A	31768	49°30'40"	115°05'30"	Jurassic	Fernie	88	52	6	14	55	37	63	3679	286
SBB86 1B	31769	49°30'40"	115°05'30"	Jurassic	Fernie	87	46	5	<6	50	40	67	3452	541
SBB86 1C	31770	49°30'40"	115°05'30"	Jurassic	Fernie	111	51	<5	<6	40	34	58	3293	1227
SBB86 1D	31771	49°30'40"	115°05'30"	Jurassic	Fernie	112	56	<5	1	42	40	68	3232	713
SBB86 2A	31772	49°31'02"	115°06'00"	Permian	Ranger Canyon	37	39	<5	<6	32	18	28	401	821
SBB86 3A	31773	49°39'15"	114°44'10"	Triassic	Sulphur Mountain	68	21	<5	<6	58	19	29	3035	323
SBB86 3B	31774	49°39'15"	114°44'10"	Jurassic	Fernie	990	350	31	<6	71	127	77	1460	1440
SBB86 3C	31775	49°39'15"	114°44'10"	Jurassic	Fernie	1012	211	6	<6	63	96	86	2434	1357
SBB86 3D	31776	49°39'15"	114°44'10"	Jurassic	Fernie	372	63	<5	4	46	44	59	3016	396
SBB86 3E	31777	49°39'15"	114°44'10"	Jurassic	Fernie	1164	59	15	<6	139	33	34	1627	556
SBB86 4A	31778	49°39'45"	114°42'30"	Jurassic	Fernie	1214	485	32	<6	89	200	116	1253	929
SBB86 4B	31779	49°39'45"	114°42'30"	Jurassic	Fernie	1290	946	38	5	94	406	224	939	1398
SBB86 4C	31780	49°39'45"	114°42'30"	Jurassic	Fernie	1293	946	42	2	91	409	222	935	1387
SBB86 4D	31781	49°39'45"	114°42'30"	Jurassic	Fernie	1307	792	45	<6	90	332	205	985	1739
SBB86 4E	31782	49°39'45"	114°42'30"	Jurassic	Fernie	1337	617	50	<6	94	247	126	1248	1135
SBB86 6A	31783	49°54'20"	114°50'55"	Jurassic	Fernie	1170	443	30	5	73	168	84	1283	1071
SBB86 6B	31784	49°54'20"	114°50'55"	Jurassic	Fernie	1273	563	35	<6	101	265	172	1082	1208
SBB86 6C	31785	49°54'20"	114°50'55"	Jurassic	Fernie	700	125	3	1	60	62	47	1921	382
SBB86 6D	31786	49°54'20"	114°50'55"	Jurassic	Fernie	1084	118	4	5	56	67	64	1996	457
SBB86 6E	31787	49°54'20"	114°50'55"	Jurassic	Fernie	782	95	<5	5	50	48	59	2001	327
SBB86 6F	31788	49°54'20"	114°50'55"	Jurassic	Fernie	556	83	<5	<6	42	54	44	1787	484
SBB86 6G	31789	49°54'20"	114°50'55"	Jurassic	Fernie	401	73	<5	14	45	57	50	1530	436
SBB86 6H	31790	49°54'20'	114°50'55"	Jurassic	Fernie	528	32	0	<6	107	23	29	1452	314
SBB86 7B	31921	49°53'20"	114°57'00"	Permian	Ranger Canyon	51	25	<5	3	14	6	21	1332	88
SBB86 8A	31922	49°27'40"	115°06'30"	Permian	Johnston Canyon	44	49	3	22	35	38	41	1347	2978
SBB86 8B	31923	49°27'40"	115°06'30"	Permian	Johnston Canyon	30	64	13	18	53	47	54	2787	227
SBB86 8C	31924	49°27'40"	115°06'30"	Permian	Johnston Canyon	23	46	6	17	45	29	44	2717	183
SBB86 8E	31925	49°27'40"	115°06'30"	Permian	Ranger Canyon	43	53	11	7	80	35	52	3135	387
SBB86 8F	31926	49°27'40"	115°06'30"	Permian	Ranger Canyon	35	41	3	5	79	24	40	3420	613
SBB86 8H	31927	49°27'40"	115°06'30"	Permian	Ranger Canyon	53	14	5	6	38	23	24	1502	250
SBB86 8K	31928	49°27'40"	115°06'30"	Permian	Ranger Canyon	163	131	37	10	174	106	45	1548	184
SBB86 8L	31929	49°27'40"	115°06'30"	Permian	Ranger Canyon	58	89	11	9	30	43	45	1441	172
SBB86 9A	31930	49°32'02"	115°04'55"	Permian	Ranger Canyon	105	51	2	18	44	28	52	2467	272
SBB86 9B	31931	49°32'02"	115°04'55"	Permian	Ranger Canyon	66	28	<5	9	41	12	35	1818	214
SBB86 9C	31932	49°32'02"	115°04'55"	Permian	Ranger Canyon	52	26	3	6	37	10	31	2128	203
SBB86 9D	31933	49°32'02"	115°04'55"	Permian	Ranger Canyon	59	29	1	6	41	27	35	2108	201
SBB86 10A	31934	49°31'40"	115°10'40"	Jurassic	Fernie	1094	164	18	8	88	81	59	787	433
SBB86 11A	31935	49°31'50"	115°10"45"	Jurassic	Fernie	1117	325	21	11	51	121	71	737	371
SBB86 12	31936	49°58'50"	114°48'40"	Jurassic	Fernie	126	11	5	18	21	19	49	1377	306
SBB86 13A	31937	50°18'25"	114°56'05"	Jurassic	Fernie	329	301	19	11	37	115	78	791	683
SBB86 13B	31938	50°18'25"	114°56'05"	Jurassic	Fernie	887	390	27	<6	52	121	75	865	2473
SBB86 13C	31939	50°18'25"	114°56'05"	Jurassic	Fernie	954	524	40	8	78	196	117	1355	7757
SBB86 14A	31940	50°12'00"	115°00'00"	Jurassic	Fernie	709	576	22	9	89	248	167	1772	3944
SBB86 14B	31941	50°12'00"	115°00'00"	Jurassic	Fernie	275	77	6	16	78	54	74	3365	5871
SBB86 14C	31942	50°12'00"	115°00'00"	Jurassic	Fernie	275	79	9	17	73	52	67	3318	5667

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Sr (ppm)	Y (ppm)	U (ppm)	Th (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Ti (ppm)	Ba (ppm)
SBB86 14D	31943	50°12'00"	115°00'00"	Jurassic	Fernie	378	23	4	12	117	16	37	2071	2743
SBB86 15A	31944	49°16'05"	114°36'00"	Jurassic	Fernie	523	575	74	13	108	245	186	2012	283
SBB86 15B	31945	49°16'05"	114°36'00"	Jurassic	Fernie	221	36	20	18	161	36	63	4805	431
SBB86 15C	31946	49°16'05"	114°36'00"	Jurassic	Fernie	212	342	33	14	75	138	128	2540	223
SBB86 15D	31947	49°16'05"	114°36'00"	Jurassic	Fernie	616	784	76	19	104	308	198	1429	255
SBB86 17A	31948	49°18'00"	114°56'55"	Permian	Johnston Canyon	60	35	4	12	35	23	35	2281	257
SBB86 17B	31949	49°18'00"	114°56'55"	Permian	Johnston Canyon	54	28	2	8	40	17	36	2352	262
SBB86 17C	31950	49°18'00"	114°56'55"	Permian	Johnston Canyon	64	27	<5	9	36	15	40	1864	218
SBB86 17D	31951	49°18'00"	114°56'55"	Permian	Johnston Canyon	62	31	3	7	66	18	33	2968	294
SBB86 17E	31952	49°18'00"	114°56'55"	Permian	Johnston Canyon	87	38	6	18	44	34	40	1913	223
SBB86 17F	31953	49°18'00"	114°56'55"	Permian	Johnston Canyon	78	35	1	9	55	28	48	2557	270
SBB86 17G	31954	49°18'00"	114°56'55"	Permian	Johnston Canyon	65	29	<5	11	70	9	51	2272	223
SBB86 17H	31955	49°18'00"	114°56'55"	Permian	Johnston Canyon	72	34	5	11	48	27	44	2722	289
SBB86 17I	31956	49°18'00"	114°56'55"	Permian	Johnston Canyon	95	39	4	10	53	29	66	2873	303
SBB86 17J	31957	49°18'00"	114°56'55"	Permian	Johnston Canyon	65	24	4	8	34	11	33	1953	218
SBB86 17K	31958	49°18'00"	114°56'55"	Permian	Johnston Canyon	85	35	9	8	37	20	28	1762	268
SBB86 17L	31959	49°18'00"	114°56'55"	Permian	Johnston Canyon	72	34	13	6	50	30	42	2561	272
SBB86 17M	31960	49°18'00"	114°56'55"	Permian	Johnston Canyon	61	23	4	0	34	16	26	2048	221
SBB86 17N	31961	49°18'00"	114°56'55"	Permian	Johnston Canyon	73	34	2	8	39	19	54	2164	233
SBB86 17O	31962	49°18'00"	114°56'55"	Permian	Johnston Canyon	75	42	7	11	52	26	47	2780	244
SBB86 17P	31963	49°18'00"	114°56'55"	Permian	Johnston Canyon	96	43	9	7	48	27	48	2197	390
SBB86 17Q	31964	49°18'00"	114°56'55"	Permian	Johnston Canyon	68	38	4	9	134	25	39	2917	396
SBB86 17R	31965	49°18'00"	114°56'55"	Permian	Johnston Canyon	62	38	10	10	75	23	39	3561	308
SBB86 17S	31966	49°18'00"	114°56'55"	Permian	Johnston Canyon	92	55	30	16	60	25	60	1900	271
SBB86 20	31967	49°51'00"	114°43'40"	Jurassic	Fernie	1315	907	42	1	126	369	239	1298	15057
SBB86 20A	31968	49°51'00"	114°43'40"	Jurassic	Fernie	1216	1147	55	14	139	472	293	1183	17534
SBB86 21A	31969	49°51'55"	114°47'10"	Permian	Johnston Canyon	300	83	99	12	60	66	43	529	236
SBB86 21B	31970	49°51'55"	114°47'10"	Permian	Johnston Canyon	125	84	2	3	66	64	41	402	117
SBB86 22A	31971	49°52'20"	114°46'40"	Jurassic	Fernie	329	120	4	18	44	94	177	2391	919
SBB86 24	31972	49°18'50	114°55'30"	Jurassic	Fernie	241	66	72	9	67	26	32	1408	874
SBB86 27A	31973	49°06'20"	114°40'45"	Permian	Ranger Canyon	87	118	6	<6	43	79	50	716	92
SBB86 27B	31974	49°06'20"	114°40'45"	Permian	Ranger Canyon	76	138	12	13	56	85	48	1079	100
SBB86 28	31975	49°05'03"	114°39'30"	Jurassic	Fernie	413	455	43	14	131	192	163	2733	443
SBB86 29A	319756	50°07'00"	114°45'30"	Permian	?	79	50	4	5	55	45	50	1245	168
SBB86 30	319757	49°39'05"	114°44'00"	Jurassic	Fernie	174	34	6	13	71	39	85	3410	257
SBB86 31A	319758	49°39'10"	114°44'00"	Jurassic	Fernie	1166	520	40	3	79	213	122	1208	4236
SBB86 31B	319759	49°39'10"	114°44'00"	Jurassic	Fernie	944	230	17	14	65	107	88	2354	964
SBB86 31C	319760	49°39'10"	114°44'00"	Jurassic	Fernie	747	142	22	6	63	63	88	2106	1920
SBB86 31D	319761	49°39'10"	114°44'00"	Jurassic	Fernie	1286	31	15	2	158	33	36	1852	396
SBB86 36A	319762	49°27'30"	114°41'40"	Permian	Johnston Canyon	49	95	12	9	95	73	46	349	67
SBB86 37A	319763	49°27'10"	114°41'50"	Jurassic	Fernie	781	452	24	9	74	198	135	2181	230
SBB86 38A	319764	49°06'40"	114°40'45"	Jurassic	Fernie	602	596	43	15	89	238	149	2049	187
SBB86 38B	319765	49°06'40"	114°40'45"	Jurassic	Fernie	517	153	23	12	154	67	96	3290	610
SBB86 38C	319766	49°06'40"	114°40'45"	Jurassic	Fernie	620	513	80	9	313	313	359	2591	689
SBB86 38D	319767	49°06'40"	114°40'45"	Jurassic	Fernie	131	51	8	12	159	37	75	3823	453
SBB86 40A	319768	49°09'30"	114°46'00"	Jurassic	Fernie	330	453	45	7	93	205	122	2511	323
SBB86 41A	319769	49°09'00"	114°46'20"	Permian	Johnston Canyon	76	45	17	<8	41	27	42	1812	262
SBB86 41B	319770	49°09'00"	114°46'20"	Permian	Johnston Canyon	35	28	12	<8	28	16	28	1479	170
SBB86 41C	319771	49°09'00"	114°46'20"	Permian	Johnston Canyon	82	44	23	0	50	25	40	2324	248
SBB86 41D	319772	49°09'00"	114°46'20"	Permian	Johnston Canyon	95	56	20	8	57	52	50	2418	256

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Sr (ppm)	Y (ppm)	U (ppm)	Th (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Ti (ppm)	Ba (ppm)
SBB86 42A	319773	49°09'30"	114°46'15"	Jurassic	Fernie	512	520	56	13	92	230	151	2461	968
SBB86 42B	319774	49°09'30"	114°46'15"	Jurassic	Fernie	491	534	61	1	95	224	136	2470	528
SBB86 43A	319775	49°05'20"	114°36'05"	Jurassic	Fernie	565	659	81	29	108	295	199	1928	840
SBB86 44A	319776	49°05'05"	114°39'20"	Jurassic	Fernie	471	906	66	17	78	413	229	1290	231
SBB86 47A	319777	49°06'20"	114°42'45"	Jurassic	Fernie	441	197	46	14	97	109	98	2761	439
SBB86 47B	319778	49°06'20"	114°42'45"	Jurassic	Fernie	262	39	29	17	121	27	55	2256	814
	319779													
SBB86 47C	319780	49°06'20"	114°42'45"	Jurassic	Fernie	785	46	24	7	148	29	48	1966	356
SBB86 47D	319781	49°06'20"	114°42'45"	Jurassic	Fernie	1217	29	18	36	194	13	33	1527	448
SBB86 47E	319782	49°06'20"	114°42'45"	Jurassic	Fernie	1120	37	28	23	211	32	42	1854	664
SBB86 48A	319783	49°09'50"	114°40'45"	Jurassic	Fernie	771	793	92	43	117	330	197	1438	182
SBB86 50A	319784	49°06'45"	114°40'50"	Permian	Ranger Canyon	73	78	22	4	39	69	44	310	69
SBB86 52A	319785	49°06'55"	114°40'10"	Jurassic	Fernie	365	415	48	15	85	196	147	2470	321
SBB86 53	319786	49°05'40"	114°41'00"	Jurassic	Fernie	89	30	15	1	280	40	64	4114	275
SBB86 54A	319787	49°05'45"	114°41'00"	Jurassic	Fernie	600	515	54	18	106	236	152	1931	437
SBB86 57A	319788	49°57'45"	114°56'25"	Permian	Johnston Canyon	1028	665	60	21	72	312	179	749	414
SBB86 56A	319789	49°57'40"	114°56'35"	Permian	Johnston Canyon	972	784	63	18	92	369	217	717	575
SBB86 58B	319790	49°57'40"	114°56'35"	Permian	Johnston Canyon	417	467	45	13	72	207	127	1419	279
SBB86 61A	319791	49°41'40"	114°56'10"	Permian		107	52	60	2	18	17	31	769	81
SBB86 62A	319792	50°17'50"	115°02'45"	Permian	Ranger Canyon	85	67	29	0	87	44	42	647	243
SBB86 62B	319793	50°17'50"	115°02'45"	Permian	Ross Creek	39	50	16	1	30	32	33	507	113
SBB86 62C	319794	50°17'50"	115°02'45"	Permian	Ross Creek	85	44	24	3	50	24	21	672	834
SBB86 62D	319795	50°17'50"	115°02'45"	Permian	Ross Creek	44	29	17	10	40	28	38	1688	223
SBB86 62E	319796	50°17'50"	115°02'45"	Permian	Ross Creek	146	44	26	7	60	37	38	2118	2550
SBB86 62F	319797	50°17'50"	115°02'45"	Permian	Ross Creek	62	49	26	1	50	45	39	2077	240
SBB86 62G	319798	50°17'50"	115°02'45"	Permian	Ross Creek	54	45	23	13	61	36	42	2476	219
SBB86 62I	319799	50°17'50"	115°02'45"	Permian	Ranger Canyon	370	278	113	13	86	203	136	821	581
SBB86 63A	319800	50°18'10"	115°02'45"	Permian	Ranger Canyon	271	122	107	9	79	104	48	640	226
SBB86 63B	319801	50°18'10"	115°02'45"	Permian	Ranger Canyon	69	25	21	14	138	29	31	1995	431
SBB86 63C	319802	50°18'10"	115°02'45"	Permian	Ranger Canyon	124	79	35	0	60	69	32	861	228
SBB86 63D	319803	50°18'10"	115°02'45"	Permian	Ranger Canyon	140	135	31	3	49	83	37	1347	561
SBB86 63E	319804	50°18'10"	115°02'45"	Permian	Ranger Canyon	56	26	13	3	43	20	27	881	157
SBB86 63F	319805	50°18'10"	115°02'45"	Permian	Ranger Canyon	44	22	16	2	39	24	27	759	123
SBB86 63G	319806	50°18'10"	115°02'45"	Permian	Ranger Canyon	36	22	9	<8	22	14	23	638	111
SBB86 63H	319807	50°18'10"	115°02'45"	Permian	Ranger Canyon	39	18	12	1	44	25	30	599	115
SBB86 63I	319808	50°18'10"	115°02'45"	Permian	Ranger Canyon	39	28	14	<8	60	24	30	928	165
SBB86 63J	319809	50°18'10"	115°02'45"	Permian	Ranger Canyon	33	19	15	1	33	13	28	643	230
SBB86 63K	319810	50°18'10"	115°02'45"	Permian	Ranger Canyon	29	18	9	<8	44	20	17	393	87
SBB86 63L	319811	50°18'10"	115°02'45"	Permian	Ranger Canyon	43	22	14	<8	43	26	30	679	98
SBB86 65A	319812	50°19'20"	115°02'50"	Permian	Ranger Canyon	249	83	28	<8	119	70	52	780	8095
SBB86 66A	319813	49°48'05"	115°03'00"	Permian	Telford	158	63	20	1	32	48	31	1011	98
SBB86 70A	319814	49°58'00"	114°48'10"	Jurassic	Fernie	782	489	49	14	126	205	121	1844	600
SBB86 70B	319815	49°58'00"	114°48'10"	Jurassic	Fernie	1236	606	46	5	98	261	148	1413	3316
SBB86 70C	319816	49°58'00"	114°48'10"	Jurassic	Fernie	1194	440	40	17	112	221	142	1951	1601
SBB86 70D	319817	49°58'00"	114°48'10"	Jurassic	Fernie	850	177	23	10	93	93	80	2870	929
SBB86 70E	319818	49°58°00"	114°48'10"	Jurassic	Fernie	722	118	21	6	65	66	59	2235	684
SBB86 71A	319819	49°39'10"	114°42'30"	Permian	162	259	109	4	114	200	76	424	62	
SBB86 71B	319820	49°39'10"	114°42'30"	Permian	257	220	167	0	105	179	66	268	49	
SBB86 72A	319821	49°44'25"	115°02'50"	Permian	Ross Creek	174	33	9	<8	51	34	43	1507	144
SBB86 73A	319822	49°44'20"	115°03'00"	Permian	Ross Creek	142	47	15	4	113	35	49	3180	332

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation	Sr (ppm)	Y (ppm)	U (ppm)	Th (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Ti (ppm)	Ba (ppm)
SBB86 74A	319823	49°36'05"	115°04'30"	Jurassic	Fernie	884	327	60	11	141	160	84	994	1707
SBB86 76A	319824	49°19'50"	114°57'00"	Jurassic	Fernie	96	40	13	18	49	54	89	1937	340
SBB86 76B	319825	49°19'50"	114°57'00"	Jurassic	Fernie	92	40	15	17	53	42	90	1997	171
SBB86 76C	319826	49°19'50"	114°57'00"	Jurassic	Fernie	80	38	11	19	55	43	93	2162	217
SBB86 76D	319827	49°19'50"	114°57'00"	Jurassic	Fernie	88	40	13	24	56	51	85	2123	258
SBB86 76E	319828	49°19'50"	114°57'00"	Jurassic	Fernie	83	38	17	18	57	40	88	2203	236
SBB86 76F	319829	49°19'50"	114°57'00"	Jurassic	Fernie	84	38	17	28	39	51	92	1771	156
SBB86 77A	319830	49°37'20"	114°39'30"	Mississippian	Exshaw	77	46	56	3	1603	50	77	3845	620
SBB86 77B	319831	49°37'20"	114°39'30	Mississippian	Exshaw	70	34	18	4	719	35	64	2796	241
SBB86 77C	319832	49°37'20"	114°39'30"	Mississippian	Exshaw	131	61	17	8	130	46	55	2289	217
SBB86 77D	319833	49°37'20"	114°39'30"	Mississippian	Exshaw	135	77	19	11	135	68	79	2899	266
SBB86 77E	319834	49°37'20"	114°39'30"	Mississippian	Exshaw	282	192	22	6	129	124	81	3060	209
SBB86 78A	319835	49°51'45"	114°59'50"	Permian	Ross Creek	122	34	10	6	90	37	59	3611	1071
SBB86 79A	319836	49°51'50"	114°59'55"	Permian	Johnston Canyon	381	185	87	1	200	140	98	750	150
SBB86 79B	319837	49°51'50"	114°59'55"	Permian	Johnston Canyon	104	48	13	<8	34	34	40	1602	1609
SBB86 80A	319838	50°01'30"	114°57'30"	Permian	Ranger Canyon	395	181	30	11	86	87	79	1781	849
SBB86 80B	319839	50°01'30"	114°57'30"	Permian	Ranger Canyon	202	62	29	13	81	50	59	1675	618
SBB86 83A	319840	49°10'30"	114°49'10"	Pennsylvanian	Kananaskis	422	88	17	6	36	50	35	804	412
SBB86 84A	319841	49°10'30"	114°49'05"	Permian	Johnston Canyon	497	109	39	16	45	67	43	647	274
SBB86 84B	319842	49°10'30"	114°49'05"	Permian	Johnston Canyon	921	113	18	12	71	68	53	2607	582
SBB86 84C	319843	49°10"30"	114°49'05"	Permian	Johnston Canyon	1173	277	55	0	216	160	144	919	20899
SBB86 84D	319844	49°10'30"	114°49'05"	Permian	Johnston Canyon	882	98	40	17	472	72	83	2014	716
SBB86 85A	319845	49°10'00"	114°47'00"	Permian	Ranger Canyon	122	80	49	2	92	77	51	606	101
SBB86 86A	319846	49°16'50"	114°47'40"	Jurassic	Fernie	1153	860	78	31	73	392	239	1164	327

APPENDIX 11
SAMPLE LOCATIONS AND RESULTS FROM NORTHEASTERN BRITISH COLUMBIA

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation/ Member	Width (metres)	P_2O_5 (%)	Zn (ppm)	U (ppm)	V (ppm)	Y (ppm)	La (ppm)	Ce (ppm)
SB87 6A	33525	54°17'05"	120°19'40"	Triassic	Vega Phroso	0.2	0.31	19	12	110	25	<7	43
SB87 6B	33526	54°17'05"	120°19'40"	Triassic	Vega Phroso	0.6	1.92	2100	29	361	74	27	82
SB87 6C	33527	54°17'05"	120°19'40"	Triassic	Whistler	1	0.35	29	30	57	23	<7	<13
SB87 6D	33528	54°17'05"	120°19'40"	Triassic	Whistler	1.3	10.05	1900	88	829	130	20	20
SB87 6E	33529	54°17'05"	120°19'40"	Triassic	Whistler	1	2.36	690	291	<7	<13		
SB87 7A	33530	54°16'30"	120°18'50"	Triassic	Whistler	0.6	0.18	313	28	1354	27	<7	5
SB87 7B	33531	54°16'30"	120°18'50"	Triassic	Whistler	0.5	0.3	775	20	1103	31	<7	10
SB87 7C	33532	54°16'30"	120°18'50"	Triassic	Whistler	0.5	6.86	786	13	929	102	19	21
SB87 7D	33533	54°16'30"	120°18'50"	Triassic	Whistler	0.5	4.35	414	315	<7	4		
SB87 7E	33534	54°16'30"	120°18'50"	Triassic	Whistler	1	2.06	1000	32	1260	35	<7	<13
SB87 7F	33535	54°16'30"	120°18'50"	Triassic	Whistler	1	2.85	656	507	<7	<13		
SB87 8	33536	54°16'30"	120°18'50"	Permian	Fantasque	grab	18.86	265	65	180	195	76	51
SB87 9A	33537	54°31'50"	120°40'00"	Permian	Fantasque	grab	15.94	70	41	244	71	5	37
SB87 11A	33538	54°31'10"	120°39'30"	Triassic	Whistler	1	0.3	65	7	282	33	8	53
SB87 11B	33539	54°31'10"	120°39'30"	Triassic	Whistler	0.8	0.79	68	22	98	54	9	48
SB87 11C	33540	54°31'10"	120°39'30"	Triassic	Whistler	1	17.61	344	67	160	205	70	35
SB87 12A	33541	54°31'00"	120°39'45"	Triassic	Whistler	1	21.48	404	167	340	391	123	48
SB87 14A	33542	55°09'10"	122°06'45"	Permian	Fantasque	grab	11.66	134	65	166	479	365	135
SB87 15A	33556	55°05'55"	121°47'20"	Triassic	Whistler	grab	24.85	103	141	97	189	35	13
SB87 16A	33545	55°31'20"	122°32'30"	Triassic	Toad	0.5	2.19	36	14	19	49	<7	<13
SB87 16B	33546	55°31'20"	122°32'30"	Triassic	Toad	0.2	5.12	50	23	77	<7	<13	
SB87 16C	33547	55°31'20"	122°32'30"	Triassic	Toad	0.5	1.14	39	25	<8	<7	<13	
SB87 16D	33548	55°31'20"	122°32'30"	Triassic	Toad	0.6	0.66	33	11	18	11	<7	<13
SB87 16E	33549	55°31'20"	122°32'20"	Triassic	Toad	0.2	4.2	60	<2	39	18	<7	<13
SB87 16F	33550	55°31'20"	122°32'20"	Triassic	Toad	grab	0.16	30	<8	<2	2	<7	3
SB87 16G	33551	55°31'20"	122°32'20"	Triassic	Toad	1	0.17	286	26	199	25	<7	13
SB87 16H	33552	55°31'20'	122°32'20"	Triassic	Toad	0.7	0.28	496	32	283	30	<7	14
SB87 16I	33553	55°31'20"	122°32'20"	Triassic	Toad	0.3	0.12	123	132	<7	<13		
SB87 16J	33554	55°31'20"	122°32'20"	Triassic	Toad	0.9	0.23	534	16	411	21	<7	17
SB87 17A	33555	55°31'00"	122°33'30"	Triassic	Toad	grab	0.7	1200	44	613	26	<7	<13
SB87 19A	33543	55°30'30"	122°34'45"	Triassic	Toad	0.05	3.84	451	29	687	48	6	37
SB87 19B	33557	55°30'30"	122°34'45"	Triassic	Toad	1	1.37	226	5	160	57	10	31
SB87 19C	33558	55°30'30"	122°34'45"	Triassic	Toad	0.6	2.92	252	10	151	82	22	42
SB87 19D	33559	55°30'30"	122°34'45"	Triassic	Toad	grab	0.33	744	18	552	23	<7	15
SB87 20A	33560	55°31'00"	122°32'30	Triassic	Toad	grab	0.23	12	35	<7	13		
SB87 32A	34326	55°13'00"	122°12'30"	Triassic	Toad	0.3	0.35	890	28	2124	42	<7	31
SB87 32B	34327	55°13'00"	122°12'30"	Triassic	Toad	1	0.35	540	27	1625	37	<7	19
SB87 32C	34328	55°13'00"	122°12'30"	Triassic	Toad	0.5	0.29	415	25	1581	34	<7	16
SB87 32D	34329	55°13'00"	122°12'30"	Triassic	Toad	0.3	0.25	665	29	1982	38	<7	8
SB87 34A	34334	56°27'50"	123°14'30"	Triassic	Toad	1	0.45	53	12	99	34	<7	31
SB87 34B	34335	56°27'50"	123°14'30"	Triassic	Toad	1	0.2	456	22	1616	37	<7	21
SB87 34C	34336	56°27'50"	123°14'30"	Triassic	Toad	1	0.22	605	18	1552	38	<7	36
SB87 34D	34337	56°27'50"	123°14'30"	Triassic	Toad	0.4	1.11	210	25	766	42	<7	21
SB87 34E	34338	56°27'50"	123°14'30"	Triassic	Toad	0.75	4.14	334	23	938	38	<7	19

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Age	Formation/ Member	Width (metres)	P_2O_5 (%)	Zn (ppm)	U (ppm)	V (ppm)	Y (ppm)	La (ppm)	Ce (ppm)
SB87 34F	34339	56°27'50"	123°14'30"	Triassic	Toad	grab	11.46	124	48	376	204	65	134
SB87 34G	34340	56°27'50"	123°14'30"	Triassic	Toad	1.4	0.93	249	15	325	50	6	58
SB87 34H	34341	56°27'50"	123°14'30"	Triassic	Toad	0.4	0.23	96	12	213	39	11	56
SB87 34I	34342	56°27'50"	123°14'30"	Triassic	Toad	0.5	0.1	937	25	1941	27	<7	<13
SB87 35A	34343	56°28'40"	123°13'50"	Triassic	Toad	0.05	11.65	17	26	75	28	<7	<13
SB87 36A	34344	56°50'55"	123°13'50"	Triassic	Toad	1	0.62	189	11	424	39	4	50
SB87 36B	34345	56°50'55"	123°13'50"	Triassic	Toad	1	0.46	30	9	200	37	1	50
SB87 36C	34346	56°50'55"	123°13'50"	Triassic	Toad	1	0.42	40	16	149	36	3	48
SB87 36D	34347	56°50'55"	123°13'50"	Triassic	Toad	1	0.53	63	18	221	40	5	47
SB87 36E	34348	56°50'55"	123°13'50"	Triassic	Toad	1.5	1.57	86	16	285	86	36	100
SB87 36F	34349	56°50'55"	123°13'50"	Triassic	Toad	1	2.68	171	17	161	70	10	52
SB87 36H	34350	56°50'55"	123°13'50"	Triassic	Toad	grab	11.74	315	56	136	190	53	100
SB87 36I	34351	56°50'55"	123°13'50"	Triassic	Toad	2	5.74	88	23	286	59	6	35
SB87 36J	34352	56°50'55"	123°13'50"	Triassic	Toad	3	5.9	464	29	980	48	<7	30
SB87 36K	34353	56°50'55"	123°13'50"	Triassic	Toad	0.5	9.9	418	36	614	81	15	41
SB87 36L	34354	56°50'55"	123°13'50"	Triassic	Toad	2	2.47	229	27	923	36	<7	27
SB87 36M	34355	56°50'55"	123°13'50"	Triassic	Toad	1	0.63	126	26	423	32	<7	22
SB87 37A	34297	57°37'30"	123°40'00"	Triassic	Toad	1	1.63	292	12	767	48	18	84
SB87 37B	34298	57°37"30"	123°40'00"	Triassic	Toad	1	0.68	588	18	748	55	16	70
SB87 37C	34299	57°37'30"	123°40'00"	Triassic	Toad	0.5	0.59	35	16	115	29	<7	17
SB87 37D	34300	57°37'30"	123°40'00"	Triassic	Toad	1.5	3	1000	18	119	49	<7	36
SB87 37E	34301	57°37'30"	123°40'00"	Triassic	Toad	1.6	1.94	20	20	85	51	2	27
SB87 37F	34302	57°37'30"	123°40'00"	Triassic	Toad	2	4.07	137	21	125	69	<7	31
SB87 37G	34303	57°37'30"	123°40'00"	Triassic	Toad	1	3.61	235	20	114	74	6	20
SB87 37H	34304	57°37'30"	123°40'00"	Triassic	Toad	1.5	4.89	1090	42	1092	71	<7	20
SB87 37I	34305	57°37'30"	123°40'00"	Triassic	Toad	1	3.05	1100	83	1822	87	24	69
SB87 37J	34306	57°37'30"	123°40'00"	Triassic	Toad	1	2.65	134	15	133	61	18	45
SB87 37K	34307	57°37'30"	123°40'00"	Triassic	Toad	1	2.76	140	20	134	63	7	52
SB87 39A	34308	57°48'00"	125°12'00"	Cambrian	Kechika	0.5	7.43	140	35	53	40	<7	45
SB87 39B	34309	57°48'00"	125°12'00"	Cambrian	Kechika	0.45	2.98	79	18	56	33	<7	65
SB87 39C	34310	57°48'00"	125°12'00"	Cambrian	Kechika	1	0.15	46	10	70	22	14	76
SB87 39D	34311	57°48'00"	125°12'00"	Cambrian	Kechika	1	0.28	49	13	85	28	0	63
SB87 40A	34312	58°40'00"	124°17'30"	Triassic	Toad	1	2.66	395	23	233	58	<7	19
SB87 40B	34313	58°40'00"	124°17'30"	Triassic	Toad	0.7	7.28	914	28	426	76	<7	7
SB87 40C	34314	58°40'00"	124°17'30"	Triassic	Toad	0.6	4.55	219	32	275	65	<7	8
SB87 40D	34315	58°40'00"	124°17'30"	Triassic	Toad	1	3.7	289	30	436	70	<7	25
SB87 40E	34316	58°40'40"	124°17'30"	Triassic	Toad	grab	1.19	19	14	70	30	<7	19
SB87 40F	34317	58°40'40"	124°17'30"	Triassic	Toad	grab	1.28	25	14	108	45	2	32
SB87 41A	34331	58°40'00"	124°18'00"	Triassic	Toad	0.15	35	26	57	72	4	32	
SB87 43A	34318	58°40'00"	124°26'30"	Triassic	Toad	0.5	8.32	324	30	859	101	<7	<13
SB87 43B	34319	58°40'00"	124°26'30"	Triassic	Toad	1	5.94	423	36	1031	95	<7	1
SB87 43C	34320	58°40'00"	124°26'30"	Triassic	Toad	0.7	2.98	344	26	1419	86	<7	13
SB87 43D	34321	58°40'00"	124°26'30"	Triassic	Toad	0.3	5.76	384	42	1080	120	15	1
SB87 43E	34322	58°40'00"	124°26'30"	Triassic	Toad	0.7	10.12	382	40	436	146	16	<13
SB87 45A	34323	58°40'00"	124°36'00"	Permian	Kindle	1	3.44	280	24	995	40	<7	4
SB87 45B	34324	58°40'00"	124°36'00"	Permian	Kindle	1	3.38	281	18	835	40	<7	13
SB87 45C	34325	58°40'00"	124°36'00"	Permian	Kindle	0.5	4.36	282	29	1089	54	<7	38
AL 86	34274	54°20'00"	120°25'00"	Triassic	Whistler	grab	18.4	392	92	208	161	46	30

APPENDIX 12
TRACE ELEMENTS - WAPITI LAKE (A. Legun, 1985)

Lab Number	Sample Number	S %	F %	Cd (ppm)	Pb (ppm)	La (	Ce	U ppm	Y	V)	Corg %	$\frac{CaO}{P_2O_5}$	$\frac{R_2O_3}{P_2O_5}$
30241	85 21 3	0.34	2.31	14	15	178	<10	133	620	153	1.08	2.21	0.08
30242	85 21 4	0.33	2.49	10	15	159	<10	89	532	87	0.74	2.4	0.11
30243	85 23 1	0.08	0.56	3	8	16	<10	34	76	76	0.19	1.59	0.33
30244	85 23 3	0.36	2.12	3	12	167	<10	63	431	59	0.51	2.11	0.2
30245	85 23 4	0.28	1.62	1	10	43	<10	65	262	69	0.96	2.75	0.34
30246	85 24 2A	0.34	1.93	1	12	138	45	42	507	54	0.51	2.2	0.19
30247	85 24 2B	0.42	2.19	21	12	168	<10	151	594	176	0.78	2.29	0.14
30248	85 24 2C	0.25	0.55	10	14	23	<10	31	62	1074	3.13	5.66	4.31
30249	85 25 1A	0.37	1.78	12	13	95	16	91	410	112	0.61	2.53	0.21
30250	85 25 1B	0.19	1.04	4	8	<10	<10	40	66	85	1.02	5.41	0.64
30251	85 25 2	0.23	1.53	13	11	38	<10	59	157	86	0.76	3.11	0.15
30252	85 26 1	0.22	1.51	2	13	10	<10	64	78	97	0.48	1.56	0.11
30253	85 26 2	0.59	1.67	8	10	116	15	79	403	123	0.71	2.88	0.36
30254	85 21 3	0.46	2.02	6	12	162	99	115	525	131	0.97	1.88	0.23
30255	85 26 3D	0.37	2.33	12	12								
Average		0.32	1.71	9	13	95	20	75	337	170	0.89	2.76	0.53

*$R_2O_3 = Fe_2O_3 + Al_2O_3 + MgO$

APPENDIX 13
MAJOR OXIDES WAPITI LAKE (A. LEGUN, 1985)
(Values in per cent)

Lab Number	Lab Number	P_2O_5	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
30241	85 21 3	22.33	8.17	0.8	0.39	0.56	49.4	0.34	0.35	0.09	0.018
30242	85 21 4	20.29	9.31	1	0.52	0.64	48.72	0.4	0.4	0.08	0.021
30243	85 23 1	6.83	76.13	0.88	1.26	0.14	10.87	0.08	0.29	0.06	0.008
30244	85 23 3	20.3	16.32	2.09	1.06	1.07	42.82	0.54	0.8	0.21	0.02
30245	85 23 4	14.81	18.16	2.14	0.82	2.11	40.73	0.48	0.84	0.18	0.024
30246	85 24 2A	19.79	16.5	1.98	1.24	0.57	43.45	0.54	0.78	0.18	0.018
30247	85 24 2B	20.08	11.13	1.11	0.45	1.21	45.96	0.36	0.43	0.11	0.014
30248	85 24 2C	3.28	38.46	6.57	3	4.56	18.55	0.62	2.75	0.46	0.027
30249	85 25 1A	17.82	15.28	1.78	0.99	0.93	45.17	0.52	0.66	0.16	0.019
30250	85 25 1B	8.24	12.7	1.71	1.26	2.31	44.6	0.23	0.77	0.1	0.029
30251	85 25 2	15.52	10.69	1.04	0.69	0.6	48.32	0.31	0.44	0.1	0.015
30252	85 26 1	16.22	52.77	0.83	0.79	0.14	25.32	0.13	0.26	0.04	0.016
30253	85 26 2	14.77	16.48	2.04	0.94	2.36	42.51	0.46	0.79	0.13	0.025
30254	85 26 3	20.33	22.15	2.9	1.26	0.57	38.32	0.67	1.15	0.27	0.033
30255	85 21 3D	22.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average		16.21	23.16	1.92	1.05	1.27	38.91	0.41	0.77	0.16	0.021

N/A Not analyzed

APPENDIX 14
RESAMPLING RESULTS OF THE ABBY AND HIGHWAY 3 PHOSPHATE LOCALITIES

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)	U (ppm)	V (ppm)	Y (ppm)	La (ppm)	Ce (ppm)	Sc (ppm)
SB87 1A	33512	50°18'25"	114°56'05"	Fernie	0.6	3.81	20	14	33	20	29	201	49	51	14.1
SB87 1B	33513	50°18'25"	114°56'05"	Fernie	1	22.05	52	13	63	27	55	355	99	61	47.7
SB87 1C	33514	50°18'25"	114°56'05"	Fernie	0.5	17.79	48	18	74	34	71	292	55	31	45.1
SB87 1D	33515	50°18'25"	114°56'05	Fernie	1	18.32	44	14	64	19	33	349	91	60	34.2
SB87 1E	33516	50°18'25"	114°56'05	Fernie	0.9	26.63	43	17	70	33	59	484	136	69	53.8
SB87 1F	33517	50°18'25"	114°56'05"	Fernie	1	0.15	63	19	76	15	95	26	<7	41	18.7
SB87 2A	33518	49°39'15"	114°44'10"	Fernie	0.7	24.88	46	16	73	55	82	463	136	79	52.1
SB87 2B	33519	49°39'15"	114°44'10"	Fernie	0.5	18.78	34	17	157	ND	61	296	228	155	57.7

ND - Not determined

APPENDIX 15
MAJOR AND TRACE ELEMENT ANALYSES - ALEY CARBONATITE
(Values in percent)

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Au (ppb)	As (	Ag	Cu	Zn	Ni	Mo	U ppm	Th	La	Ce	Y	Nb	Cd	Se	Sc)	Pb
SB87 33	34254	56°27´30´´	123°48´00´´	<20	3.8	<0.5	6	9	<2	5	34	223	393	800	95	4270	<1	2	30	8

P_2O_5	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	LOI	FeO	CO_2	S	Corg.
4.79	2.27	0.1	0.14	2.81	0.25	16.88	33.06	<0.10	<0.10	39.5	2.07	35.12	<0.10	1.94

APPENDIX 16
ANALYTICAL RESULTS FOR CARBONATITES SAMPLED

Lab Number	Sample Number	Latitude	Longitude	Locality	Sample Type	P_2O_5 %	La (ppm)	Ce (ppm)	Ta (ppm)	Nb (ppm)	Sc (ppm)	U (ppm)	Th (ppm)	Yb (ppm)
33520	SB87 3	52°25'05"	119°09'00"	Verity	Grab	2.41	82	207	15	88	42.8	27	26	N/A
33521	SB87 4	52°24'15"	119°09'00"	Verity	Grab	6.18	48	171	3	9	33.7	20	19	N/A
33522	SB87 5	52°24'15"	119°09'00"	Verity	Grab	3.18	119	299	209	1020	34.7	112	21	N/A
33523	SB87 5A	52°24'15"	119°09'00"	Verity	Grab	0.6	26	81	16	53	10.7	<8	16	N/A
33524	SB87 5B	52°24'15"	119°09'00"	Verity	Grab	5.62	265	615	4	18	40.8	29	40	N/A
34293	SB87 33A	56°27'30"	123°48'00"	Aley	Grab	2.67	258	598	93	4175	30.4	22	204	4
34294	SB87 33B	56°27'30"	123°48'00"	Aley	Grab	2.99	211	483	11	1512	28.6	22	64	2
34295	SB87 33C	56°27'30"	123°48'00"	Aley	Grab	3.54	564	1180	31	3583	28.5	23	106	4
34296	SB87 33D	56°27'30"	123°48'00"	Aley	Grab	2.84	325	704	31	3897	30.9	18	189	2

N/A Not analyzed

APPENDIX 17
SAMPLE LOCATIONS AND RESULTS FOR THE QUESNEL AREA

Sample Number	Lab Number	Latitude	Longitude	Age	Formation Unit	Width (metres)	P_2O_5 (%)	Cu (ppm)	Zn (ppm)	Ba (ppm)	V (ppm)	Y (ppm)	U (ppm)	Ag (ppm)
SB87 22A	34275	53°02'40"	121°13'45"	Devonian	Black Pelite	1.2	0.45	48	108	6721	581	30	8	N/A
SB87 22B	34276	53°02'40"	121°13'45"	Devonian	Black Pelite	0.5	0.68	30	79	6880	693	31	13	N/A
SB87 22C	34277	53°02'40"	121°13'45"	Devonian	Black Pelite	0.5	0.33	33	100	1894	369	28	8	N/A
SB87 22(3)	34332	53°02'40"	121°13'40"	Devonian	Waverly Fm.	grab	0.34	12	176	755	386	31	4	N/A
SB87 23A	34278	53°01'10"	121°13'40"	Devonian	Black Pelite	0.75	1.39	30	107	10550	1921	21	22	N/A
SB87 23B	34279	53°01'10"	121°13'40"	Devonian	Black Pelite	0.7	3.55	370	847	9100	1735	85	44	N/A
SB87 24A	34380	53°00'55"	121°13'45"	Devonian	Black Pelite	grab	1.41	238	788	855	981	49	31	N/A
SB87 25A	34281	53°00'45"	121°13'35"	Devonian	Black Pelite	0.3	0.4	16	28	2497	758	20	16	N/A
SB87 25B	34282	53°00'45"	121°13'35"	Devonian	Black Pelite	0.5	0.3	17	70	2682	220	15	9	N/A
SB87 25C	34283	53°00'45"	121°13'35"	Devonian	Black Pelite	0.25	2.29	20	56	2623	285	29	13	N/A
SB87 25D	34284	53°00'45"	121°13'35"	Devonian	Black Pelite	0.5	8	20	61	1645	198	60	20	N/A
SB87 27A	34285	52°58'50"	121°18'15"	Devonian	Black Pelite	0.5	0.78	102	3300	540	654	47	14	N/A
SB87 27B	34286	52°58'50"	121°18'15"	Devonian	Black Pelite	0.85	0.13	55	3300	1382	217	34	8	N/A
SB87 27C	34287	52°58'50"	121°18'15"	Devonian	Black Pelite	0.5	0.16	57	169	1723	300	53	29	N/A
SB87 27D	34288	52°58'50"	121°18'15"	Devonian	Black Pelite	0.5	0.15	54	282	1621	232	32	7	N/A
SB87 27E	34289	52°58'50"	121°18'15"	Devonian	Black Pelite	0.8	0.16	37	226	1846	272	40	14	N/A
SB87 29A	34290	53°00'45"	121°20'55"	Devonian	Waverly Fm.	1	0.36	57	89	37	241	21	2	<0.5
SB87 29B	34291	53°00'45"	121°20'55"	Devonian	Waverly Fm.	grab	0.52	27	55	578	267	28	3	<0.5
SB87 30A	34292	53°00'55"	121°20'00"	Devonian	Waverly Fm.	0.7	0.43	49	100	1916	357	21	4	<0.5
SB87 31A	34333	53°03'58"	121°13'15"	Devonian	Black Pelite	0.35	0.23	14	113	591	329	20	16	<0.5

N/A Not Analyzed

APPENDIX 18
MAJOR ELEMENT ANALYSES QUESNEL AREA

Sample Number	Lab Number	Latitude (N)	Longitude (W)	Formation	P_20_5 (Values	$Si0_2$ in	$Ti0_2$ per	Al_20_3 cent)	Fe_20_3	Mn0	Mg0	Ca0	Na_20	K_20	$C0_2$	L0I	H_20	S	Fe0
SB87 25	34246	53°00'45"	121°13'35"	Black Stuart	0.95	82.66	0.17	3.65	2.75	0	0.44	1.4	<0.10	1.17	15.68	5.74	0.41	1.07	0.64
SB87 27	34247	52°58'50"	121°18'15"	Black Stuart	1.43	70.66	0.08	1.94	1.68	0.05	3.1	7.57	<0.10	0.67	18.98	12.45	0.3	0.36	1.28
SB87 22(1)	34248	53°02'40"	121°13'45"	Black Stuart	0.37	45.88	3.32	18.43	12.31	0.08	4.44	1.84	2.86	2.51	1.66	6.6	0.41	0.84	6.07
SB87 28	34249	53°00'40"	121°20'50"	Black Stuart	0.17	64.24	0.79	15.9	5.53	0.03	1.74	0.29	0.85	4.3	2.82	3.88	0.15	<0.01	3.02
SB87 29	34250	53°00'45"	121°20'55"	Waverly	0.36	42.14	1.7	10.79	10.18	0.12	6.68	12.89	1.58	0.04	9.52	13.04	0.2	0.08	8.83
SB87 30(2)	34251	53°00'55"	121°20'00"	Black Stuart	0.5	46.98	2.61	13.74	14.18	0.18	4.59	4.48	4.25	1.59	2.35	5.67	0.52	0.01	9.7

APPENDIX 19
TRACE ELEMENT AND MINOR ELEMENT GEOCHEMISTRY - QUESNEL AREA

Sample Number	Au (ppb)	Ag	Cu	Pb	Zn	Ni	Mo	As	Cd	Ba	U	Th	La	Ce	V	Y	Se	Corg	Cl	Sc	F
		(							ppm								)	(%	)	(ppm)	%
SB87 25	<20	2	29	29	182	43	21	39.3	<1	2264	28	22	21	40	270	9	12	3.06	<0.01	2.3	0.12
SB87 27	<20	4	105	1500	2500	64	13	7.6	1	350	24	<5	25	23	710	28	39	4.06	<0.01	6.6	0.13
SB87 22(1)	<20	<0.5	19	5	140	35	<8	1.4	13	2808	20	<6	48	49	412	26	<1	<0.01	<0.01	20.7	0.08
SB87 28	<20	0.5	37	15	215	42	<8	6.2	<1	1054	31	61	49	98	257	28	2	0.53	<0.01	9.4	0.07
SB87 29	<20	<0.5	58	7	98	200	<8	6.6	<1	68	23	<5	68	89	271	19	<1	0.37	<0.01	26.7	0.09
SB87 30(2)	<20	0.7	134	3	131	160	<8	2.6	<1	4416	20	<6	60	74	283	17	<1	<0.01	<0.01	19.5	0.06

APPENDIX 20
MINERALOGICAL COMPOSITION OF PHOSPHATE - WHISTLER MEMBER OF THE SULPHUR MOUNTAIN FORMATION
(values in per cent)

Sample* No.	Fluorapatite	Quartz	Muscovite-sericite and Clay	Carbonate	Organic Matter
SB87-6	59.1	2.1	1	31.6	7
SB87-7	12.5	18.2	1.2	64.2	4.1
SB87-11	68.6	14.6	3	17.3	2.7
SB87-12	70.8	10.9	1.7	17.4	3.3
SB87-15	70.1	8.7	4.5	14	2.3
85-21-3	55.8	7.2	2.1	35.5	1.3
85-21-4	50.7	8.1	2.6	39.1	0.9
85-23-3	50.8	13.9	5.4	28.5	0.6
85-23-4	37	15.7	5.6	37.7	1.2
85-24-2A	49.5	14.2	5.2	30.8	0.6
85-24-2B	50.2	9.8	2.9	34.6	0.9
85-24-2C	8.2	30.8	17.1	25.3	3.8
85-25-1A	44.6	13.2	4.6	38.5	0.7
85-25-1B	20.6	10.7	4.4	60	1.2
85-25-2	38.8	9.5	2.7	49.5	0.9
85-26-2	36.9	14.1	5.3	40.9	0.9
85-21-3	50.8	18.9	7.5	20.4	1.2

*Sample numbers refer to those in Appendices 4 and 13.

APPENDIX 21
MINERALOGICAL COMPOSITION OF PHOSPHATE - FERNIE FORMATION
(values in per cent)

Sample* No.	Fluorapatite	Quartz	Muscovite-sericite and Clay	Carbonate	Organic Matter
Liz	61.8	8.9	2.7	27.1	2.3
SBB86-3	68.2	14.3	5	12.7	2.7
SBB86-4	55.8	17.4	4.9	20.6	1.9
SBB86-6	33.5	14.3	5.2	38.4	3.5
SBB86-11	30.4	22.4	2.8	39	1.9
SBB86-13D	58	33.1	4.4	6.24	1.5
SBB86-15	77.7	10.4	8.1	--	1.2
SBB86-22	9.7	60.2	22.4	1.05	0.07
SBB86-37	80	10	4.9	--	3.2
SBB86-38	63.2	17.7	6.8	6	3.1
SBB86-40	18.2	71.7	6.5	1.1	0.6
SBB86-42	47	42.1	7.3	2.9	0.8
SBB86-52	67.4	10.9	7.7	8.5	2.6
SBB86-54	8.7	77.8	9.1	0.9	0.6
SBB86-70	71.1	16.3	9.3	1.5	2.9
SBB86-86	68.4	16.7	10.7	1.4	1.4

*Sample nos. refer to those in Appendix 5.