INDUSTRIAL MINERALS, GEMS AND MINOR METALS IN THE YUKON

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PREFACE

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This paper follows a similar format used by D. Downing in his 1993 report entitled 'Industrial Minerals and Minor Metals and Their Potential for Development in the Yukon'. The report's objective is to encourage and inform mineral explorationists about industrial minerals and their potential for development in the Yukon. A discussion about gemstones and minor metals is also included, because of the potential for economic deposits to occur in the territory.

Primary sources of information compiled in this report are from government and industry commodity forecast reports, geological bulletins, papers, open file reports, industry summary reports, company property reports and maps, industrial mineral trade magazines, and through personal communications. Information about documented Yukon industrial mineral occurrences was extracted from the most recent Yukon Minfile database (Yukon Minfile 2001) and from company reports and assays.

For organizational purposes and to allow for easier reading, this report is divided into five separate chapters. A brief description of each chapter follows:

Part A - Introduction

Provides a brief general overview about industrial minerals and minor metals. Included in this chapter is:

- A general overview and introduction to industrial minerals;
- Classifications of industrial minerals;
- Methods used to explore for industrial minerals;
- Sampling methods and deposit evaluations;
- Physical and analytical testing of industrial minerals; and
- Economic and market forces and their impact on industrial minerals.

Part B – Industrial Minerals

Lists alphabetically industrial minerals, which have been documented in the Yukon or have the potential to occur in the territory. Included in each description is:

- Chemical and Physical Characteristics;
- Deposit Examples;
- General Geology;
- World Production;
- End Use;
- Quality and Specifications;
- Market Trends;
- Price;
- Economic Factors - whenever possible includes reserve and grade estimates from producing mines and other factors such as the importance of an established infrastructure, power supply or industrial demand which may have an influence on the success of any new development.
- Yukon Occurrences (including listings from Yukon Minfile).
- Exploration Guidelines to consider when searching for an industrial mineral in the Yukon.

In this report, particular attention is given to industrial minerals which are imported into the Pacific Northwest Economic Region (PNWER*) for which the Yukon may find a market.

** Formed in 1991, PNWER is a statutory public/private partnership created by the states of Alaska, Idaho, Montana, Oregon, Washington and the Canadian provinces of British Columbia, Alberta and the Yukon Territory to increase the economic well being of these regions. PNWER states and provinces represent the 11th largest economy in the world and have a combined population base of 18 million people.*

Part C - Gemstones

Describes gemstones that have been documented in the Yukon or have the potential to occur in the Yukon.

Part D – Minor Metals

Describes minor metals that have been documented in the Yukon or have the potential to occur in the Yukon.

Part E – Yukon Infrastructure

Describes Yukon infrastructure including hydro development, air and road access, and the Territory’s access to year-round ocean port facilities.

In addition, the report includes a listing of abbreviations and element symbols and a glossary of terms.

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To assist geologists, prospectors and developers in assessing which industrial minerals and minor metals should be considered targets for exploration, industrial minerals discussed in Part B, have been grouped according to their market potential and/or their likelihood of occurring in economic deposits in the Yukon.

Group 1

Consists of Yukon industrial mineral and minor metals with proven resource which could be developed, given a change in favourable market conditions:

Industrial Minerals – barite
Minor Metals – antimony, platinum group elements.

Group 2

Consists of industrial minerals and minor metals known to occur in the Yukon for which there is a reasonable chance of discovering economic deposits:

Industrial Minerals - asbestos, barite, cassiterite, chromite, clay minerals (common clays), feldspathic minerals, fluorspar, garnet, gemstones (agate, emerald, hematite, jasper, jade, lazulite, rhodonite, topaz, zircon), graphite, gypsum, limestone, magnesite, manganese oxides, magnetite, mica, nepheline syenite, olivine, peat, phosphate minerals, rare earth elements, silica and quartz, strontium (celestite), sulphur, talc, titanium dioxides (ilmenite, rutile), wollastonite, zeolite, zircon.
Minor Metals - bismuth, cadmium, chromite, cobalt, niobium (columbium), germanium, mercury, molybdenum, rhenium, selenium, tellurium, tungsten, thorium, vanadium.

Group 3

Based on favorable geology, includes industrial minerals and minor metals which, though presently not documented in the Yukon, could be expected to occur in economic deposits:

Industrial Minerals - abrasives (industrial diamond, corundum, emery, staurolite), bentonite, clay minerals, (kaolin, china clay), diatomite, gemstones (diamond, ruby, sapphire), sillimanite, andalusite, perlite, pumice, tephra.
Minor Metals – beryllium, gallium, indium, lithium, scandium,

Group 4

Includes, industrial minerals and minor metals which have good world market forecasts and/or would be sufficiently cost competitive, to encourage exploration (See Table 10):

Industrial Minerals - dimension stone, celestite, clay minerals (fire clay), gemstones (diamond, emerald, ruby, sapphire), graphite, industrial diamond, magnesite, mica, peat, phosphate, rare earth elements, talc, titanium minerals (rutile), specialty zeolite, zircon.

Minor Metals – Nearly all "minor metals" are recovered as by-products from base and/or precious metal mines, often supplementing a producer's income. All are sold on world markets at negotiated prices. When evaluating base or precious metal deposits, all anomalous minor metals should be considered as part of any subsequent production plan. Minor metals which economic forecasters have predicted have a growing world market include antimony, beryllium, bismuth, niobium (columbium), germanium, and platinum.

Group 5

Includes industrial minerals which are known to occur in the Yukon, but for which systematic field evaluation is required to document their occurrence, depositional environment, physical and chemical characteristics and reserve potential, in order to determine their development potential.

Industrial Minerals - dimension stone, limestone, structural clays (ceramic or fireclay), peat, sand and gravel deposits.

PART A

INTRODUCTION

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General Overview and Introduction of Industrial Minerals Ove

Industrial minerals and rocks, are minerals which are neither metallic nor used as fuels, but which are mined and processed for their economic use. A broader definition describes an industrial mineral as any rock, mineral, or naturally occurring substance of economic value, exclusive of metallic ores and mineral fuels, and gemstones. In essence they are the raw materials used in many industrial, agricultural and construction products. For convenience, gemstones are frequently grouped together with industrial minerals under one umbrella.

In some instances, an industrial mineral or rock has several uses. For example, magnesite is both a magnesium metal ore, and an industrial mineral used for caustic, dead-burned or fused magnesia production (Simandl and Hancock, 1996). Other minerals used for multiple purposes include silica, chromite, diamond and beryl. Diamond for example, while considered an important and highly sought after gemstone, is also considered an industrial mineral when used as an abrasive. Magnetite in western Canada is used exclusively as an industrial mineral in heavy separation mediums in processing coal.

Worldwide trade in industrial minerals is an important component of the industry and offers producers the opportunity to compete internationally as well as locally. For example, some industrial minerals such as mica, graphite and the calcined product MgO are traded worldwide because of their relative scarcity and high-unit value. Other industrial minerals such as gypsum or lime, which are commonly found in many industrialized regions, have a resulting low-unit value because of their widespread availability. These minerals are generally restricted to local or regional markets.

In Canada, industrial minerals and rock production reached a value exceeding seven billion dollars in the year 2000. As illustrated in Table 1, they represent an important contribution to the economies of most territories and provinces as well as to the prosperity of the Nation as a whole. In the Yukon, Natural Resources Canada reported 1,087 kilotonnes of sand and gravel produced during the year 2000 at a value of approximately three million dollars. No other non-metallic minerals were produced in the Territory during this report period (the most recent year in which statistics were available).

Table 1

Estimates of Non-metallic Mineral Production in Canada for the Year 2000*

Territory/Province	Value in Mllions of Canadian Dollars
Yukon*	3
Northwest Territories**	646
Nunavut	-
British Columbia	449
Alberta	657
Saskatchewan	1700
Manitoba	76
Ontario	1986
Québec,	1368
New Brunswick	243
Nova Scotia	226
Prince Edward Island	5
Labrador and Newfoundland	39

*Source: Natural Resources of Canada; * The value indicated is for sand and gravel only. No other industrial minerals are currently produced in the Yukon. ** Includes diamonds and structural materials.*

Classification of Industrial Minerals Clas

There is no single classification for industrial minerals since different end-users divide them according to their own needs and disciplines. Industrial minerals have been classified according to their geological settings, end-use, chemistry or physical characteristics. As a geologist or prospector, one useful classification, based on geological setting, is illustrated in (Table 2).

Table 2

Industrial Minerals Grouped by Geological Setting

IGNEOUS

- **Intrusive**

Alaskite
Aplite
Chromite
Corundum & Emery
Diamond
Fluorite
Garnet
Granite
Graphite
Mica
Nepheline Syenite
Olivine
Phosphate Minerals
Rare Earth Elements
Zircon

- **Extrusive**

Agate
Basalt
Hematite
Opal
Perlite
Phlogopite
Pumice & Tephra
Ruby & Sapphire
Sulphur
Topaz

- **Pegmatite**

Cassiterite
Emerald
Feldspar
Graphite
Hematite & Jasper
Lazulite
Mica
Ruby
Sapphire
Staurolite
Titanium Minerals
Topaz

- **Hydrothermal Vein and/or Stockwork**

Agate
Barite
Fluorite
Graphite
Hematite
Kaolin
Opal
Pyrophyllite
Silica & Quartz
Strontium Minerals
Topaz

WEATHERING PRODUCTS

Bentonite
Kaolin
Vermiculite

- **Residual**

Apatite
Andalusite
Chromite
Magnesite
Pyrochlor
Pyrite
Sillimanite

METAMORPHIC

Asbestos
Dolomite
Emerald
Fluorite
Garnet
Graphite
Greenstone
Jade
Lazulite
Magnesite
Magnetite
Magnesium Compounds
Marble
Rhodonite
Ruby
Sapphire
Silica & Quartz
Sillimanite Minerals
Slate
Staurolite
Talc & Pyrophyllite
Wollastonite
Zeolite
Zircon

SEDIMENTARY

- **Clastic/Placer**

Cassiterite
Clay
Corundum & Emery
Diamond
Feldspathic sand
Garnet
Magnetite
Sandstone
Titanium Minerals
Topaz
Zircon

- **Biogenetic**

Diatomite
Limestone
Peat
Phosphate Minerals

- **Chemical**

Barite
Bentonite
Borates
Gypsum
Kaolin
Manganese Minerals
Potash
Salt
Sodium Carbonate
Sodium Sulphate
Sulphur
Zeolite

Methods Used to Explore for Industrial Minerals Meth

The first step when considering an exploration program for an industrial mineral(s) is to determine whether there is a market for the mineral(s) and whether a deposit's location allows it to be economically viable.

When exploring for new industrial mineral deposits, the first basic step is to develop a business plan defining the objectives, specifications, and economic parameters for the exploration program. Within this framework, deposit parameters (i.e. location, minimum reserve tonnage, mineralogy, quality or grade mining costs) need to be established. The exploration plan should establish the probable mineralized geological settings in order to identify and characterize known deposits, occurrences and mineral target areas, and should define a specific program that will discover or identify new ore bodies. This work includes the study of known districts, deposits and occurrences, which may be applicable to the area of interest. For example, when searching for diamonds, it is important to study the geological parameters of known deposits as they may be useful in finding new occurrences.

The plan should also evaluate which industrial minerals have the best potential for commercial development. Useful criteria for evaluating a particular commodity include:

- Potential market constraints (i.e. local, domestic and/or international);
- Mining and processing parameters (i.e. cost effectiveness and whether a reliable energy source is available);
- Distance to market (i.e. transportation costs and whether they are prohibitive);
- Existing or potential competitors and consumers;
- Tenure regulations (i.e. certainty for resource ownership);
- Transportation constraints (i.e. whether the available infrastructure is sufficient);
- Environmental standards (i.e. whether they are clear and manageable);
- Social concerns (i.e. whether the community would support a development);
- Tariff restrictions (e.g. whether there are tariff restrictions on the commodity being exported).
- Added value by further processing.

Once the exploration and marketing parameters have been evaluated and a mineral(s) commodity identified, the exploration program can be implemented. During this phase the area selected may be explored by detailed geological mapping, and geophysical and geochemical surveys. Once a potentially viable deposit has been identified, the mineral occurrence must be defined spatially and mineralogically. Then, after exploration has progressed through the initial sampling, drilling and testing phases, representative bulk samples can be collected. They are tested to determine physical and/or chemical characterizations of the material, and also may be subjected to some of the end-use testing by prospective users.

One method for proving the ore reserve, is quantifying the spatial relations by volume or tonnage, and the grade or quality of mineralization in the ground. The reserve may be expressed as a “geological reserve”, the actual mineral tonnage in the ground, or as a “recoverable or mineable reserve” indicating how much material can be extracted under a specific mining plan**.** In Canada, each Territory and Province has its own tenure system and mineral definition.

Mineral title over promising industrial mineral targets is usually obtained through mineral claims, by licensing or leasing, if on government lands, or by options to lease or purchase, if on private ground. Before claiming title or ‘staking a claim’ it is necessary to review each jurisdictions (Territorial or Provincial) Mineral Act to ensure compliance with local mining laws, regulation and ownership provision.

Sampling Methods and Deposit Evaluation Samp

Properly sampling an industrial mineral occurrence is a critical step in determining its economic potential. Samples must be carefully collected so that they are not contaminated with other minerals or elements. Sample locations must be accurately documented and samples must be of sufficient size to be properly tested. As well, samples must be representative of the deposit or the mineable portion of the deposit.

When evaluating an industrial mineral prospect, there are several types of samples, which should be collected to evaluate it properly. These vary in both the effort required to obtain them and the cost required to accurately test them. Brief descriptions of some sampling methods are illustrated in Table 3:

Table 3

Common Sampling Methods for Industrial Minerals

Surface chip/grab samples	Usually easy to obtain and are useful in helping to identify the minerals in the occurrence. Samples may help in determining the potential for development.
Drill samples	Are more expensive to obtain but are essential in providing information on the change in colour and weathering with depth, the change in lithology or mineral mix, and the geological characteristics with depth.
Bulk samples	Taken from surface or at depth will give you a more representative sample than smaller samples.
Plant samples	Are used in instances where sampling an existing plant is done to obtain material for new product development or to evaluate an existing operation. In most instances, the larger the sample collected, the better.

Table 4 illustrates the sample size required for a given particle size.

Table 4

Sample Size Required for a Given Particle Size

Sample Weight (gm)										
									Safety	
								Line	#	
									#	
	100 tonnes								#	
10,000,000	10 tonnes						**Safe Side**	#		
1,000,000	1 tonne							#		
100,000	100 kg						#			
10,000	10kg						#		**Unsafe Side**	
1000	1kg					#				
100					#					
10				#						
1				#						
0.1	1µm	10µm		100µm		1mm		10mm		100mm

Source: adapted after A.G. Royle, from Edwards and Harben, 1999.
The 'Safety line' is a curve on log-log paper indicating the sample size required for a given particle size.

In simple terms, if the weight of the sample increment that is taken falls to the left of the 'safety line' it is "safe", while if it is to the right, you must take a bigger sample to ensure at least a 10 percent accuracy.

This curve can be used to reduce samples for transportation and laboratory analysis. If for example, you obtain a 50 kg sample of crude feldspar with lumps of about 25mm, you will need to crush the entire sample to about minus –1mm to split it to 100 gram samples, one of which will be sent to the laboratory. The laboratory, in turn, will have to reduce that entire sub-sample to minus –100mm in order to extract a representative 1-gram sample for dissolution and analysis.

Physical and Analytical Testing of Industrial Minerals Ana

Mineralogical and chemical analysis as well as physical testing, play important roles in determining an industrial mineral's economic and market potential. Some of the more important tests used to analyze industrial minerals are illustrated in Tables 5, 6 and 7 (adapted after Dalheim and Cox, 1989).

Table 5

Testing Industrial Minerals: Mineralogical Analysis

Visual identification	Usually done in the field, aided by a hand lens. May use simple on-site chemical testing (i.e. HCl to see if the sample is a carbonate).
Petrographic Analysis	Microscopic analysis of a thin or polished section of the mineral using transmitted or reflected polarized light. Petrography is used to determine the morphological character of minerals and their relationship to the host rock as well as alteration characteristics such as locking, grain size and mineral chemistry.
X-Ray Diffraction	A laboratory technique method of analyzing a powdered sample for its constituent crystalline phases. Every mineral has a unique pattern. The interpretation of each pattern offers an estimate of mineral concentrations. This method is a relatively inexpensive yet efficient technique for determining the mineralogy of a collected sample.
Electron Microscopy	Using this technique, a mineral sample is “excited” by a stream of electrons producing x-rays and back scattered electrons. The resulting spectra produces a chemical “map” which is used to identify the mineral by its chemistry. The drawback of this test is that it is expensive.

Table 6

Testing Industrial Minerals:Chemical Analysis

Atomic Absorption (“AA”)	An elemental analysis performed on dissolved samples. This widely used technique allows for low detection limits, reduction of matrix interferences, is widely industry accepted, and results are generally reproducible between labs.
Inductively Coupled Plasma Spectrophotometry (ICP)	A multi-element technique performed using dissolved mineral samples. Although often a lengthy process, this analytical procedure allows for multi-element analysis, a reduction of matrix interferences, and is relatively inexpensive.
X-Ray Fluorescence (XRF)	A form of multi-element analysis performed on solid or liquid samples. The strengths of XRF are that no sample dissolution is required, and it is relatively inexpensive. However, the process requires higher detection limits than other methods such as AA, and XRF is not as widely accepted as is atomic absorption.
Specific Element Analyzers	Are used in mineral analyses based upon the unique chemical property of the element in question.
Wet Chemical Analyses	Are based on the unique properties or reactions of a specific element or molecule. There are many industry dependent referee methods which are often complex, time-consuming and expensive but may be required to meet industry standards. Examples of wet chemical analyses are gravimetric, volumetric, and colorimetric analysis.

Table 7

Testing Industrial Minerals Physical Tests

Physical Tests	Physical testing of an industrial mineral determines characteristics such as hardness, strength, specific gravity, brightness, aspect ratio, grain size and plasticity. The tests are usually determined by industry and are designed by industrial organizations such as the Canadian Standard Association (CSA), the American Society of Testing Materials International (ASTMI), the Federal Food and Drug Administration (FDA) and the Technical Association of the Pulp and Paper Industry (TAPPI). The ASTMI tests are listed in a series of volumes that can be found in most technical libraries. The TAPPI standards are listed in technical monographs that can be obtained from that organization.

Ask What Tests Are Required Te

When carrying out analytical, chemical or physical testing of an industrial mineral(s), it is important to remember to ask the potential buyer or producer which tests they require. Some will be obvious, but others may not. It is also important to remember that a targeted market governs the types of tests required for a particular mineral. For example, the mineral olivine may be used for metallurgical purposes for its magnesia and silica content, or as foundry sand for its high melting point and resistance to thermal shock. Each industry will have different physical and chemical standards.

Selecting A Laboratory To Test Industrial Mineral Samples Lab

Selecting a laboratory to conduct mineral processing studies is a critical step to ensuring both the quality and accuracy of sample results. The following eleven guidelines outlined in Table 8 are useful tools when selecting a testing laboratory.

Table 8

Eleven Guidelines for Selecting an Analytical Laboratory*

1) Determine your analytical needs – characterization, specification, quality control.
2) Determine, if possible, the analytical methods required.
3) Decide on a realistic time frame for your project. Allow time for sample submittal and analysis; time to study the analytical report and discussion with laboratory personnel; allow time for repeat samples and additional samples if necessary.
4) Plan a preliminary budget.
5) Call the laboratories. You can start with those recommended by colleagues, clients or even those listed in your telephone directory's yellow pages.
6) Establish a "contact" at the laboratory (preferably, a technical person who understands your analytical goals). Ask the person to send you a price list and any descriptive literature the laboratory publishes.
7) Repeat number 6 for at least two laboratories unless you have very sound reasons for selecting the first laboratory you contact.
8) Read the laboratory's literature and price lists before you discuss specifics with them.
9) Call the laboratory contact to discuss your specific analytical requirements. Ask about detection limits, accuracy, quality control procedures, reporting format, and turnaround time and price, as they apply to your samples. The information you collect should contain at least some statement about detection limits and the analytical methods used. Get a written bid from the laboratory if the prices and/or turnaround time for your samples are not given in the standard price list.
10) Submit hidden replicate samples and standard reference materials (if they exist for your particular analytical tests) to check the accuracy and consistency of your laboratory results throughout the project.
11) Discuss and consult with an industrial mineral specialist of a territorial or provincial government, the Geological Survey of Canada and/or an industrial mineral consultant.

Source: adapted after Dalheim and Cox

Economic and Market Forces and Their Impact on Industrial Minerals For

Economic evaluation of industrial minerals is an on-going process done at each major business decision point. If done correctly, this prevents the continuance of a project or venture long past the point where it should have been identified as unprofitable or unattractive. It is important to remember that a good industrial mineral geologist or prospector is not only knowledgeable of exploration techniques used to locate undiscovered deposits, but will also pay attention to the marketing aspects of the commodity and its market trends.

Industrial Mineral Markets Mar

The business of industrial minerals has changed in recent years, and generally has become more sophisticated. This is a result of market forces whereby consumers have increased their qualitative and quantitative demand on suppliers. In order to compete, industrial mineral suppliers have accommodated these changes by paying attention to the most critical factors that affect markets. A summary of these factors is illustrated in Table 9.

Table 9

Factors Which Affect Industrial Mineral Markets

Physical Properties	Some industrial minerals such as fluorspar, borates and salt, are valued for their chemical and/or metallurgical properties, but most minerals physical properties or characteristics, are of primary importance. For example, the mineral olivine can withstand very high temperatures making it useful as foundry sand.
Rigid specifications on the part of consuming industries	Modern methods of manufacture require raw materials with a high degree of uniformity. For example, in glass making, there is no “slagging stage” and what goes in stays in. Therefore, precise control of the quality of raw materials used to manufacture glass is absolutely essential.
Increasingly elaborate processing techniques	Industry is increasingly using more sophisticated processing techniques, e.g., kaolin, mica, talc and other value-added fillers may be micronized and further processed (like surface coated) to meet manufacturing requirements for new products.
Development of new applications	The development of new applications for industrial minerals can result in their enhanced use. For example, minerals such as kaolin, talc, mica used as fillers in rubber, paper, paint and plastics, through new applications can contribute to a product’s electrical conductivity or add to a product’s flexural strength.
Increased government involvement	Government policies or programs can have an impact on an industrial mineral supply and/or market; e.g., government-imposed prices, nationalization of an industry, saturating a market with an industrial mineral to raise revenue. In Canada, changes in land tenure or in a mineral’s definitions may affect or impact supply or market availability.
Concern about environment and health	Issues related to the environment and health such as land-use zoning faced by gravel-pit or stone quarries, or concerns over health hazards, may affect a whole industry, e.g. the asbestos industry.
Major shifts in emphasis within certain industries	A good example of this is the sulphur industry, where there has been a marked decline in the production of elemental sulphur by the Fraseh process, with a concurrent increase of involuntary production of sulphur from the refining of crude oil and sour natural gas.
International trade in industrial minerals	For many years minerals such as sheet mica and industrial diamonds have been shipped overseas. Today, bulk substances such as phosphate rock have joined them. Even crushed granite aggregate is now moving from Scotland across the Atlantic Ocean to Texas (due to a combination of circumstances which include a large-scale quarry adjacent to a deep-water port, operated by a company that owns ships requiring a back-haul to a region of the United States (which has a shortage of these good-quality aggregates)
Diversity of supply	A North American manufacturer’s security of supply can be an important fact in long term planning. For example, users of chromite, who must rely on supplies from Russia, South Africa, or the Philippines may wish that chromite deposits were more equitably distributed and would support new developments in North America.
Industrial complexities	Changes in sulphur supply described above, has had a profound effect on the sulphur industry. The takeover of soda ash markets, at least in North America, by the mineral trona, is another marked change, as is lithium production from brines in South America.
Timing of a market study	A critical factor of an industrial minerals exploration program is knowing when to commence coordination of a market study with the technical consideration of geology and mineral processing. Early evaluation of the markets is essential, since there is no sense in expending large sums of money on a project, if there is no suitable market for the mineral.

Source: adapted after Dalheim

Freight Rates and Terms (Shipping) Fre

Mineral freight is transported on either handysize vessels (26,000 to 30,000 DWT), handymax vessels (38,000 to 45,000 DWT), Panamax vessels (60,000 to 75,000 DWT) or Capsize vessels (100,000 to 190,000 DWT). Rates for freight are controlled by supply and demand factors, essentially driven by the difference between demand for ships in a region and availability in that region.

Contracts are based on International Commercial Terms, (INCO terms) which define the division of costs and risks between buyer and seller, the transport of goods, and import and export clearance. The terms are published by the International Chamber of Commerce and are recognized worldwide (Sims, 1999).

For a list of terms you can contact the International Chamber of Commerce at the website provided at the end of this report.

The Effects of Currency Fluctuations on Industrial Minerals Cur

The global industrial minerals industry is essentially a dollar industry. Despite the fact that companies usually pay for their impute in domestic currencies, the price quoted for the final product is more often than not in dollars. Because of this, currency can play an important part in competitiveness between producers in different regions. For example, in the late 1990's, the sudden decline in Asian economies, sometimes referred to as the "Asian crisis", resulted in price rises for minerals exported by the west to Asia. These price rises were not accepted in 1998, and volumes suffered. This in turn resulted in excess material on the non-Asian markets, itself putting downward pressure on prices. Minerals as diverse as soda ash, rutile, zircon, salt, sillimanite minerals, lithium minerals all felt the effects of the drop in Asian demand, either through lower prices, or a fall-off in sales (Sims, 1999).

Negotiating Industrial Mineral Prices Neg

Prices are fundamental to the industrial minerals industry. Finding out about prices, however, is not always easy, as there is no open forum where prices are settled, no formal exchanges, and no futures markets. Prices of industrial minerals are basically the result of private negotiations between buyers and sellers. This is very different from the precious and base metal industries, where prices for metals are set and publicly reported daily. It is not unusual for the same material to be sold to different end users at a very different price.

For geologists, and prospectors wishing to stay informed about the value of a particular industrial mineral, they must be prepared to continually communicate as much as possible, with industrial mineral producers, consumers, traders and industry observers. This process is constant, but effective, and is perhaps the best way to stay informed about the industry.

In this report, prices quoted for specific industrial mineral(s) are obtained from trade magazines and from industry and government reports. These are publicly available and are a good source of information. However, prices quoted, represent a snapshot of the industrial minerals marketplace, and may not actually reflect prices negotiated by producers and receivers in a demanding and competitive marketplace. Table 10 illustrates reported industrial mineral, gemstone and minor metals prices during 2002.

Table 10
Industrial Minerals and Minor Metals by Price +

C$1.50- 15 per tonne *(US$1-10 per tonne)*				
Aggregates	Gypsum		Sand & Gravel	
C$15-150 per tonne *(US$10-100 per tonne)*				
Aggregates	Flurospar	Magnesium Compounds*	Potash	Strontium Minerals (Celestite)*
Barite	Fuller's Earth	Magnetite	Pyrophyllite	Sulphur
Bentonite	Graphite*	Olivine	Salt	Talc
Clay	Gypsum	Peat*	Silica	Titanium Minerals (rutile)*
Chromite	Kaolin	Perlite	Sodium Carbonates	Zeolites
Feldspathic Minerals	Lime	Phosphate*	Sodium Sulphates	
C$150-600 per tonne *(US$100-400 per tonne)*				
Asbestos	Diatomite	Lime	Potash	Talc
Clays*	Emery	Magnesium Compounds*	Rare Earth Elements*	Titanium Minerals (Rutile)*
Barite	Feldspathic Minerals	Magnetite	Salt	Wollastonite
Bentonite	Fluorspar	Manganese Oxides	Silica	Zeolites
Cassiterite	Garnet	Mica	Sillimanite	Zircon
Chromite	Graphite*	Olivine	Sodium Carbonate	
Corundum	Kaolin	Perlite	Staurolite	
C$600-1500 per tonne *(US$400-1000 per tonne)*				
Asbestos	Ceramic clay*	Mica	Talc	Zeolite (specialty)*
Borates*	Graphite*	Rare Earth Elements*	Titanium Minerals (Rutile)*	Zircon*
C$1500-15,000 per tonne *(US$1000-10,000 tonne)*				
Asbestos	Ceramic Clay*	Minor Metals*	Talc	
Boron	Mica	Rare Earth Elements*	Zeolites (specialty)*	
Over C$15,000Over *(US$10,000 per tonne)*				
Abrasives (industrial diamond)	Gems*	Rare Earth Elements*	Minor Metals*	

* Although subjective, future world economic growth is predicted for these commodities.

\+ Note – currency exchange rates between Canada and the United States fluctuate daily.
Prices obtained by producers and buyers very widely according to type, source, quality, quantity purchased and application. The following quotations can only serve as a guide to the prices obtained. The unit of weight is the tonne. Prices are quoted in both Canadian and United States dollars with a currency exchange calculated at (C$1..50 = US$1.00).

The Role of Tariffs Tar

To protect domestic markets and/or workforces, countries may impose tariffs on imported or exported industrial minerals. Rates set for tariffs may vary widely between countries and producers. Importers must remain aware of restrictions such as tariffs, which may affect the marketplace. Information about tariffs can be obtained quickly from government agencies tasked with reporting these import/export restrictions. For example, import tariffs on the minerals of beryllium by the United States, are reported under mineral commodities with the United States Geological Survey's website.

PART B

INDUSTRIAL MINERAL COMMODITIES

IND

ABRASIVES ABR

Abrasives are natural or manufactured substances that are used to abrade, clean, etch, grind, polish, scour or remove materials by rubbing action (e.g. grinding wheel), or impact (e.g. pressure blasting). They play an important role in the fashioning and finishing of many consumer products that have a wide range of end-use applications.

Popular natural abrasives discussed in this report include a number of minerals (in decreasing order of hardness) such as industrial diamond, corundum, emery, garnet, and staurolite. Other mineral abrasives (not discussed in this report) can include silica sand, copper or nickel slag and grits but at present they may cause serious health risks, and so their use is generally discouraged.

Manufactured abrasives generally dominate high-grade abrasive markets, as opposed to natural abrasives, since their superior physical properties and more uniform quality can be tailored to meet user needs. Manufactured abrasives include aluminum-zirconium oxide, boron carbide, fused aluminum oxide, metallic shot and grit, and silicon carbide.

The most important physical properties for abrasives are hardness (scratch hardness), toughness (rigidity), lack of friability, grain shape and size (roundness and angularity), character of fracture (cleavage) and purity (uniformity). Additional considerations include thermal stability, bonding characteristics, cost, and availability. To follow is a description of five abrasives that have the potential to occur in economic concentrations in the Yukon.

INDUSTRIAL DIAMOND IND

Chemical and Physical Characteristics

Industrial diamond (C) is a naturally occurring crystalline form of carbon dimorphous with graphite, and being the hardest substance known, makes it an excellent abrasive. It often occurs in octahedrons with rounded edges or curved faces. Pure diamond is colourless or nearly so, becoming tinted yellow, brown, red, orange, green, blue, violet, or black with impurities such as vanadium, chromium or iron.

World Production

Natural diamond resources have been discovered in more than thirty-five countries but account for less than ten percent of all industrial diamonds used. Synthetic diamonds account for the remainder, and at least fifteen countries have the technology to produce these diamonds.
World production of industrial diamonds is illustrated in Table 11.

Table 11

Diamonds (Industrial): Estimated World Mine Production 2002 (millions of carats)

Australia	230
Botswana	200
Brazil	15
China	20
Congo (Kinshasa)	350
Russia	65
South Africa	150
Other countries	200
World total (rounded)	1,200

Source: Olson, 2001

End Use

Diamond is more than twice as hard as cubic boron nitride or silicon nitride (manufactured abrasives) its nearest competitor. Because it is the hardest substance known, diamond has been used for centuries as an abrasive in grinding, drilling, cutting, and polishing. Industrial-grade diamond continues to be used as an abrasive for many applications.

Quality and Specifications

Industrial diamonds are divided into four categories (adapted after The Industrial Minerals HandyBook II, pg. 54):

1. Industrial stones (Fine-industrials): are large stones unsuited for gem use due to shape, mechanical imperfections, or colour.
2. Bort: a low-grade (small irregular shape with flaws and imperfections) natural industrial diamond crushed into finer grades is used chiefly in drilling (drilling bort) or as grit, powder or dust. Diamond-grit ranges in size from very coarse (2.0-2.4 mm) to fine (38-44µm) to a very fine micron powder.
3. Carbonado (Black diamond): a compact, opaque dark grey to black diamond, graphite, amorphous carbon mixture, with no cleavage.
4. Ballas (Short-bort): a dense globular aggregate that is extremely hard and tough.

Market Trends

World consumption of industrial diamonds during 2001 was estimated to be about 1.15 billion carats. World demand for diamond grit and powder is expected to grow during the next five years. Most of the dramatic increase in demand for industrial diamond will likely occur in the construction sector, as both the American (the world's largest market for industrial diamond) and the Canadian highway systems are upgraded. Industrial diamonds coat the cutting edge of saws used to cut cement in highway construction and repair work (Olsen, 2000).

Price

Natural and synthetic industrial diamonds differ significantly in price. Natural industrial diamond normally has a more limited range of values, with prices varying during 2000 from US$0.45 per carat for bort-size material, to about US$7 - 25 per carat for most stone products. Synthetic industrial diamond with a much larger range of prices ranged from US$0.10 per carat to 0.95 per carat for grinding and polishing materials, to as high as US$4.75 per carat for sawing and drilling stones (Olson, 2000).

Additional Information

Natural industrial diamond is found in the same deposits as gem quality stones. Additional information including deposit examples, general geology, economic factors, potential Yukon occurrences and exploration guidelines are included in this report under Gems (See Diamond).

CORUNDUM AND EMERY COR

Chemistry and Physical Characteristics

Corundum (Al_2O_3) occurs as shapeless grains and masses or as variously coloured rhombohedral crystals (such as prisms or tapering hexagonal pyramids) including the gem varieties such as ruby and sapphire. Corundum is extremely tough, has a hardness of 9 on Mohs' scale and varies in colour from grey, green, red or tan.

Emery is a dark (grey-black) granular, impure variety of corundum that contains varying amounts of iron oxides (usually magnetite or hematite). It has a specific gravity of between 3.2 and 4.5 and a hardness of 7.25. It is formed by the intergrowths of corundum with magnetite, hercynite or hematite.

Deposit Examples

Blu Starr (BC Minfile 82FNW259), (British Columbia, Canada); Elk Creek, Bozeman and Bear Trap deposits (Montana, USA); Gangoda and Tannahena occurrences (Sri Lanka).

General Geology

Corundum and emery deposits occur in alumina-rich metasediments and ultramafic-related corundum deposits. The latter is discussed in this report under Gems (Sapphires and Rubies).

Corundum in alumina-rich metasediments - corundum deposits can occur in alumina-rich metasediments as porphyroblasts or idiomorphic, xenomorphic or skeletal crystals within high-grade, regionally metamorphosed belts. In this environment, it is confined to specific metamorphic layers and concordant lenses of alumina-rich gneiss and schist. Emery commonly forms in medium to high-grade metamorphic environments.

Corundum, in gneiss, occurs mostly in fold belts or deep cratonic environments exposed in thrust belts or by erosion. These gneiss and schist are associated with sillimanite-garnet-biotite gneiss, kyanite-mica schist, quartzite, clinopyroxenes, pegmatite, syenite or alkaline intrusions, anorthosites, charnockites, migmatites, granitic and intermediate intrusive rocks, quartz-mica schist, granulites, aplites, marbles, cordierite-bearing gneiss amphibolite and wollastonite-scapolite rocks. Rocks hosting metasedimentary emery lenses commonly have a lower metamorphic grade equivalent than the above host lithologies.

Corundum deposits are stratabound with discontinuous layers and lenses from 20 to a few metres thick extending laterally for tens to hundreds of metres. These layers are usually strongly deformed and coarse-grained. Emery may form lenses from 5 to 50 metres thick and more than 100 metres long.

Corundum-bearing metasediments are believed to form by the isochemical metamorphism of alumina-rich regoliths, including bauxite protoliths formed under conditions of tropical weathering. Hydrothermal alteration zones containing clays, alunite and diaspore and igneous rocks, such as nepheline syenite and anorthosite, are also considered as favourable, pre-metamorphic protoliths. Alternatively, some deposits are interpreted to have formed by preferential concentrations of alumina in restites associated with extreme metamorphism, migmatization and granitization.

Associated deposit types include sillimanite deposits, corundum and garnet placer deposits. Crystalline flake graphite vein deposits and muscovite and quartz feldspar pegmatite may occur in the same geological settings (Simandl and Paradis, 1999).

World Production

World corundum and emery (non-gem variety) production is estimated at 50 to 60 thousand tonnes annually (Harben, 1995). Corundum and emery produced in the United States is estimated at 10,000 tonnes per year (Simandl and Paradis, 1999).

End Use

Corundum can be sized for use as a polishing abrasive for use in optical grinding, and metal burnishing, and as an abrasive for lapping medium-hardness metals. It is also used as a filler and as a friction powder.

Emery, an impure corundum, is used as a coated abrasive and/or bonded abrasive for use in tumbling or de-burring media including de-husking and polishing of rice; for medium to low pressure blasting; for stone surfacing; rough grinding of glass and stone sawing; and metal polishing. Non-abrasive uses of emery include its use in the production of nonskid wear resistant floors, as an epoxy coating, as a grouting agent, and as a concrete surface hardener or nonskid dusting agent, for oily floors.

Quality and Specifications

Tables 12 and 13 illustrate the commercial specifications for corundum and emery (adapted after The Industrial Minerals HandyBook II, pg. 52).

Table 12

Commercial Specifications for Corundum (%)

Al2O3	86.55
SiO2	7.56
TiO2	2.88
Fe2O3	0.45
Na2O	0.14
MgO	0.98
Cr2O3	1.12
CaO	0.32
Average particle size	4.5-42 µm

Table 13

Commercial Specifications for Emery*

	USA Oregon Emery	***Turkey Etibank***	***Turkey Ranar Mineral***	***Turkey Lutfullah***
Al2O3	50-55	54-56	61.02	64
Fe2O3	20	25-27	24.95	25
SiO2	28	3-5	7.96	4
TiO2	2	2.5	2.60	3
CaO	-	1.5	0.70	0.2
LOI	-	8.0	2.25	3
Hardness	8-9	8-9	8.5	8-9

** Average particle sizes for Turkish crude emery: -240+50mm, -150+50mm, and –50+10 mm which are further processed into about 35 grades ranging from 2.36mm to 53µm plus emery flour.*

Market Trends

Markets for corundum and emery are dependent on the health of manufacturing industries such as steel and glass. Competition from synthetic abrasives will continue to grow and will have a negative impact on natural abrasives.

Price

Prices (reported by Industrial Minerals, No. 419) in 2002 were:

- Emery, coarse grain CIF £210-275
- Emery, medium and fine grain, CIF £265-295

Economic Factors

Typically, corundum-bearing deposits contain 5 to 28 percent corundum with ore reserves usually less than 7500 tonnes. In emery rock the corundum content may reach as high as 70 percent.

Synthetic corundum competes with natural corundum in gem applications and has replaced it in most high technology industrial applications.

Yukon Occurrences

There are no reported corundum and/or emery occurrences listed as a commodity in Yukon Minfile 2001.

Exploration Guidelines

Good exploration targets for corundum and emery occurrences are aluminous lithologies within metasedimentary sequences in high-grade metamorphic belts. Of particular focus should be contacts between silica-deficient intrusions and alumina-rich metasediments.

Magnetite-bearing emery deposits may be detected by magnetometer surveys, while corundum and associated minerals (sillimanite, garnet, sapphirine and pyroxene) as well as emery can be detected through analysis of heavy mineral samples from streams, lakes, tills and residual soils.

GARNET GARN

(See under Garnet in this report)

STAUROLITE STA

Staurolite [$(FeMgZn)_2Al_9Si_4O_{23}(OH)$] is a common constituent in rocks (such as mica schist and gneiss). Staurolite is red brown to black in colour, has a specific gravity of 3.6 and a hardness of 7 to 7.5. It is often twinned, and may resemble a cross.

Deposit Examples

Willis Mountain, Virginia and Graves Mountain, Georgia, (United States); Sonapahar area (India).

General Geology

Staurolite, a metamorphic mineral typical of medium-temperature conditions (characteristic of the upper part of the amphibolite facies), is associated with garnet and kyanite. It is occasionally found in some pegmatite and contact metamorphic rocks. Because of its hardness (7-7.5), and insolubility it is also often found in alluvial sands. Staurolite is a byproduct of heavy mineral production and it also may be a co-product of andalusite mining from either hard rock or residual deposits (for additional information on geology see under Sillimanite Minerals).

World Production

Staurolite is a byproduct of titanium placer mining. The amount produced varies with titanium mineral production.

End Use

Fine and medium grades of staurolite concentrates are used as a loose-grain blasting abrasive for metal cleaning and for buildings. Coarse grades are used for engraving and polishing marble monuments and headstones. Staurolite is also used in nonferrous foundry mold sand applications (aluminum, brass, bronze, magnesium) and in ferrous metal molds (e.g. copper). The mineral's resistance to weathering and chemical attack, lends its use as a filler in paint primers. It also is used as a source for Al_2O_3 and Fe_2O_3 (to replace clay and iron) in Portland cement manufacturing.

Quality and Specifications

Table 14 illustrates specifications required for staurolite by use.

Table 14

Commercial Specifications of Staurolite

US Standard mesh size; (% retained)	*Opening µm*	*Coarse (Cement)*	*Starblast® (Abrasive)*	*Biasil® (Foundry)*
20	850	1	-	-
30	600	3	<1	-
40	425	23	4	<1
50	300	51	11	5
70	212	13	20	19
100	150	9	45	53
140	106	-	17	19
200	75	-	3	3
270	53	-	<1	<1
Pan	<53	Trace	Trace	Trace
APS (µm)		317	215	188

Source: adapted after The Industrial Minerals HandyBook II, pg.175

Market Trends

Fused alumina (bauxite and alumina), corundum/emery, industrial diamond, garnet, iron oxide (magnetite) and olivine are some of the minerals which can be substituted or used as an alternative to staurolite. Generally, market conditions are small and local for staurolite.

Price

Staurolite is priced to sit between silica sand/slags and garnet in the range of blasting abrasives which in 2002 was listed at between US$180-240 per ton (Industrial Minerals, No. 419).

Economic Factors

Because it is a byproduct of titanium mineral mining, the price is unrelated to the cost of production.

Yukon Occurrences

There are no staurolite occurrences listed as significant commodities in Yukon Minfile 2001.

Exploration Guidelines

(See under Sillimanite Minerals in this report).

ASBESTOS ASB

Chemical and Physical Characteristics

Asbestos is the generic name given to six minerals namely chrysotile, crocidolite, amosite, anthophyllite, tremolite and actinolite. The only commercial asbestos mineral used today is the natural fibrous hydrated silicate chrysotile [$Mg_3Si_2O_5 (OH)_4$]. This green, greyish-white to yellow or brown fibrous variety of serpentine (asbestos) has a characteristic structure with individual layers which are fibrous in appearance. Asbestos is semi-hard (2.5-4), light, exhibits no cleavage, but can be divided into elastic fibres flexible enough to be woven.

The asbestos minerals are a product of metamorphism, with chrysotile being the fibrous form of serpentinite. Deposits are found in either ultramafic rocks or those derived from dolomitic limestone. The property common to all asbestos minerals is a fibrous crystal habit, characterized by closely packed crystals that have a high aspect ratio, tensile strength and flexibility. Asbestos fibres are non-flammable and so are very heat and chemical resistant.

Deposit Examples

Clinton Creek (Yukon Minfile 116C 025), Yukon; Cassiar (BC Minfile104P 005), McDame (BC Minfile 104P 084), British Columbia; Thetford Mines, Black Lake, Asbestos Quebec, (Canada); Coalinga, California, (United States); Barraba, New South Wales, (Australia); Barberton, Transvall, (South Africa).

General Geology

Chrysotile asbestos deposits develop in ultramafic rocks under low grade metamorphic conditions with temperature of 300 ± 50ºC and water pressure less than 1Kbar.The asbestos forms as a result of fluid flow, where water gains access to serpentinized ultramafics along fault and shear zones. The deposits occur in accreted oceanic terranes, usually as part of an ophiolite sequence or within alpine-type ultramafic rocks. They are also found in syn-volcanic ultramafic intrusions of komatiitic affinity in Archean greenstone belts.

Chrysotile occurs as cross-fibre or slip-fibre stockworks, or agglomerates of finely matted chrysotile fibre. Deposits are usually equidimensional zones from 100 to 1000 metres in diameter with vertical mineralized zones of up to several hundreds of metres. Asbestos veins fill tension fractures in the serpentinized ultramafics or form a matrix of crushed and brecciated serpentinite which can grade from frequent stockwork in the centre, to less frequent crosscutting veins near the edges of the deposit. Individual veins may be up to several metres in length but usually are less than one centimetre thick.

Serpentinization may be pervasive but can be fracture controlled with incomplete serpentine surrounding peridotite. Since serpentinization is a multiple stage process, which can be either prograde or retrograde, many deposits contain minerals that do not form in the same stability field. These include brucite, magnetite and possibly antigorite and lizardite.

In some deposits there may be a spatial association (but not a genetic relationship) with podiform chromite deposits and jade in ophiolitic sequences. Cryptocrystalline magnesite veins, ultramafic-hosted talc-magnesite and anthophyllite asbestos deposits may be genetically related (Hora, 1999).

World Production

World producers with the amounts each produced in 2001, are listed in Table 15.

Table 15

2001 Estimated World Production and Main Producers of Asbestos (tonnes)

Country	*Production*
Russia	750,000
China	360,000
Canada	340,000
Brazil	170,000
Zimbabwe	120,000
Kazakhstan	235,000
Swaziland	10,000
South Africa	15,733
United States	5,260
Others	44,007
World Total	2,050,000

Source: Virta, 2001

At present, about 70 percent of Canadian production is exported to Asia, 19 percent to South American countries, six percent to European nations and five percent to other world destinations (Canadian Minerals Yearbook 1999). Canada supplied 97 percent (12,700 tonnes) of the asbestos that was imported by the United States (Vitra, 2001).

End Use

Asbestos is used in the manufacture of asbestos cement products such as pipe and sheet products, particularly in developing countries, owing to its cost effectiveness, and its resistance to the effects of damp, warm climates. The mineral is also used in asphalt and vinyl flooring tiles, fireproofing insulation, reinforcing agents, plastics, paints and seals.

Major producers classify asbestos into grades based on the type of asbestos, fiber length, and surface area. The length of fiber dictates its use. For example, in decreasing length, chrysotile is used in textiles, clothing, packing, brake linings, electrical insulation and asbestos-cement pipe.

Quality and Specifications

The length of the asbestos fiber is a critical parameter. Lengths vary significantly within and between deposits. Different regions of the world have their own classification system for asbestos. In Canada, chrysotile fibres are classified into seven groups, each one with its own sub-category, with the longest fibers assigned to Group 1 and the shortest to Group 7 (Table 16).

Table 16

Quebec Asbestos Mining Association - Asbestos Grades

Application	*fi inch oz.*	*4 mesh, oz.*	*10 mesh, oz.*	*Pan, oz.*
Long fibers				
Group 1	Crude-cross fiber veins having 19 mm staple and longer.			
Group 2	Crude-cross fiber veins having 9.5-19mm staple.			
Group 3 (textile or shipping fibres)	2.0	8.0	4.0	2.0
Medium fibers				
Group 4 (asbestos cement filler)	0	1.5-7.0	6.0-10.0	3.0-5.0
Group 5 (paper stock grade)	0	0-0.5	8.6-12.0	4.0-7.4
Group 6 (paper and shingle fillers)	0	0	6.0-7.0	9.0-10.0
Short fibers				
Group 7 (shorts and floats)	0	0	0-5.0	11.0-16.0

Source: Sims 1999, pg. 16. Note- Groups 3,4,5,6 and 7 are all used in producing asbestos cement

Market Trends

Although asbestos has proven to be a hazardous substance to health, it is still produced in various applications throughout the world. Its high tensile strength, chemical and thermal stability, high flexibility, low electrical conductivity and large surface area complement its versatility and cost effective use in cements and structural products, gaskets, and friction products.

For many years traditional markets for asbestos have been replaced by a variety of substitute materials including fiberglass reinforced products, glass and mineral wool, calcium silicate, ceramic fiber, carbon fiber, mica and wollastonite. With the economic recovery of the Asian region (Thailand, India, Malaysia, Indonesia and South Korea), worldwide chrysotile consumption is expected to increase by 8 to 10 percent over the next several years.

In September 2000, the World Trade Organization (WTO) ruled that the French ban of January 1997 on all imports of products containing asbestos, was legal on health grounds. It is expected that this will have an impact on future Canadian exports of asbestos (Canadian Minerals Yearbook, 1999). While Canada is appealing this decision, the expected ban across Europe which will be imposed by the European Union by 2005, will negatively impact future exports of asbestos to Europe and potentially to other regions of the world (Virta, 2001).

Price

Price is dependent on the length and quality of asbestos fiber. The following prices for Canadian asbestos (chrysotile) was reported in Industrial Minerals, No. 419, in 2002.
Canadian chrysotile ex-mine:

- Group No 3 C$1,494-1,803; Group No 4 C$1,030-1,442; Group No 5 C$684-950; Group No 6; C$425-610; Group No 7 C$210-435

Economic Factors

Fiber content in commercial deposits ranges from 3 to 10 percent with reserve tonnages of between 500,000 and 150 million tonnes. For example, in the Yukon, the Clinton Creek deposit produced 15 million tons grading 6.3 percent asbestos fiber (Hora, 1999).

Yukon Occurrences

Thirty-five asbestos deposits and occurrences are described in Yukon Minfile, 2001. Of these, 27 occurrences have been described as major deposit commodities (Table 17; Figure 1).

Table 17

Yukon Asbestos Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1*	105B 52	105B/16	MARK	SMT	UM	60º57’53”/130º02’16”
2*	105C 010	105C/5	RIBA	CCT	UM	60º24’46”/133º50’38”
3*	105C 011	105C/5	SEA FORTH	CCT	UM	60º25’49”/133º44’36”
4	105D 048	105D/14	EFFIE	NST	UM	60º58’29”/135º9’38”
5	105D 069	105D/8	MARSH	CCT	Magmatic	60º21’43”/134º11’22”
6	105D 070	105D/9	LAVALEE	CCT	UM	60º34’47”/134º03’24”
7*	105F 005	105F/12	DUNITE MTN.	SMT	UM	61º37’25”/133º53’54”
8*	105F 009	105F/6	DODY	SMT	UM	61º16’00”/133º07’49”
9*	105F 063	105F/6	RHYORCHUK	SMT	UM	61º18’18”/133º11’39”
10	105G 016	105G/6	EL	YT	V	61º28’26”/131º18’42”
11	105G 048	105G/12	ELDORADO	YT	V	61º42’55”/131º42’45”
12	106D 004	106D/1	BAG	MP	V	64º09’41”/134º07’49”
13*	115A/044	115A/5	ISLAND	WT	UM	60º16’30”/137º35’21”
14*	115G 010	115G/6	DUKE	WT	UM	61º18’52”/139º11’39”
15*	115G 065	115G/11	TINCUP	NT	UM	61º41’31”/139º20’40”
16	115I 069	115I/4	SCHIST	NT	?	62º01’42”/137º45’23”
17*	115O 047	115O/13	INDIAN	SMT	UM	63º45’34”/139º42’07”
18*	115O 121	115O/15	ASBESTOS BLUFF	SMT	UM	63º58’57”/138º46’03”
19*	115P 019	115P/3	ROSEBUD	YT	UM	63º13’02”/137º24’25”
20*	116B 011	116B/3	TITO	SMT	UM	64º02’57”/139º22’23”
21*	116B 012	116B/3	RICKY	SMT	UM	64º04’04”/139º24’32”
22*	116B 044	116B/5	TOC	SMT	UM	64º17’59”/139º57’47”
23*	116B 117	116B/3	TOS	SMT	UM	64º05’25”/139º15’24”
24*	116C 025	116C/7	CLINTON CREEK+	SMT	UM	64º26’21”/140º42’58”
25*	116C 026	116C/7	EMU	SMT	UM	64º25’52”/140º38’08”
26*	116C 033	116C/8	UTE	SMT	UM	64º18’25”/140º11’47”
27*	116C 119	116C/7	DODGE	SMT	UM	64º27’09”/140º42’31”
28*	116C 120	116C/7	JUDY	SMT	UM	64º26’32”/140º37’33”
29*	116C 121	116C/7	SUM	SMT	UM	64º28’44”/140º45’20”
30*	116C 122	116C/7	DATES	SMT	UM	64º26’47”/140º46’47”
31*	116C 123	116C/8	CHUDY	SMT	UM	64º27’14”/140º29’54”
32*	116C 129	116C/8	TJOP	SMT	UM	64º20’43”/140º01’55”
33	116C 141	116C/7	CAROL	SMT	UM	64º26’42”/140º40’51”
34*	116C 144	116C/8	BROWNIE	SMT	UM	64º17’42”/140º14’44”
35*	116C 145	116C/7	ROSE	SMT	UM	64º23’43”/140º38’16”

* *Listed as a major commodity in Minfile 2001.* + *Past producer*
SMT (Slide Mountain Terrane), CCT (Cache Creek Terrane), WT (Wrangellia Terrane), NT (Nisling Terrane), YT (Yukon Tanana Terrane), MP (Mackenzie Platform), UM (Ultra Mafic), NST (Northern Stikine Terrane), M (Magmatic), V (Volcanogenic).

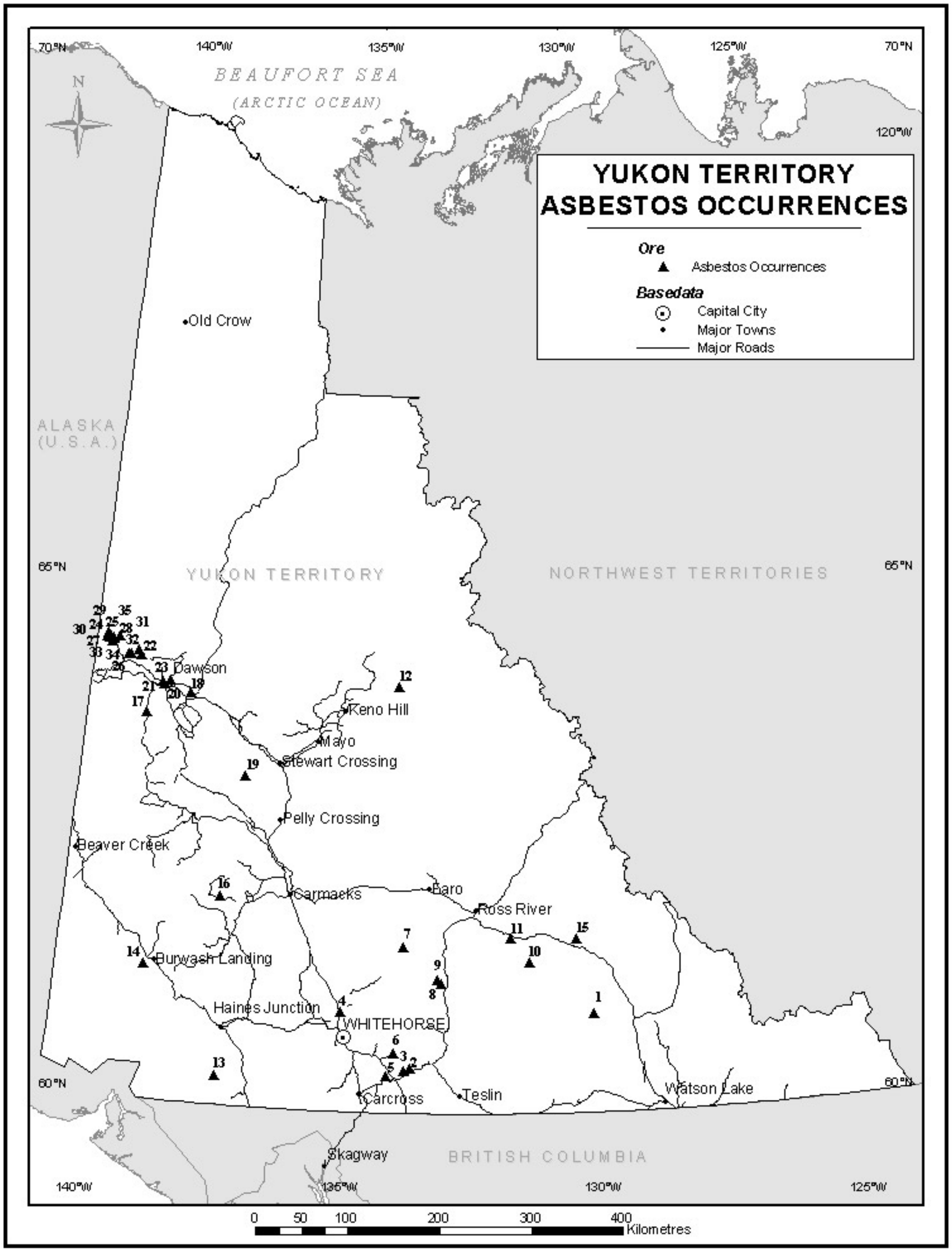


Figure 1. Yukon Asbestos Occurrences Fig1

Exploration Guidelines

Prospecting massive, ultramafic bodies that are partly or fully serpentinized along faults and shear zones are good exploration targets for asbestos. Magnetite, which is a product of serpentinization and the formation of chrysotile can produce well defined, magnetic anomalies when using gravity surveys. In geochemical surveys, asbestos fibers are readily detected in soil samples. Some very short fiber length deposits (like

Coalinga in California) may be lacking visible fibers in spite of having an asbestos content of over 50 percent – these fibers will appear like massive shear zones and be very inconspicuous.

In the Yukon, ultramafic rocks in the Kluane, Campbell Ranges and near Teslin, would be good potential exploration targets for asbestos occurrences.

BARITE BAR

Chemical and Physical Characteristics

Barite ($BASO_4$), a commercial source of barium, can appear colourless, yellow, red, green or even black when inclusions of bituminous matter are present. The mineral is semi-hard (2.5-3.5), very heavy (S.G. 4.8), and in ore is laminated, layered or massive. Witherite ($BaCO_3$), currently a minor source of barium, is a semi-hard (3-3.75), fragile, transparent or translucent mineral with a glassy to resinous luster. It becomes fluorescent in ultraviolet light.

Deposit Examples

Barite - TEA (Yukon Minfile 105O 020), Yukon; Kwadacha (BC Minfile 094F 020), British Columbia, (Canada); Greystone, Nevada, (United States); Fig Tree and Mabiligwe, (South Africa); Guangxi Province, (China).
Witherite - El Portal, California (United States); Sardinia (Italy); Chengkou and Ziyang, (China).

General Geology

Barite deposits are principally vein/cavity infills, bedded/stratiform bodies or surface weathering products of underlying bedrock. Although barite deposits are relatively common worldwide, sedimentary-hosted, stratiform barite deposits are the most important deposit type because they contain large reserves which can be mined commercially.

Witherite ($BaCO_3$), a barium carbonate, occurs as an accessory mineral in some barite deposits and can occasionally form a deposit on its own. However, there has been no commercial witherite production in the western world since the mines in Northumberland, England closed.

Recently, the Chengkou and Ziyang witherite deposits were discovered in China (Wang and Chu, 1994). These deposits may form as a result of severe depletion of seawater in SO^{-2}_4 and enrichment in Ba (Maynard and Okita, 1991). Alternatively, these deposits may have formed by high temperature replacement of barite with witherite (Turner and Goodfellow, 1990).

Sedimentary-hosted stratiform barite deposits form in intracratonic or continental margin-type fault controlled marine basins. Some deposits form from hydrothermal fluids that exhaled on the seafloor and precipitated barite and other minerals (e.g. sulphides, chert) as chemical sediments. These sediments change composition, with distance from the vent reflecting changes in temperature and other parameters of the hydrothermal fluid as it was mixed with seawater. Sedimentary-hosted stratiform barite deposits can be tens of metres thick and occur over several kilometres in strike length. Major host rocks include carbonaceous and siliceous shells, siltstone, cherts, argillites, turbidites, sandstones, dolomites and limestones.

Deposits are hosted by Archean to Mesozoic aged rocks but are most common in Phanerozoic, especially in the mid to late Paleozoic rocks.

Associated deposit types include shale-hosted Zn-Pb deposits, massive sulphide deposits, and sedimentary manganese deposits and vein barite deposits. In oxygen-starved basins, barite deposits may be stratigraphically associated with black shales enriched in phosphates, vanadium, strontium sulphate (celestite), rare earth elements (REE), uranium mineralization and possibly shale-hosted Ni-Mo-PGE, (Paradis et al, 1999).

World Production

China is the largest producer of barite accounting for approximately 53 percent of the world's total production. Table 18 illustrates the world's five leading barite producers, plus a preliminary estimate of Canadian production.

Table 18

Barite: World Production (2000e)

Country	*Production (tonnes per annum)*
China	3,500,000
India	550,000
United States	392,000
Morocco	350,000
Turkey	130,000
Canada	20,000p/

Source: Searls, 2000; e/estimated; p/preliminary

In 2001, Fireside Minerals Inc. mined 15,000 tonnes of barite from a vein at the Fireside barite mine located 125 kilometres east of Watson Lake. The company used jigs to recover 10,000 tonnes of barite for use in northwestern British Columbia's and Alberta's oil and gas drilling industries (BC Mineral Exploration Review, 2001).

End-Use

Approximately 90 percent of all barite produced is used primarily by the oil and gas industries. It is used as a component in drilling-mud, where its high specific gravity helps to control down-hole pressures. Its non-abrasive nature and chemical inertness make it environmentally neutral.

In other consuming industries, barite's light colour and high brightness make it attractive in acoustical compounds, adhesives, athletic goods, and as a primer in paints. It is also used in the glass industry as a source of BaO where it acts as a flux, oxidizer and decolourizer.

Medically, barium's ability to block x-rays make it a useful diagnostic tool when a person ingests a barium meal to allow an assessment of their digestive tract.

Quality and Specifications

Most barite is ground to a small uniform size before it is used as a filler or as an extender, in industrial products or as a weighting agent in petroleum well-drilling mud. Barite used for drilling petroleum wells can be blue, black, buff, brown or grey depending on the orebody. It must be finely ground so that at least 97 percent of the material, by weight can pass through a 200-mesh screen, and no more than 30 percent by weight, can be less than 6 micrometers in diameter (measured using sedimentation techniques).

Ground barite must be dense enough to not damage the bearing of a tricone drill bit, chemically inert and contain no more than 250 milligrams per kilogram of soluble alkaline salts. In particular, some carbonates like siderite may react under high pH conditions with other mud components, resulting in a complete change in mud consistency and the corresponding required properties of drilling mud.

A small percentage of iron oxide is allowable. Barite will not interfere with magnetic measurements taken in boreholes during logging or drilling. In offshore drilling, the United States Environmental Protection Agency limits the content of mercury to one milligram per kilogram of barite and that of cadmium to three milligrams per kilogram of barite.

Alaska requires that barite used in drilling mud contains less than three ppm Cd and less than one ppm Hg; this limit may be applied to California and the Gulf Coast states and may preclude the use of barite associated with metal sulfides. Other proposed rules include the banning of any discharge from drilling platforms within 6.4 kilometres of shore; discharge within this limit would be required to contain less than three ppm Cd and less than one ppm Hg. (Harben, 1995).

Depending on the end-use, there are different specifications required for barite which may include low abrasivity, grade of concentrate, colour, whiteness, brightness, density, type of impurities, oil index, water index, refractive index and base metal content.

Tables 19 and 20 illustrate the American Petroleum Institutes (API) specifications required for barite, and specifications for commercial filler-grade barite.

Table 19

Barite: API Requirements for Weighting Agents*

Density, g/cm^3 minimum	4.2
Water soluble alkaline earth metals as calcium, mg/kg maximum	250
Residue >75µ	3% weight % maximum
Particles >6µin equivalent spherical diameter	30% weight % maximum

* *API Specifications 13A, Specifications for Drilling-fluid materials, 1993*

Table 20

Specifications of Some Commercial Filler-Grade Barite

	USA (industrial-grade) BARA-200C	***USA (plastics) CIMBAR 1025P***	***USA (powder coatings) CIMBAR CF***	***USA (paints, plastics) CIMBAR UF***
BaSO4	94	97-98	98	98
SiO2	2.5			
Total silicates		0.2	0.82	0.82
SrSO4	1.5			
Fe2O3	0.50	0.015	0.04	0.04
MgO	0.03			
CaO	0.03			
Al2O3	0.05	0.01	0.01	0.01
Total heavy metals			0.05	0.05
Moisture	<0.1		0.15	0.15
LOI		0.25	0.75	0.75
Oil absorption	8-9	11.0-12.0	10	11
Dry brightness		89.0-92.0	90+	90+
Surface area, m^2/g		2.0		
Mean particle size, µm		2.0-3.0	4.8	2.5
% passing 200 mesh	97.0			
% passing 325 mesh	85.0			

Source: adapted after The Industrial Minerals HandyBook II; CIMBAR Performance Minerals

Market Trends

The amount of barite consumed is largely dependent on the oil and gas sector that over the past decade has prospered. As more petroleum fuels are imported to the United States and exploration for oil and gas becomes concentrated in other regions of the world, barite suppliers are expected to decrease exports to North America and increase exports of barite to other petroleum producing regions - principally, Africa, the Asia Pacific region, and the former Soviet Union (Searls, 2000).

One very special market area is for a high brightness white barite, which is used in a variety of filler applications. This type of product is currently imported from overseas to North America. With renewed interest in oil and gas exploration in the Mackenzie Delta (Northwest Territories) and Beaufort Sea, and the existence of the Dempster Highway to access this region, there is great potential for a Yukon producer to capture this market.

Price

According to Industrial Minerals No. 419 (2002), over 80 percent of the cost of Chinese, Indian or Moroccan barite delivered to the Gulf of Mexico ports is spent on transportation and other logistics (i.e., insurance). The United States price per tonne ranges for American Petroleum Institute (API) grade lump barite are Chinese $42-48; Indian $48-51; Moroccan $50-52. Other reported prices include:

- Ground, white, paint grade, 96-98% $BaSO_4$, 350 mesh, 1-5 tonnes, del UK £195-220
- Micronised, off white min 99% <20m del UK £140-150
- Unground, OCMA/API bulk, SG 4.2 FOB Morocco US$39-41
- Ground, bagged FOB Morocco SG 4.22 US$75-85
- Ground OCMA/API big bags (1.5 Tonnes) FOB S. Turkey US$68-70
- Ground OCMA bulk, del Aberdeen £50-55
- del Gt Yarmouth £58-65

Economic Factors

Barite deposits range from 1 to 25 million tonnes, grading 30-95 percent barite, with a median size of 1.24 million tonnes, containing 87.7 percent $BaSO_4$.

Transportation cost, specific gravity and content of water-soluble alkaline earth metals, iron oxides and sulphides are important factors for barite to be used in the petroleum industries. Currently, barite producers prefer sulphide-free barite deposits. It is possible that in the future, due to changing technology, a substantial portion of barite will originate as a by-product of metal mining (Paradis et al, 1999).

Yukon Occurrences

Ninety-six barite deposits/occurrences are described in Yukon Minfile 2001. Of these, 41 are described as major commodities (Table 21; Figure 2).

Table 21

Yukon Barite Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1*	95D 005	95D/6	MEL	SB	V	60º21’19”/127º23’55”
2	95D 027	95D/5	JONI	SB	SEDEX	60º23’40”/127º17’56”
3	105A 006	105A/2	NAZO	SB	V	60º01’20”/128º38’20”
4*	105B 034	105C/3	BILL	?		60º02’10”/131º05’26”
5	105C 003	105C/9	BAR	YT	SEDEX	60º30’16”/132º14’26”
6	105C 038	105C/9	MINDY	YT	S	60º38’53”/132º23’46”
7	105C 055	105C/5	EAGLENEST	CCT	V	60º22’2”/133º53’22”
8	105D 026	105D/3	EMPIRE	CPC	V	60º10’34”/135º15’56”
9*	105F 012	105F/17	ARNOLD	CP	VOLC.	61º27’29”/132º38’32”
10	105F 015	105F/8	KAY	MV	CP	61º29’14”/132º09’3”
11*	105F 038	105F/14	BARITE MTN.#	CP	V	61º50’17”/133º00’37”
12	105F 071	105F/9	CHZERPNOUGH	YT	VOLC.	61º36’43”/132º26’11”
13*	105F 073	105F/10	BNOB	CP	VOLC.	61º34’27”/132º32’08”
14	105F 074	105F/10	H	CP	V	61º37’06”/132º47’33”
15	105F 080	105F/8	NOKLUIT	CP	S	61º29’21”/132º10’27”
16*	105F 088	105F/15	GROWTH	YT	VOLC.	61º56’05”/132º56’42”
17*	105F 089	105F/14	WOODSIDE	YT	SEDEX	61º57’52”/133º01’54”
18	105F 090	105F/16	SPURT	SB	V	61º48’19”/132º21’49”
19	105F 095	105F/9	TREE	YT	V	61º38’22”/132º25’24”
20*	105F 115	105F/15	MT. ROSS	SB	SEDEX	61º51’11”/132º34’27”
21	105G 008	105G/6	HASSELBERG	CP	VOLC.	61º20’24”/131º29’38”
22	105G 011	105F/5	AXE	CP	V	61º28’15”/131º48’11”
23	105G 016	105G/6	EL	YT	VOLC.	61º28’26”/131º18’42”
24*	105G 040	105F/8	FISHER	YT	VOLC.	61º29’23”/130º15’41”
25	105G 082	105G/1	AKHURST	YT	VOLC.	61º12’58”/130º12’51”
26*	105G 090	105G/5	FAIRBANK	CP	VOLC.	61º28’50”/131º54’51”
27*	105G 094	105G/14	DWONK	CP	SEDEX	61º56’48”/131º04’49”
28	105G 099	105G/14	BRENDEX	YT	VOLC	61º48’28”/131º24’14”
29	105G 136	105G/1	WHITE CREEK	YT	VOLC	61º13’40”/130º15’44”
30	105H 047	105H/12	FIN	SB	SEDEX	61º39’55”/129º49’14”

Barite *Table 21 (cont’d)*

31*	105H 048	105H/12	TED	CP	V	61º38’15”/129º52’36”
32	105H 075	105H/11	MAXI	SB	SEDEX	61º39’01”/129º10’16”
33	105I 007	105I/13	BIRR	SB	S	62º50’34”/129º58’37”
34*	105I 036	105I/12	ORO	SB	SEDEX	62º36’54”/129º46’45”
35	105I 043	105I/5	DIANNE	SB	SEDEX	62º26’18”/129º35’54”
36	105J 015	105J/16	GUN	SB	S	62º50’50”/130º00’51”
37	105J 022	105J/7	RICH	SB	?	62º22’15”/130º46’46”
38*	105J 023	105J/16	PETE	SB	SEDEX	61º59’44”/130º03’24”
39*	105J 024	105J/16	COCO	SB	SEDEX	62º58’44”/130º29’20”
40*	105J 025	105J/13	ST GODDARD	SB	SEDEX	62º52’00”/131º36’21”
41*	105L 032	105L/14	HORSFALL	SB	SEDEX	62º54’31”/135º05’42”
42	105L 045	105L/14	CLEAR LAKE	SB	SEDEX	62º47’07”/135º07’56”
43*	105L 051	105L/15	DROMEDARY	SB	SEDEX	62º53’53”/134º41’10”
44*	105L 052	105L/9	ANACONDA	SB	SEDEX	62º44’22”/134º20’24”
45*	105L 054	105L/14	KAL	SB	SEDEX	62º54’12”/135º15’20”
46*	105M 080	105M/16	GORDEY	SB	SEDEX	63º55’53”/134º11’01”
47*	105N 016	105N/15	ANDREA	SB	SEDEX	63º48’40”/132º31’34”
48	105N 019	105N/8	DOG	SB	V	63º19’51”/132º01’55”
49	105N 020	105N/10	JAGOWEREITE	SB	V	63º34’51”/132º48’29”
50	105N 022	105N8	FIDO	SB	?	63º26’36”/132º22’18”
51*	105O 001	105O/1	TIM	SB	SEDEX	63º09’53”/130º08’40”
52	105O 005	105O/3	NIDDERY	SB	S	63º10’44”/131º15’52”
53*	105O 006	105O/6	SCOT	SB	SEDEX	63º19’38”/131º15’34”
54*	105O 013	105O/1	RACICOT	SB	SEDEX	63º04’15”/130º12’37”
55*	105O 019	105O/1	JASON	SB	SEDEX	63º08’55”/130º15’33”
56*	105O 020	105O/20	TEA+	SB	SEDEX	63º01’11”/130º36’55”
57*	105O 021	105O/7	BAR#	SB	SEDEX	63º16’35”/130º33’48”
58*	105O 023	105O/3	RAIN	SB	SEDEX	63º09’28”/131º08’18”
59*	105O 024	105O/1	NIDD	SB	SEDEX	63º11’14”/130º26’36”
60*	105O 027	105O/1	GARY	SB	SEDEX	63º05’18”/130º11’34”
61*	105O 028	105O/1	FETCH	SB	SEDEX	63º06’35”/130º14’44”
62*	105O 029	105O/6	TH	SB	SEDEX	63º17’48”/131º07’07”
63*	105O 036	105O/8	FAN	SB	SEDEX	63º15’21”/130º21’55”
64*	105O 045	105O/7	STROSHEIN	SB	SEDEX	63º16’54”/130º48’56”
65	106B 013	106B/6	ECONOMIC	MP	V	64º19’53”/131º11’46”
66*	106B 030	105B/5	MARTHA	SB	SEDEX	64º28’10”/131º51’52”
67	106C 059	106C/15	CAB	MP	MV	64º59’32”/132º31’19”
68	106C 082	106C/4	COOKER	SB	SEDEX	64º10’36”/133º51’04”
69	106D 052	106D/16	FORD	MP	WB	64º54’24”/134º16’02”
70	106D 065	106D/10	BOND	MP	WB	64º39’42”/134º55’38”
71	106D 070	106D/16	SLAB	MP	WB	64º59’43”/134º01’46”
72	106D 072	106D/10	BOZO	MP	WB	64º39’55”/134º46’22”
73	106E 001	106E/1	OTIS	MP	WB	65º01’58”/134º23’21”
74	106E 003	106E/1	QUARTET	MP	WB	65º07’44”/134º22’58”
75	106E 009	106E/2	IGOR	MP	WB	65º02’49”/134º37’42”
76	106E 010	106E/3	MAGIC	MP	MV	65º00’20”/135º04’41”
77	106E 020	106E/14	TUKU	MP	R	65º58’56”/135º23’55”
78	115G 027	115G/12	SWEDE JOHNSON	WT	V	61º30’10”/139º33’36”
79	115I 055	115I/6	EMMONS HILL	NST	V	62º16’13”/137º03’14”
80	115O 071	115O/14	BOX CAR	YT	V	63º54’59”/139º03’27”
81	115O 073	115O/14	VIOLET	YT	V	63º51’25”/139º16’50”
82*	115P 045	115P/14	OMEGA	SB	ST	63º59’09”/137º10’48”
83	115P 047	115P/14	ZETA	TPS	V	63º59’23”/137º17’31”
84*	116A 029	116A/12	ST. BRIDGET	SB	SEDEX	64º38’56”/137º51’35”
85*	116A 030	116A/12	LOMOND	SB	SEDEX	64º36’54”/137º41’12”
86	116B 113	116B/14	PETTET	MP	V	64º51’09”/139º18’14”
87	116B 128	116B/9	REIN	SB	ST	64º42’39”/138º10’23”
88	116B 159	116B/3	ALPHA	YT	?	64º00’23”/139º08’13”
89	116C 082	116C/2	ELSIE	YT	V	64º00’22”/140º50’43”
90	116C 115	116C/1	CLIP	YT	VOLC.	64º13’50”/140º23’53”
91*	116G 048	116G/7	BILBO	MP	MV	65º15’46”/138º43’11”
92*	116G 058	116G/1	HIP	MP	V	65º13’16”/138º20’32”
93*	116G 062	116G/1	MILCH	MP	SEDEX	65º10’12”/138º07’33”
94*	116G 066	116G/8	BANGON	MP	V	65º26’01”/138º00’49”
95	116I 064	116I/16	TOUCHE	MP	V	66º51’35”/136º01’20”
96	116O 059	116O/16	DRIFTWOOD	MP	?	67º57’29”/138º13’21”

* *Listed as major commodity in Yukon Minfile 2001; + Past Producer # Reserves reported*
VOLC. (Volcanogenic deposit), SEDEX (Sedimentary Exhalative deposit), V (Vein), S (Skarn), MV (Mississippi Valley), WB (Wernecke Breccia), R (Replacement), ST (Stratiform), YT (Yukon Tanana Terrane), CP (Cassiar Platform), SB (Selwyn Basin), MP (Mackenzie Platform), CCT (Cache Creek Terrane), WT (Wrangellia Terrane), NST (Northern Stikine Terrane), TPS (Tombstone Plutonic Suite).

Past Producers

There are two reported past barite producers and one drilled barite property in the Yukon. A brief description of each follows:

TEA Deposit (Minfile 105O 020) - in 1983 Yukon Barite Company Ltd. signed an agreement to supply Gulf Canada and Esso with drilling barite from the TEA deposit for use in the Beaufort Sea petroleum play. Approximately 8000 tonnes were mined and stockpiled near Ross River and although a mill was constructed five kilometres south of Ross River, management and legal problems forced the closure of the operation before any of the feed was milled. Further reserve drilling, took place in 1986 when the claims were transferred to H. Coyne and Sons Ltd. in October 1989. In 1995, H. Coyne and Sons constructed a 40,000 tonne per year mill to process barite from the property. The company processed a 600 tonne bulk sample from the material stockpiled at the mill site, and produced 15,000 bags of barite containing 40 kilograms each.

The TEA deposit consists of a 100 metre thick bedded barite section with accessory interbeds of baritic limestone, limestone chert and shale at the base of the shale member of the Devonian-Mississippian Earn Group. The barite processed in 1995 had an average specific gravity of 4.26. At the end of 1995 the deposit hosted open pit reserves of 250,000 tonnes (requiring no stripping). Geological reserves are estimated at one million tonnes.

A report prepared for the Indian and Northern Affairs in 1995 (Craig, 1995) concluded:

- The TEA barite deposit has suitable tonnage to support any likely scale of production (5-10 thousand tonnes) for at least 25 years.
- The barite is of suitable grade such that with moderate beneficiation (from a mine run grade of approximately 4.15 S.G., to drilling mud grade of 4.20 S.G.), it should find a market in both northern Canada or Alaska, enjoying a transportation cost advantage over materials presently brought from Nevada.
- The ore is amenable to beneficiation, based both on the preliminary laboratory work by Lakefield Research of Ontario and the production scale test runs by H. Coyne and Sons Ltd. with the mill at Ross River.

Barite Mountain Deposit (Minfile 105F 038) - discovered in 1944, barite in unreported amounts was mined during 1963 by hand sorting from talus. On the property, at least a dozen barite veins (0.3-3 metres wide) were documented as well as a zone of brecciated limestone 9.1 metres wide, which was partly cemented by barite. The GSC in 1945 estimated reserves at 45,360 tonnes of barite. Other barite veins located 3.2 kilometres to the north and east were reported. Two analyses by the GSC showed 99.2-99.7 percent BaSO4, 0.17-0.23 percent SrSO4 and 0.1-0.23 percent CaO. The host rock is Siluro-Devonian dolomite which was thrust over Devono-Mississippian black slate.

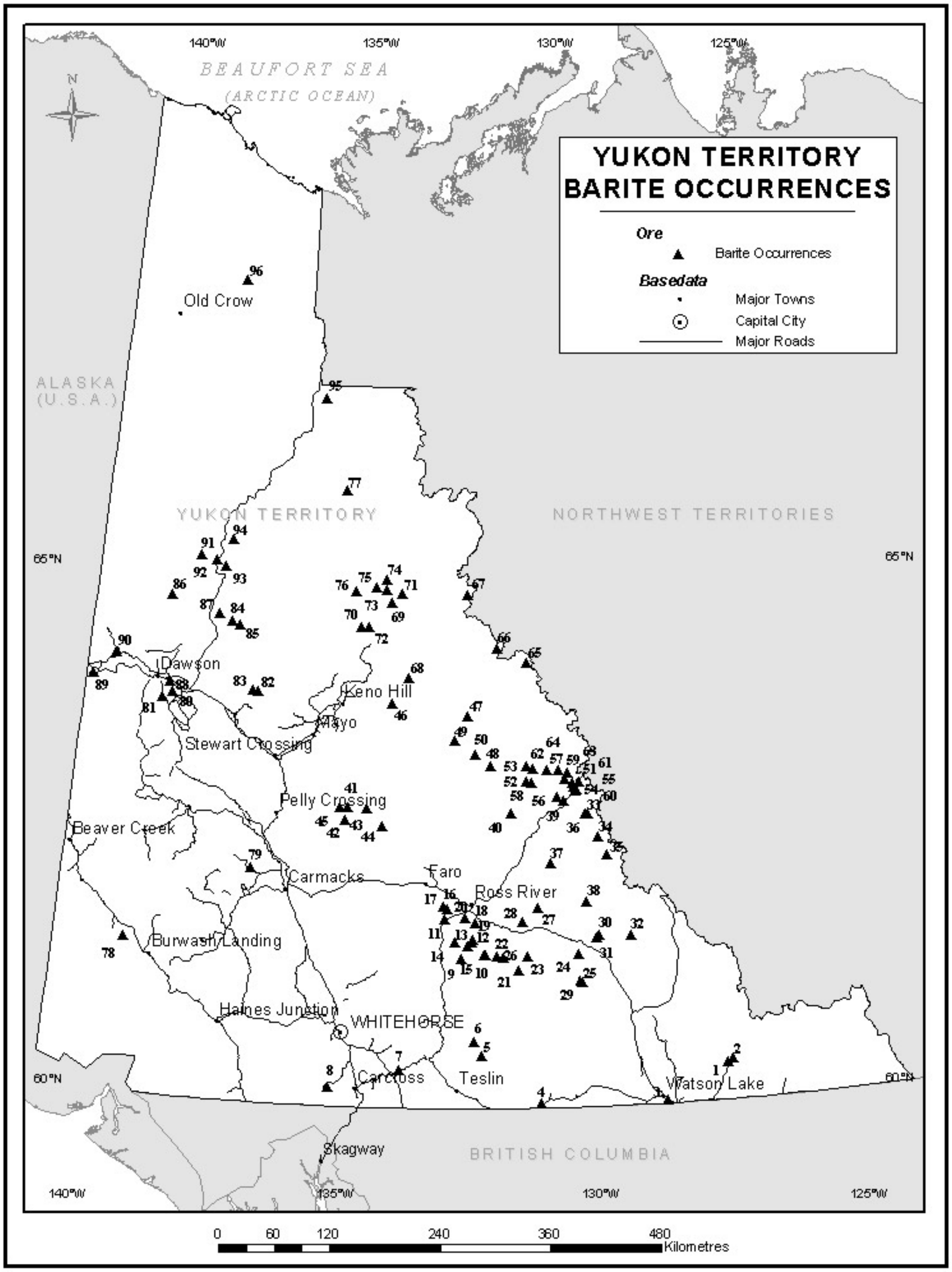


Figure 2. Yukon Barite Occurrences Fig2

Plate 1. The TEA Barite Deposit Processing Area, Yukon. Photograph Courtesy of H. Copland Pla1

Bar Deposit (Minfile 105O 021) - first staked in 1973, the BAR (WALT) property consists of small barite zones occurring in faulted slices of Devono-Mississippian Earn Group shale thrust over Ordovician to Lower Devonian Road River Formation sediments. The barite zones form part of a stratabound, sheet-like body up to 60 metres thick and 2 kilometres long, which is zoned from a brecciated barium carbonate core outward to massive barium carbonate, massive barite and laminated barite. A 1980 drilling program outlined about 450,000 tonnes of commercial grade barite (with a specific gravity of over 4.25) in the main zone that is up to 30 metres thick and 150 metres long. A 160 kilogram bulk sample of barite taken in 1993, yielded a weighted average specific gravity of 4.19.

Exploration Guidelines

Barite produces well-defined heavy mineral anomalies in stream sediments which should not be confused with barium (Ba) anomalies due to the presence of basic feldspars. Weather resistant barite may form significant downstream silt anomalies. While barite breaks down rapidly during stream transport, geochemical signatures reporting high values of barite in stream and heavy sediments may suggest close proximity to a primary barite source. Barite deposits may also correspond to gravity-high readings.

Other useful exploration tools include investigation of appropriate tectonic and depositional settings, proximity to known occurrences of barite, shale hosted sedex or massive sulphide occurrences, exhalative-cherts, hematite-chert iron formations or regional manganese marker beds. Vegetation "kill zones" may also be indicative of a barite deposit or occurrence (Paradis et al, 1999).

BENTONITE BEN

Chemical and Physical Characteristics

The mineral/rock bentonite is soft, plastic, water absorbing, porous, has a soapy texture and is waxy in appearance. It is generally a light-coloured substance ranging from white to light green or blue when fresh exposed. Bentonite is greasy and soap-like to the touch and commonly has great ability to absorb large quantities of water (swelling to between 15 to 30 times from its original dry bulk volume). It consists largely of colloidal silica and clay minerals, chiefly of the montmorillonite group of clays [$5Al_2O_3 \cdot 2MgO \cdot 24SiO_2 \cdot 6H_2O(Na_2O, CaO)$].

Bentonite is also referred to as a sodium and calcium montmorillonite clay, smectite clay, volcanic clay, soap clay, and mineral soap. Terms for sodium montmorillonite clays include sodium bentonite, swelling bentonite, and Wyoming or Western bentonite. Calcium montmorillonite clay may also be referred to as calcium bentonite, non-swelling bentonite, Southern bentonite or fuller's earth.

Deposit Examples

Hat Creek (BC Minfile 092INW084), Princeton (BC Minfile 092HSE151), British Columbia; Rosalind, Alberta, Morden, Manitoba (Canada); Black Hills District, Big Horn Basin (Wyoming, USA); Milos (Greece); Annaka, (Japan); Campina Grande (Brazil).

General Geology

Bentonite deposits are found in continental platform or island arc settings. They form when volcanic ash is deposited in a lacustrine (freshwater) or marine basin which is characterized by a low energy depositional environment with temperate climatic conditions. Deposits tend to be Cretaceous to Miocene in age, however they can be as old as Jurassic or as recent as Pleistocene.

When deposited, volcanic pyroclastic material is altered through the devitrification of volcanic ash through hydration and crystallization of the smectite minerals. In some deposits there is evidence of a loss of alkalies during the alteration process and also silicification of beds underlying the bentonite – indicative of a downward migration of silica. Bentonite beds can range in thickness from several centimetres to tens of metres and may extend over hundreds of kilometres. In island arc environments, bentonite may occur as lens-shaped bodies with limited lateral extent. The regional extent of bentonite deposits is controlled by the limit of the depositional environment, paleogeography and distribution of the volcanic pyroclastic ash.

Ore mineralogy contains principally montmorillonite with minor beidellite and illite. Other minerals may include (usually less than 10%) mica, feldspar, quartz, calcite, zeolite, gypsum, opaline silica, cristobalite, and unaltered volcanic glass. Associated deposit types can include other clays, zeolite, lignite coal or sepiolite (Hora, 1999).

World Production

World production of bentonite was estimated at 9.9 Mt during 2001. The United States was the leading producer (3.82 million tons), followed by Greece (950,000 tons), and the former Soviet Union countries with 750,000 tons combined (Virta, 2002).

Market Trends

The outlook for bentonite use is dependent on the strength of industrial manufacturing applications such as foundry sand bond, iron ore pelletizing and refractories. A slowing economy will have a negative effect on sales of this clay. Continued interest in oil exploration and processing however, should provide a steady market for catalysts and drilling mud, and the market for pet litter absorbents should remain strong.

End Use

Major markets for swelling bentonite in decreasing order were pet absorbents, foundry sand, drilling mud, iron ore pelletizing and waterproofing and sealing. The major American markets for nonswelling bentonite in decreasing order were in clarifying, decolourizing, and filtering of oils and greases, foundry sand, as a catalyst, and for miscellaneous absorbents, animal feed and for chemical manufacture (Virta, 2000).

Quality and Specifications

The value received for bentonite depends on the type of impurity, colour, size of clay particles, cation exchange capability, rheological properties and the structure of the clay. Tables 22 and 23 illustrate the quality and specifications for bentonite, by use:

Table 22

Analysis of Commercial Bentonite

	W. US (Na) Standard Foundry	W. US (Na) Pure Bentonite	S. US (Ca) Foundry	United Kingdom (Ca)
SiO2	63.59	61.3-64	62.12	55.2
Al2O3	21.43	19.8	17.33	13.7
Fe2O3	3.78	3.9	5.30	8.1
CaO	0.66	0.6	3.68	6.3
MgO	2.03	1.3	3.30	3.3
Na2O	2.70	2.2	0.50	Trace
K2O	0.31	0.4	0.55	0.6
TiO2	Na	0.1	Na	0.7
Trace elements	Na	3.2	Na	Na
Bound water	5.50	7.2	7.22	9.9

Source: The Industrial Mineral HandyBook II, pg. 23

Table 23

Bentonite in Drilling Muds

Requirement	API Bentonite	OCMA Bentonite
Suspension properties Viscometre dial reading @ 600 rpm	30 minutes	30 minutes
Yield point/plastic viscosity ratio, max.	3	6
Filtrate volume, cm^3, max.	15.0	16.0
Residue >75 µm max.	4.0 wt.%	2.5 wt. %
Moisture, max.	10.0 wt.%	13.0 wt.%

Source: The Industrial Minerals HandyBook II. pg. 23

Price

The value of bentonite depends on the type and quantity of impurities, colour, size of clay particles, cation exchange capability, rhelogical properties and clay structures. Prices listed during 2002 (by Industrial Minerals, No. 419) were:

- Wyoming, foundry grade, 85% <200 mesh, bagged, 20ton lots, del Uk £160-170
- Wyoming ex-works, rail cards, crude, bulk s ton US$26-63
- Wyoming, ex-works, rail cards, foundry grade, bagged, s ton US$52-76
- Wyoming, API, ex-works, rail cars, bagged, s ton US$45-53
- Fullers' earth, soda ash-treated, del, UK foundry grade, bagged £110-120
- Civil engineering grade, bulk £90-100
- OCMA, bulk ex-store UK £90-100
- Cat litter grade, 1-7mm, bulk, ex-store UK £55-65

Economic Factors

Montmorillonite content in bentonite is usually greater than 80 percent. While published reports about bentonite deposits are few, typically beds are continuous over several kilometres and range in thickness up to 1.5 metres. The Wilcox mine in Saskatchewan has three bentonite seams 61, 46 and 30 centimetres thick within a six metre interval of shale (Hora, 1999).

Economic viability is often determined by the thickness of the overlying strata and overburden as costs rise significantly with the increased stripping ratio.

Yukon Occurrences

There are no bentonite occurrences reported in Yukon Minfile 2001. But, bentonite has been reported in the Tertiary coal-basins near Watson Lake and Braeburn (Dowling, 1993). However, the mineral's extent and quality in this location are unknown.

Exploration Guidelines

In most instances the most useful exploration tool is the recognition of sedimentary basins with volcanic ash layers. In these deposits, bentonite layers may form planes of weakness that result in landslides, or when exposed to the atmosphere, display a "popcorn texture" on the dry surface.

There is no recognized geochemical signature for bentonite. However, resistivity logs and refraction seismic surveys may assist in identifying bentonite beds within sedimentary units.

BORATES BOR

Chemical and Physical Characteristics

Materials containing boron oxide are known as borates. More than 200 minerals contain boric oxide, but only a few are of commercial significance (Table 24). Of these, four minerals comprise almost 90 percent of borates used by industry. Three of these include the sodium borates: borax and kernite; the calcium borate: colemanite; and the sodium-calcium borate; ulexite. Of these, the principal boron mineral is colemanite (Sims, 1999).

Table 24

Boron Minerals of Commercial Importance

Mineral	*Chemical Composition*	*Boron oxide (B2O3) weight percent*
Boracite (stassfurite)	Mg6B14O26C12	62.2
Colemanite	Ca2B6O11·5H2O	50.8
Datolite*	CaBSiO4·OH	24.9
Hydroboracite	CaMgB6O11·6H2O	50.5
Kernite (rasorite)	Na2B4O7·4H2O	51.0
Priceite (pandermite)	CaB10O19·7H2O	49.8
Probertite (kramerite)	NaCaB3O9·5H2O	49.6
Sassolite (natural boric acid)	H3BO3	56.3
Szaibelyite (ascharite)	MgBO2·2OH	41.4
Tincal (natural borax)	Na2B4O7·10H2O	36.5
Tincalconite (mohavite)	Na2B4O7·5H2O	47.8
Ulexite (boronatrocalcite)	NaCaB5O9·8H2O	43.0

*Source: adapted after Lyday, 2000. Parentheses include common names. * Produced in the former USSR, now deposit is considered uneconomic.*

Deposit Examples

Billie Mine, Death Valley, California; Searles Lake (mineral rich brines), San Bernardino County, California; Boron, California; (United States); Salta and Jujuy Provinces, (Argentina).

General Geology

Usually, borates are found near hot springs and in lakes in volcanic regions. Boron is emitted in vapours and exhalations escaping from fumaroles and solfataras. These vapours are dissolved in water, and the boron compounds are deposited by natural evaporation as surface efflorescences, lake deposits or evaporates.

World Production

The estimated world production of boron minerals during 2001 was 4.6 million tonnes. Major producing countries included: Turkey (1.4 million tonnes), United States (1.3 million tonnes), Russian (1.0 million tonnes), Argentina (360,000 tonnes) and Chile (340,000 tonnes) (Lyday, 2002).

End Use

Total annual world consumption of borates was as follows: insulation, textile, fiberglass, and heat-resistant glass (41 percent); ceramic and enamel frits and glazes (13 percent); detergents, soaps, and personal care products (12 percent); and agricultural micronutrients (6 percent) (Lyday, 2001).

Quality and Specifications

Ore is purchased and priced based on the chemical B_2O_3 content. Colemanite, in calcined concentrated form, contains around 42 percent B_2O_3. Glass use requires a low content of colour metals such as Fe, Co, Ni, Cu and Ti. Typical analysis of glass containing boron is illustrated in Table 25.

Table 25

Typical Chemistry of Glass Types Containing Boron (% by weight)

	Container glass	***Fiber-glass E***	***Boro-silicate glass***	***Lead-crystal glass***	***Fibre optics***
SiO_2	72.0	54.5	80.2	60.0	61.0
Al_2O_3	2.0	14.5	2.4	0.02	3.0
Na_2O	14.0		4.2	1.0	14.0
K_2O	-	-	-	14.9	-
CaO	10.0	17.0	0.1	0.2	-
MgO	-	4.5	-	-	-
B_2O_3	7.0	7.5	12.9	0.025	22.0
Fe_2O_3	-	0.5	-	-	-
PbO	-	-	-	31.4	-
TiO_2	-	0.1	-	-	-
SO_3	1.0	-	-	-	-

Source: adapted after The Industrial Minerals HandyBook II, pg. 31

Market Trends

World demand for boron is expected to grow, primarily in the glass industry. New applications in gypsum board, as well as strong demand in the glass industry, are expected to increase consumption in the United States. Boron compounds and chemicals can reduce energy use in the creation process of many products. This may become an important sector, if energy costs continue to rise.

Price

Ore is purchased and priced based on the B_2O_3 content. Prices quoted for Boron minerals during 2002 by Industrial Minerals, No 419 were:

- Turkish lump colemanite, FOB, 40-42% B_2O_3, USA/Japan US$270-290
- Europe €250-258
- Argentinean natural colemanite, 40-42% B_2O_3 ground, bagged FOB Argentina US$400-450
- Latin American ulexite, 40% B_2O_3, FOB Lima US$220-250

Economic Factors

Boron minerals are mined using open pit and underground methods. In California, a tertiary kernite deposit near Kramer in the Mojave dessert reports the deposit to be 1.6 kilometres wide, and 30 metres thick at a depth of 120 metres. Production of the deposit involves dissolving the kernite followed by evaporation and re-deposition of borax from the super-saturated solution.

Boron use is influenced by the economy in general and specifically the construction industry. Supply is dominated by a limited number of large producers in the United States and Turkey although South America and some Commonwealth of Independent States (CIS) are expected to have an increasing influence in the market. Datolite skarn in Russia's Far East is a unique resource capable of producing boron chemicals although it is questionable if it can be competitive with sedimentary borates in a global market.

South America has large reserves of boron minerals. However, limiting factors to its production of boron, include, distance from markets, infrastructure and processing problems (Lyday, 2000).

Yukon Occurrences

There are no reported borate commodity occurrences in Yukon Minfile 2001.

Exploration Guidelines

The presence of borate minerals in hotsprings and lakes within volcanic regions could be evaluated. However, given Yukon's temperate climate, it is unlikely commercial quantities of these minerals are present in the Territory.

CASSITERITE CAS

Chemical and Physical Characteristics

The only mineral of commercial importance as a source of tin is cassiterite (SnO_2), although small quantities of tin may be recovered from complex sulfides, such as stannite, cylindrite, franckeite, canfieldite, and teallite.

Cassiterite is a brown or black mineral occurring in isometric crystals of brilliant adamantine lustre. It also occurs in massive forms, compacted with concentric fibrous structure (colloidal cassiterite or wood tin) or in rolled or pebbly fragments (non-colloidal or stream tin) within placer deposits. It has a high specific gravity (6.8-7.1), is hard (6-7), and is fragile with imperfect cleavage and a conchoidal fracture.

Deposit Examples

Germaine Creek, (116B/6), Yukon, East Kemptville deposit, Nova Scotia (Canada); Custer, South Dakota (United States); near Urumqui province (China); Belitung Island, (Indonesia); Huanuni tin mine, (Bolivia); Pirquitas silver-tin-zinc mine, (Argentina); Cornwall (England).

General Geology

Most of the world's tin is produced from placer deposits. These surficial deposits are formed by mechanical concentration of mineral particles from weathered debris. The mechanical agent is usually alluvial but can also be marine, eolian, lacustrine or glacial. In situ deposits of cassiterite occur in pegmatite, skarn and greisen. They are also usually in, or near a specific kind of granite called 'tin granite'.

World Production

Twenty-two countries produced tin during 2000 with most of the world's tin produced from placer deposits; at least one-half came from Southeast Asia. World consumption of tin during 2001 was estimated at 242,000 tonnes of tin produced with China (95,000 tonnes), Indonesia (50,000 tonnes), Peru (38,000 tonnes), Brazil (15,000 tonnes), Bolivia (12,000 tonnes) and Australia (9,000 tonnes) as the leading mine producers (Carlin, 2002).

Canada has no current tin producer since the country's only producer Rio Algom, closed its East Kemptville deposit near Yarmouth, Nova Scotia in the fall of 1991.

End Use

Most tin is used as a protective coating or as an alloy with other metals such as lead or zinc. Tin is used in coatings for steel containers, in solders for joining pipes or in electrical/electronic circuits, in bearing alloys, in glass-making, and in a wide range of chemical applications. Secondary, or scrap tin is an important source of the tin supply.

Market Trends

World tin reserves appear to be adequate to meet future demands. Secondary sources of tin are likely to remain an important component of tin supply, especially in North America. American demand for primary tin is expected to grow slowly over the next several years at an estimated rate of 1 percent per year. This rate however, could double within a few year if new applications – especially those in which tin is substituted for toxic materials are developed (Carlin, 2000).

Price

The USGS reported the average price per pound of tin ranged from between US$212-326 during 2001.

Yukon Occurrences

Intense exploration for tin in the Yukon during the 1970’s, resulted in the discovery of numerous occurrences. Primarily these occurred in two areas, the Swift River-Seagull Creek area in south central Yukon, and the McQuesten River area, in central Yukon.

Placer miner Peter Risby on his Indian River claims reported cassiterite concentrations of 4.13 percent tin in 2002 assays. Recovered titanium and tin (ilmenite and rutile) concentrates from the claims are discussed in greater detail under Titanium Minerals in this report.

Fifty-six tin mineral occurrences are described in Yukon Minfile 2001. Of these, 33 were described as major commodities (Table 26, Figure 3).

Table 26

Yukon Cassiterite (Tin) Mineral(s) Deposit/Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1*	95E 006	95E/6	MARGE	MP	V	61º24’06”/127º19’50”
2*	105B 030	105B/3	VAL	YT	S	60º06’09”/131º15’09”
3	105B 031	105B/3	MOD	YT	S	60º08’20’’/131º12’41”
4	105B 034	105B/3	BILL	YT	?	60º02’10’’/131º05’26”
5*	105B 035	105B/3	PEAK	YT	V	60º06’16”/131º23’19”
6*	105B 036	105B/3	VALLEY	YT	S	60º03’34”/131º27’05”
7*	105B 040	105B/4	JC	YT	S	60º11’45”/131º42’16”
8*	105B 070	105B/4	CAN	YT	S	60º13’10”/131º35’22”
9*	105B 073	105B/3	MUN	YT	S	60º07’40”/131º22’58”
10*	105B 078	105B/3	STQ	YT	?	60º09’52”/131º13’32”
11*	105B 079	105B/3	SKIN	YT	?	60º04’59”/131º17’37”
12*	105B 080	105B/3	SLOUCE	YT	S	60º03’02”/131º25’42”
13*	105B 081	105B/4	DUVAL	YT	V	60º13’38”/131º36’41”
14*	105B 082	105B/3	PONT	YT	S	60º09’40”/131º29’01”
15*	105B 083	105B/3	SIN	YT	S	60º08’43”/131º25’18”
16*	105B 084	105B/4	DU	YT	V	60º12’11”/131º34’33”
17*	105B 085	105B/4	CCAN	YT	S	60º12’47”/131º30’50”
18*	105B 086	105B/4	ZINC	YT	V	60º12’46”/131º39’07”
19*	105B 088	105B/4	MC	CP	S	60º12’14”131º44’25”
20	105B 099	105B/9	LOGAN	MLB	V	60º30’05’’/130º28’12”
21	105B 106	105B/8	URSUS	CP	S	60º28’03’’/130º20’36”
22	105B 108	105B/7	CAR	CP	?	60º23’10’’/130º43’00”
23	105B 111	105B/4	DORSEY	YT	?	60º10’50’’/131º34’03”

24*	105B 120	105B/5	KARTUHINI	YT	S	60º23’22”/131º52’38”
25	105C 003	105C/9	BAR	YT	SEDEX	60º30’16’’/132º14’26’’
26*	105C 029	105C/8	MCCLEERY	YT	S	60º19’05”/132º02’01”
27*	105C 036	105C/8	MULLIGAN	YT	S	60º21’28”/132º04’03”
28*	105C 038	105C/9	MINDY	YT	S	60º38’53”/132º23’46”
29*	105C 040	105C/8	BAS	YT	S	60º24’19”/132º05’08”
30*	105G 071	105G/7	MYDA	YT	S	61º24’39”/130º30’26”
31*	105J 008	105J/11	MT. SHELDON	SPC	V	62º43’06”/131º05’29”
32*	105J 016	105J/16	ITSI	SB	V	62º56’02”/130º07’03”
33	105K 013	105K/4	LIL	CP	S	62º00’50’’/133º42’52’’
34	105K 090	105K/16	SOLO	SB	V	62º58’41’’/132º10’26’’
35	105L 003	105L/1	LITTLE SALMON	CP	S	62º12’00’’/134º09’35’’
36	105M 001	105M/14	UNITED KENO HILL	SB	V	63º54’35’’/135º18’01’’
37*	105M 031	105M/13	JOUMBIRA	SPC	V	63º51’06”/135º49’12”
38	105M 056	105M/13	SUNDOWN	SB	V	63º50’09’’/135º53’12’’
39*	105M 066	105M/7	KALZAS	SB	V	63º15’58”/134º42’07”
40	105N 002	105N/3	ARMSTRONG	SB	?	63º07’33’’/133º27’24’’
41*	106D 024	106D/4	TIN DOME	SB	V	64º02’27”/135º50’03”
42	106D 084	106D/1	BLUELITE	SB	S	64º13’41’’/134º19’19’’
43	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36’’/140º55’14’’
44	115N 027	115N/10	SANTA	YT	V	63º31’43’’/140º35’49’’
45	115P 004	115P/16	SCHEELITE DOME	TSZ	I	63º47’05’’/136º16’01’’
46	115P 007	115P/15	MAHTIN	SB	S	63º55’11’’/136º49’37’’
47	115P 008	115P/15	BOULDER CREEK	SB	S	63º46’29’’/136º43’55’’
48	115P 010	115P/15	RIDGE	SB	V	63º48’25’’/136º56’34’’
49	115P 028	115P/16	SECRET	SB	?	63º58’20’’/136º00’43’’
50*	115P 030	115P/15	EPD	SB	S	63º45’35’’/136º30’43’’
51*	115P 031	115P/15	BIX	MPC	V	63º49’47”/136º38’31”
52*	115P 034	115P/4	BARNEY	SB	V	63º48’47”/137º16’11”
53	115P 047	115P/14	ZETA	TPS	V	63º59’23’’/137º17’31’’
54*	115P 048	115P/16	SCHEELITE DOME	TSZ	I	63º45’33”/136º17’02”
55*	115P 051	115P/15	JABBERWOCK	SB	V	63º47’36”/136º57’32”
56*	116B 004	116B/2	GERMAINE	TV	P	64º02’52”/138º56’56”

** Listed as a major commodity in Minfile 2001.*
MP (Mackenzie Platform), YT (Yukon Tanana), CP (Cassiar Platform), SPC (Selwyn Plutonic Complex), SB (Selwyn Basin), MPC (McQuesten Plutonic Complex), TSZ (Tombstone Strain Zone), TPS (Tombstone Plutonic Suite), MLB (Marker Lake Batholith), NST (Northern Stikine Terrane), TV (Tertiary Volcanics); V (Vein), S (Skarn), ? (Unknown), I (Intrusive), P (Porphyry).

Exploration Guidelines

Placer deposits in streams and rivers could be evaluated for cassiterite concentrations.

In situ deposits of cassiterite occur generally in, or could be evaluated near a specific kind of granite, often referred to as, a ‘tin granite’. These types of granites are usually enriched in fluorine, boron and silica, and may be detected through geochemical surveys. Such granites may be characterized as late- and post-orogenic plutons in areas of sialic crust (e.g. Surprise Lake batholith near Atlin, British Columbia). Topaz rhyolites are a volcanic equivalent.

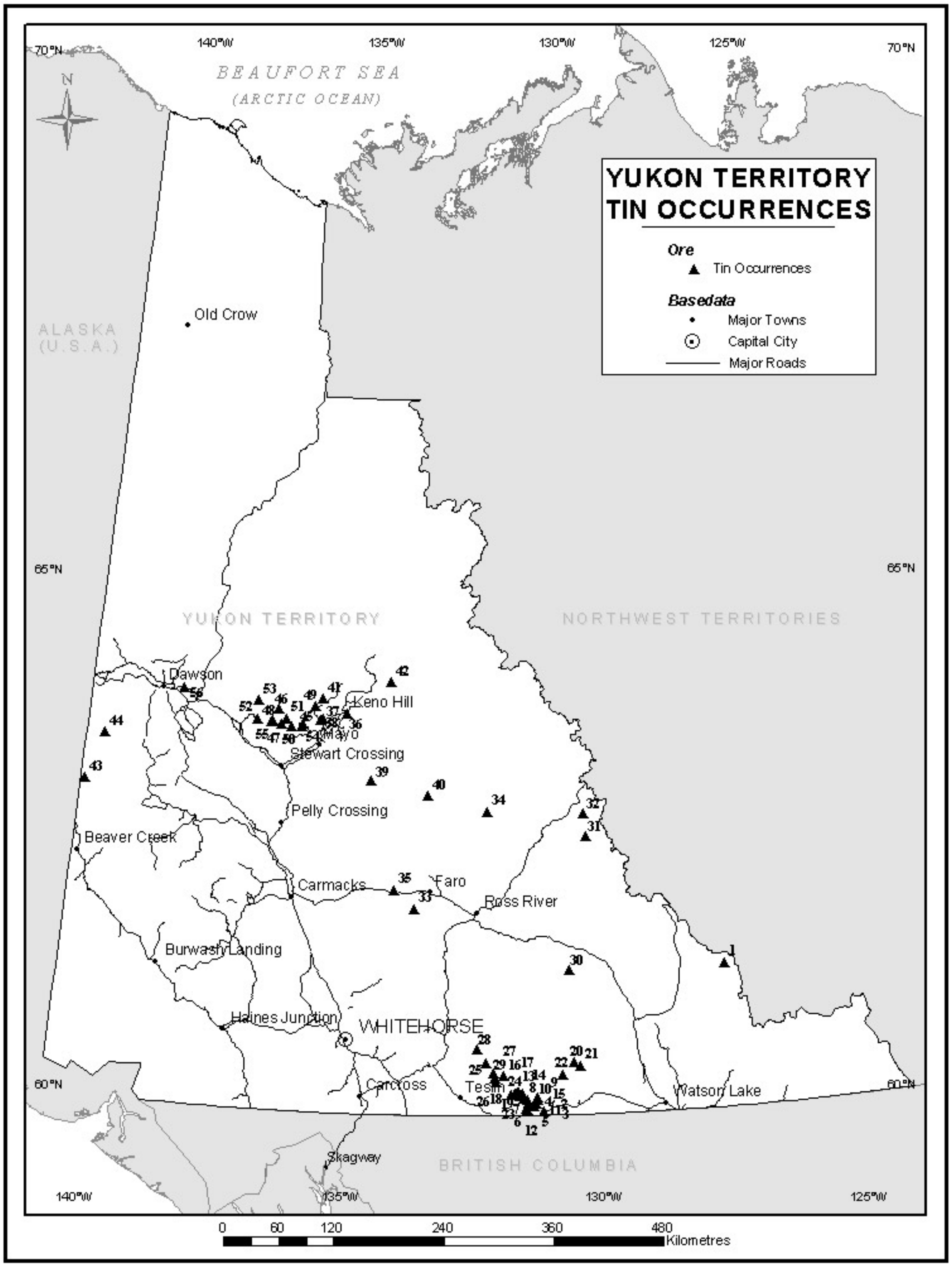


Figure 3. Yukon Tin Occurrences Fig3

CHROMITE CHR

Chemical and Physical Characteristics

Chromite [(Mg, AL) $FeCr_2O_4$], an ore of chromium, is a brownish to iron black mineral of the spinel group. It occurs in octahedral crystals as a primary accessory mineral in basic and ultrabasic rocks and has a specific gravity of 4.5 and a hardness of 5.5-6.5.

Deposit Examples

Bushveld Complex (South Africa); Stillwater Complex (Montana, USA).

General Geology

Chromite occurs in layered intrusion type deposits such as in the Bushveld in South Africa or in podiform deposits (e.g. Urals, Kazakhstan). In such deposits, chromite rich layers form in situ in ultrabasic intrusions as a result of magmatic segregation.

Podiform deposits are thought to have formed in a similar way in the oceanic crust but have subsequently been thrust up into mountain belts in highly deformed ophiolite complexes. These occur much more widely, but in small deposits only. These lenses rarely exceed hundreds of metres in length. Podiform or nodular deposits occur in the western cordillera, and are usually hosted in Alpine type ultramafics.

World Production

World chromite ore production during 2001 was estimated at 12.4 million tonnes. The major producing countries included: South Africa (5.4 million tonnes), Kazakhstan (2.3 million tonnes), India (1.5 million tonnes), and Turkey (500,000 tonnes). Chromite ore was produced in the Western Hemisphere during 1999 by Brazil (420,000 tonnes), and Cuba (production rates not reported) (Papp, 2002).

End Use

Approximately 85 percent of chromium ferroalloys and metals are consumed in the production of stainless and heat-resisting steel and superalloys. The refractory and foundry chromite market accounts for about seven percent of world consumption, where it is used as refractory bricks and as specialized foundry sand in metal casting (since it imparts a high quality finish and dimensional accuracy). The chromium chemical industry consumes a further eight percent of the world's production. This industry uses chromium in coating applications, inorganic pigment manufacturing, timber preservation, textile dye fixing, and leather tanning processes (Papp, 2002).

Quality and Specifications

Chromite when converted to ferro-chromium is used as a source of chromium metal in the steel-making process. As it is such an important product, most major chromite mines often have a ferrochrome production facility nearby, or even on site.

Table 27 illustrates the quality and specifications for different grades of chromite:

Market Trends

Stainless steel, the major end-use market for chromium, has shown increased long-term growth, equivalent to about one or two new ferro-chromium furnaces per year. To meet this demand South African plants have either built new plants or have expanded production at existing facilities. A new round of plant development and furnace additions are expected in both Kazakhstan and South Africa to meet future anticipated demand growth (Papp, 2002).

Table 27

Chromite: Quality and Specifications for Foundry, Chemical and Refractory Grade (%)

	South Africa Foundry-grade Chromite Elandsdrift HenryGould	*South Africa Foundry-grade Chromite, Rand Mines*	*Brazil Chemical-grade Chromite Elandsdrift*	*South Africa Chemical-grade Chromite Rand Mines HenryGould*	*South Africa Refractory-grade Chromite Rand Mines Winterveld3*	*Phillippines Refractory-grade Chromite Benguet – Masinloc1*
Cr_2O_3	45.90	46.20	46.3	46.00	46.94	31.55
FeO	25.40	26.50	25.4	26.50	24.50	-
Fe	-	-	-	-	-	11.34
SiO_2	1.30	1.00	1.20	1.00	0.30	5.84
Al_2O_3	15.4	15.50	15.4	15.50	15.60	-
$Cr_2O_3+Al_2O_3$	-	-			-	58.79
MgO	9.8	9.80	9.8	9.80	11.50	-
TiO_2	0.55	0.50	0.55	0.50	0.50	-
V_2O_5	0.36	0.40	0.36	0.40	0.30	-
CaO	0.33	0.25	0.33	0.25	0.25	-
Ni	0.08	-	0.08	-	-	-
P	0.005	0.003	0.005	0.003	0.003	-
S	0.0000	0.002	0.0000	0.002	0.002	-
Cr:Fe	-	-	-	1.53	-	-

Source: adapted after the Industrial Minerals HandyBook II, pg. 49

Price

The price received for chromite is dependent on its end-use. Prices reported by Industrial Minerals, No. 419 for chromite during August, 2002 were:

- Transvaal, chemical grade, 46% Cr_2O_3, wet bulk, FOB US$40-50
- Transvall, foundry grade, 45% Cr_2O_3, wet bulk, FOB US$48-70
- Transvaal, refractory grade, 46% Cr_2O_3, wet bulk, FOB US$ 100-120
- Philippine, refractory grade, concentrates, FOB US$125-145
- Sand, molding grade, 98% <30 mesh, del UK £135-155

Economic Factors

Table 28 illustrates typical grades for chromite ores.

Table 28

Chromite Ores - Typical Grades

Ore grade	*Deposit type*	*%Cr_2O_3*	*Cr:Fe*	*Use*
High chromium	Podiform and stratiform	46-55	> 2:1	Metallurgical
High iron	Stratiform	40-46	1.5-2.1	Metallurgical and chemical refractory
High aluminum	Podiform	33-38	1-2.5:1	22-34% Al_2O_3

Source: Industrial Minerals Prices and Data 1999, pg. 56

Chromite ore has no substitute in the production of ferro-chromium, chromium chemicals or chromite refractories. Future sales of chromium, although stable, will be dependent on the continued production of the iron and steel industries. Chromite refractory bricks have suffered an ongoing decline due to environmental concerns related to their disposal after use, since some of the chromium is known to have converted to hexavalent form, a known carcinogen (Papp, 2002).

Yukon Occurrences

Seven chromite occurrences are described in Yukon Minfile, 2001. Of these, four are described as major commodities (Table 29; Figure 4).

Table 29
Yukon Chromite Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1*	105C 012	105C/5	SQUANGA	CCT	Magmatic	60º27’32”/133º43’25”
2	105C 028	105C/5	DALAYEE	CCT	V	60º24’59”/133º36’49”
3*	105D 071	105D/9	MICHIE	CCT	UM	60º37’59”/134º09’58”
4*	105G 074	105G/6	BEV	YT	UM	61º29’57”/131º15’35”
5	106D 078	106D/16	ARCTOS	MP	WB	64º56’56”/134º21’26”
6*	115A 037	115A/12	CHROMITE	GNT	UM	60º42’55”/137º46’59”
7	115O 116	105O/1	PYROXENE	YT	?	63º01’16”/138º20’59”

** Listed as a major commodity in Minfile 2001.*
CCT (Cache Creek Terrane), YT (Yukon Tanana), MP (Mackenzie Platform), GNT (Gravina-Nutzotin Terrane); UM (Ultra Mafic), V (Vein), WB (Wernecke Breccia).

Exploration Guidelines

Heavy mineral concentrations of chromite and magnetite may be found in placer deposits and in association with instrusive complexes like Alaskan intrusives and ultramafic belts in the Cordillera. Ultramafic rocks may include anorthosite and gabbro intrusive complexes along deep fracture and fault zones.

Geochemical signature may show anomalies in Cr, Ti, Fe, V, Ni, Cu and Co. Deposits may indicate a magnetic or electromagnetic (EM) response.

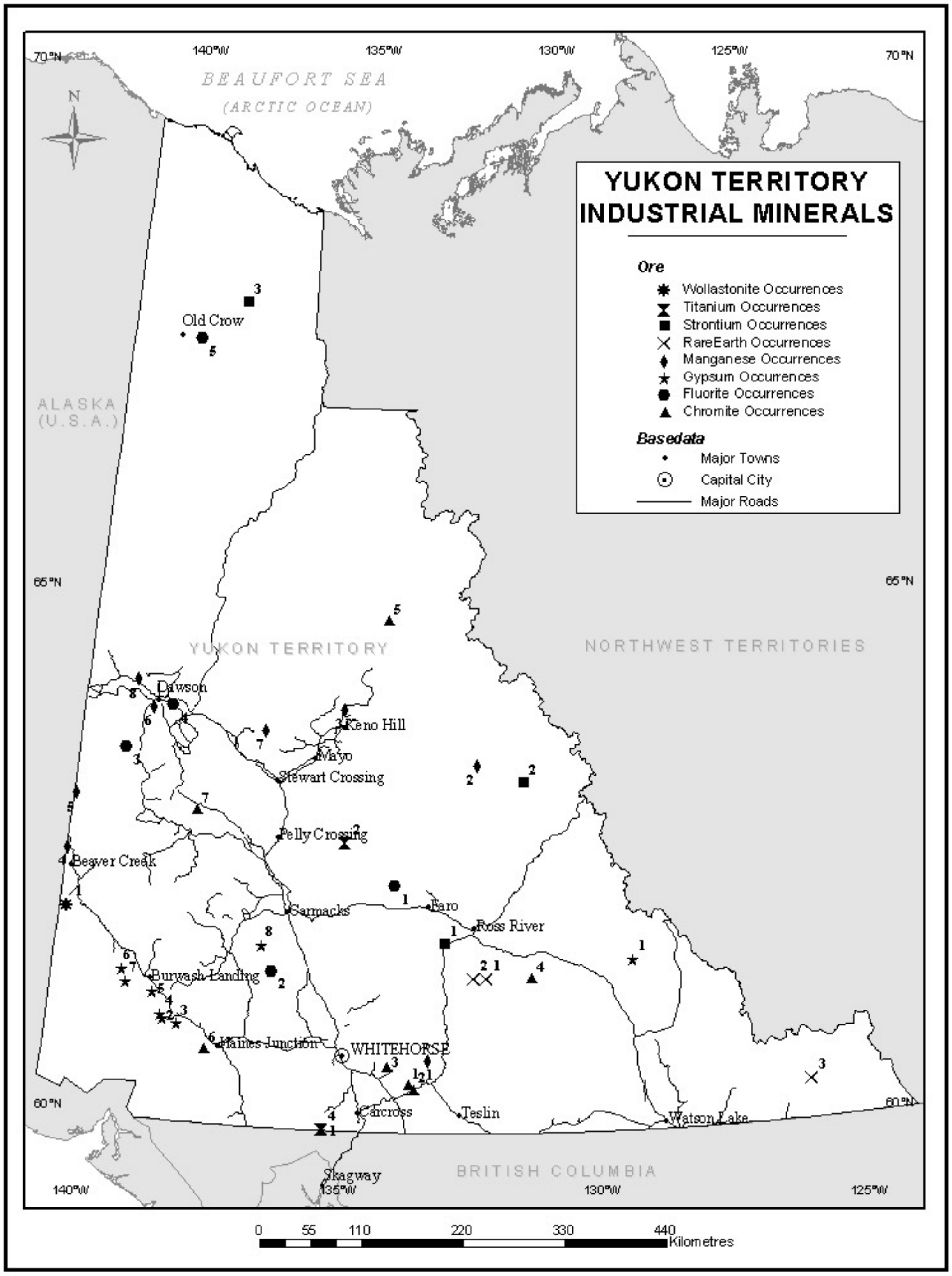


Figure 4. Yukon Chromite, Fluorite, Gypsum, Manganese, Rare Earth, Strontium, Titanium, Wollastonite Occurrences Fig4

CLAY MINERALS CLA

Clay is a loose, earthy, extremely fine-grained (less than 1/256 millimetres or 4 microns) natural sediment or soft rock composed primarily of clay-size or colloidal particles (greater than 50 percent clay particles) and characterized by high plasticity containing a considerable amount of clay minerals (hydrous aluminous silicates). Clay forms a pasty, plastic, moldable, impermeable muddy mass when finely ground and mixed with water, retaining its shape upon drying, and becoming firm, rock-like, and permanently hard upon heating or firing. Clays are classified by use, origin, composition, mineral constituents and colour.

In this report attapulgite, ball clay, bentonite, china clay, fire clay, fuller's earth, kaolin clay and stoneware clays are discussed.

Attapulgite - or palygorskite is a lath-shaped clay mineral $(Mg, Al)_2\ SiO_4O_{10}^-\ (OH)\cdot 4H_2O$ with a chain-type structure, which forms a specific, type of fuller's earth. The term refers to a group of lightweight tough, matted, fibrous clay minerals showing a considerable amount of substitution of aluminum, for magnesium.

Ball clay - or pipe clays, are highly plastic, sometimes refractory clays, commonly characterized by the presence of organic matter. They have unfired colours ranging from light buff to various shades of grey. They have wet and dry strength, long vitrification range, and high firing shrinkage. The clay being highly plastic, can be readily molded before firing, after which it becomes white or cream coloured. Ball clay is named because of the early English practice of rolling the clay into balls (weighing about 13-22 kilograms and having diameters of about 25 centimetres). It is a very fine-grained kaolinite based clay.

Bentonite - is a commercial name for material containing greater than 80 percent of the clay mineral, montmorillonite. The rock is more fully discussed in this paper under its own heading.

China clay - or ceramic clay is the commercial term for kaolin. China clay is obtained from china-clay rock which is a kaolinized granite containing quartz, kaolin, and sometimes mica and fluorite. China-clay is used in the manufacture of china.

Common clays - and shales are used almost entirely for the manufacture of structural clay products, bricks and ceramic pipe. It is also used as alumina component in the manufacturing of Portland cement.

Fire clay - or refractory clay is a siliceous clay rich in hydrous aluminum silicates which are capable of withstanding high temperatures without deforming (either by disintegrating or becoming soft and pasty), and are used for the manufacture of refractory ceramic products (crucibles, firebrick or for lining furnaces). Fire clay is deficient in iron, calcium, and alkalies and approaches kaolin in composition. Better grades contain at least 35 percent alumina when fired.

Fuller's earth - is a very fine-grained, naturally occurring earthy substance (such as a clay or clay-like material) possessing a high absorptive capacity consisting largely of hydrated aluminum silicates (chiefly the clay minerals montmorillonite and palygorskite). Originally used in England for whitening, degreasing or fulling (shrinking and thickening by application of moisture) woolen fabrics, it is now used extensively as an absorbent and in refining and decolourizing oils (mineral, vegetable, and animal fats). Fuller's earth is a synonym for bentonite, which is discussed in this report under its own heading.

Kaolin - is a soft, fine, earthy, nonplastic, usually white or nearly white clay composed essentially of clay minerals of the kaolin group, principally kaolinite. Kaolinite is derived from in-situ decomposition (extreme weathering) of aluminous minerals such as feldspars in a granitic rock. It is used in the manufacture of ceramics, refractories and paper. The mineral is more fully discussed in this paper under its own heading "kaolinite".

Stoneware clay - or brick clay, has good plasticity, contains fusible minerals and has a long firing range. Used for manufacturing stoneware (ceramic ware fired to a hard, dense condition and with an absorption of less than 5 percent), it is used to produce items such as crocks, jugs, and jars. Stoneware usually contains less than 20 percent Al_2O_3 and up to 50 percent silica and is compositionally between low-grade common clays and purer kaolinitic clays. Deeply weathered shales may also be used as stoneware clays.

Deposit Examples

Attapulgite - Florida and Georgia deposits (United States).
Ball clay- Whitemud and Ravenscrag Formations, Southern Saskatchewan (Canada).
Bentonite - Princeton (092HSE151), French Bar (0920099), Hat Creek (0921NW084), British Columbia; Traux, Saskatchwan; Morden, Manitoba (Canada); Big Horn Basin, Wyoming, Gonzales and Lafayette Counties, Texas (USA); Campina Grande (Brazil).
China clay - Georgia, South Carolina, (United States), Brazil.
Common clay - Yukon glaciolacustrine deposits.
Fire clay – Sumas Mountain (BC Minfile 92GSE 004), British Columbia (Canada)
Fuller's earth - Florida and Georgia (United States).
Kaolin - Sumas Mountain (92GSE004), Lang Bay (92F137), British Columbia, (Canada); Kao-ling , Kiangsi Province (China); Weipa (Australia).
Stoneware clay - Giscome Rapids north of Prince George, Quesnel, British Columbia, Whitemud Formation, Southern Saskatchewan (Canada).

General Geology

Most common clay deposits in Canada are the result of Pleistocene continental glaciation and subsequent stream transport and deposition. Deposit types include marine and lake sediments, reworked glacial tills, interglacial clays and floodplain clays. Clay deposits consist of loose, earthy, very fine grained natural sediment or soft rock, composed mostly of clay size (less than 4 microns diameter), or colloidal particles of hydrous aluminum silicates. The deposits generally form through the decomposition and accumulation of fine grains of quartz, decomposed feldspar, carbonates, ferruginous matter and other impurities. The physical and chemical characteristics of each clay deposit are governed by the composition of the source material and the manner and environment of deposition. The kaolinite and bentonite types of clays are products of chemical weathering of silicate rocks under tropical and subtropical weather conditions.

World Production

Clays are divided for commercial purposes into ball clay, bentonite, common clay, fire clay, fuller's earth and kaolin. World resources of these types of clay are extremely large (e.g. kaolin in Georgia, United States is estimated at 1.4 billion tons), except for lesser resources of high-grade ball clay and sodium-bentonite. Geographically such deposits are very unevenly distributed.

In British Columbia, Clayburn Industries Ltd. of Abbotsford processed fire-clay from Sumas Mountain into a variety of refractory bricks and castable products that were exported worldwide (B.C. Mineral Exploration Review, 2001).

Alaska is the only American State not to report any clay production during 2000 (Virta, 2000).

End Use

Ball clay - is primarily used to strengthen the unfired bodies of ceramic clays used in consumer goods, for floor and wall tile, sanitary ware, and refractories. It is also used to produce ceramics, electrical porcelain, fine china and dinner ware.
Bentonite - (see under bentonite in this paper)
China clay - or ceramic clay is used in the manufacture of good quality china and fine ceramics, sanitary ware, tile and refractories.
Common clays and shales - are used primarily in the manufacture of heavy clay products such as building brick, drain tile, flue linings, fibreglass, mineral wool, alumina correction in Portland cement, sewer pipe, structural tile, and terra cotta.
Fire clay - is used in refractory products such as firebrick and block, grogs and calcines, high-alumina brick

and specialties, saggers, refractory mortars and mixes, and ramming and gunning mixes. Fire clays are also used to produce specialty facing brick and pottery.

Fuller's earth - the major uses for attapulgite and montmorillonite varieties in decreasing order include pet waste absorbents, oil and grease absorbents, animal feed, pesticide carrier, filtering, clarifying and decolourizing of oils and greases, fertilizer carriers, and pesticide carriers.

Kaolin - (see under Kaolin in this paper)

Stoneware clay - is used to produce ceramics such as jugs, crocks and jars, floor tile and ceramic pipe.

Plate 2. Clay Showing Near Whitehorse, Yukon Pla2

Quality and Specifications

The most important physical commercial characteristics of clays are plasticity, degree of swelling when wet, retention of shape during firing and after drying, shrinkage while firing and after drying, and hardening while firing and after drying. The quality and specifications for bentonite and kaolin clays are described under their own headings.

Market Trends

The outlook for the clay industry is expected to be mixed for the next few years. Construction-oriented markets are likely to experience little growth or even light declines, as the world economies continue to slow. This will affect the sales of clays for adhesives, brick, ceramics, fiberglass, lightweight aggregate, paint, and other construction-orientated markets. Similarly, a slowing economy will affect sales of clays for industrial manufacturing applications such as foundry sand bond, iron ore pelletizing, and refractories. Interest in oil exploration and processing should provide a slight boost in sales for catalysts and drilling mud. Pet litter markets also should remain strong ((Virta, 2000).

Price

The following prices for clay materials during 2000 were reported by the USGS (Virta, 2000).

Ball clay - the average value for ball clay reported by domestic producers was US$42.46 per ton. The average values for imported and exported ball clay were US$301.59 and $86.60 per ton, respectively.
Common clay and shale - the average prices for lightweight aggregate produced from clay and shale range from US$30-50 per ton for most applications.
Fire clay - the average value for fire clay reported by domestic producers was US$15.88 per ton. The average of imported fire clay was US$383.56 per ton. The average value of exported fire clay was US$86.11 per ton.
Fuller's Earth - attapulgite-type fuller's earth was US$110 per ton. Montmorillonite-type fuller's earth was US$90.00 per ton. The average value for fuller's earth was estimated to be US$91.83 per ton.
Bentonite and Kaolin - See under their own headings in this report.

Economic Factors

The value of clay is dependent on its end-use performance, that is, the type of impurities, colour, and size of clay particles. Clays in general are considered a low-end commodity. The deposit location in close proximity to its end-user, is a cost advantage. Some exceptions are for example some ball clays, or hectorite (a very rare, lithium variety of bentonite).

Yukon Occurrences

In the Yukon, the distribution and potential of clay as an industrial mineral, specifically its ceramic potential, is directly linked to the physical characteristics of deposit types and the Quaternary history. A study by Mougeot, in 1994, assessed the clay deposits in selected areas of the Whitehorse Map Sheet (105D). In this survey, three potential sources of clay materials were evaluated in the Takhini River Valley, the Yukon River Valley and the Carcross Valley. The report concluded:

The Takhini River Valley - several areas in the Takhini River Valley were identified as containing clay deposits of significant thickness and having consistent physical properties considered favorable as a potential source of ceramic clay for industrial purposes. However, lime specks (carbonate concretions) and a very short firing range of tested samples were identified as possible limiting factors which may have a significant impact on the potential use of clay deposits in this area.

The Yukon River Area - the Yukon River area may have suitable clay deposits on the eastern side of the river and north of the City of Whitehorse but land use issues (e.g. land claims) and access problems reduce the regions priority as a potential source of industrial clays. The area south of the City of Whitehorse does have promising clay deposits and in addition the McClintock River Valley has favorable clay deposits and should be further investigated in any exploration program.

The Carcross Valley - the Carcross Valley was not considered a promising area for clay deposits within the scope of the study, mainly because of great variability of Quaternary deposits, which are chiefly sand and gravel. Clay bodies present in this area would probably contain numerous sandy inclusions and would have small volume.

Exploration Guides

Investigation of clays in other regions of the Yukon, have not been systematically conducted. Such surveys should include a basic feasibility study about the industry's potential in the Yukon and include extraction techniques, mixing and firing methods and costs, types of clay products most suited to clay deposits found in the territory, volumes of favorable clay deposits, and their potential markets. Higher quality clays – kaolinite based and bentonite, may have potential to occur in sedimentary basins of Tertiary (particularly Eocene) and Upper Cretaceous age.

CRUSHED STONE/AGGREGATE CRU

Exploration for stone and aggregate is expanding in many parts of the world, as demand increases in regions where these commodities are now scarce or nonexistent. For example, in British Columbia, shipments of crushed stone (limestone) from Texada Island are being exported by barge to Vancouver, Seattle, San Diego, San Francisco and Los Angeles markets. Polaris Minerals Corporation is in the permitting process of starting up a combined crushed rock/natural aggregate operation in the Bella Coola and Port Alberni areas of British Columbia (B.C. Mineral Exploration Review 2001). Once permitted, exports may be transported to distant markets by ship.

During 1999, Alaska produced 1.8 million tonnes valued at US$9.9 million dollars of crushed stone of all types: fine to coarse aggregate (-3/8 inch to +1½ inch), riprap, jetty stone, and filter stone, which was produced and sold in that State (U.S. Geological Minerals Yearbook 2000).

The Yukon, with its access to port facilities in Skagway, Alaska, may have an opportunity to develop crushed rock/aggregate resources for export, if suitable sources of these materials can be located along established transportation corridors which have reliable access to the year-round port facilities in Skagway.

PUMICE AND TEPHRA

Pumice is a light coloured vesicular lava used in lightweight concretes, water filtration, and as an aggregate. Tephra is a general term referring to volcanic pyroclastics such as dark coloured cinder.

In British Columbia, Canada Pumice Corporation has produced has about 19,000 cubic metres of tephra from its Nazko quarry located west of Quesnel. The material was used for landscaping, sporting facilities, growing and filtration media and for lightweight aggregate applications. Great Pacific Pumice Ltd. has shipped a variety of pumice-based products from its Pum property on Mount Meager, north of Pemberton, British Columbia. Production estimates in 2001 were 12,000 cubic metres (B.C. Mineral Exploration Review 2001).

In the Yukon, there are currently no reported vesicular lava or tephra that have been evaluated for their commercial potential. Given Yukon's geology, deposits of vesicular lava and tephra, which would be suitable for commercial applications, almost certainly exist in the territory. However, if deposits which meet industry standards are located, the Territory's remoteness from large population centers may be prohibitive to exporting these materials. A market study would be required to fully assess their potential as a resource.

SAND AND GRAVEL

Sand and gravel used in the construction industry is generally considered a low value commodity. There has been no systematic study of sand and gravel deposits in the Yukon although the Department of Transportation Engineering has compiled a list of deposits that they use primarily in road construction and for maintenance purposes. This information, while not available in open file format, may be requested from the department. The department is compiling an internal report on Yukon sand and gravel deposits on a data base, and will eventually be preparing a map illustrating the location of these deposits (Bruce Fulcher, personal communications).

The Energy, Mines, and Resources Lands Branch of the Yukon government, estimates approximately 200,000 cubic metres of sand and gravel from Commissioners Lands, are consumed in the territory annually.

The City of Whitehorse, reported consuming 29,000 tonnes of sand and gravel during 2001 (Brian Crist, personal communication). No sand and gravel statistics from other Yukon municipalities were available.

Plate 3. Sand and Gravel Pit 30 Kilometres West of Whitehorse on the Alaska Highway, Yukon Pla3

DIATOMITE DIA

Chemical and Physical Characteristics

Diatomite ($SiO_2 \cdot nH_2O$) is a chalk-like, relatively soft (4.5-5), friable, earthy, very-fine-grained, siliceous sedimentary rock, and is usually light in colour (white if pure, commonly buff to grey in situ, and rarely black). It is very finely porous, has a low density (SG 1.95) and as a result can float in water, until saturated. It is chemically inert in most liquids and gases, with a low thermal conductivity and a high fusion point.

The term "diatomaceous earth" is a common alternate name but is more appropriate for the unconsolidated or less lithified sediment. Diatomite is also known as kieselgur (a German name compounded from the words for flint and for earthy sediment in water) and as tripolite (after a diatomite occurrence near Tripoli, Libya).

Deposit Examples

Quesnel, British Columbia (Canada); Lompoc, California; Quincy, Washington; Lovelock and Fernley, Nevada; Christmas Valley, Oregon (United States).

General Geology

Diatomite deposits result from an accumulation in oceans or fresh waters of the amorphous hydrous silica ($SiO_2 \cdot H_2O$) cell walls of dead diatoms. Diatoms are microscopic single-celled, often colonial aquatic plants (algae), which contain an internal, elaborate siliceous skeleton consisting of two valves (frustules), which fit together much like a pill-box. Diatoms extract silica from the water and secrete it to form an intricate microporous exoskeleton that is often symmetrical in shape. Fossilized diatom skeletal remains vary in size from less than one micrometre to more than one millimetre in diameter; they are typically 10-200 micrometres across and have a broad variety of lacy, perforated shapes varying from spheres and cylinders, to discs, ladders, feathers, and needles. Each deposit has characteristic assemblages that have been used to identify the source of material for forensic purposes.

There are more than 10,000 species of extinct and living diatoms. Some live in either cold or hot springs or in marshes, or even on moist tree bark, but they are most abundant in sunlit water - fresh or salt, that is constantly enriched with suitable nutrients and dissolved silica. Live cells are covered by jelly, and masses appear as films of brownish water in streambeds. Extensive blooms of diatoms (algae) in coastal waters have caused severe pollution and anoxic conditions. Some species produce domoic acid, a nerve poison that if ingested, quickly causes death in many animals.

Commercial deposits worldwide are reported as mostly freshwater lake (lacustrine) deposits of Miocene to Pleistocene age, that were formed between 24 million to 10,000 years, before present. The oldest marine occurrences are believed to be of Cretaceous age. The largest deposits in North America – at Lompoc in California, are of Miocene age and are considered to be of marine origin.

World Production

Over twenty-seven countries produced approximately 1,950,000 tonnes of diatomite during 2001. The six major producers (75 percent of world production) included the United States at 33 percent, followed by China at 18 percent, Japan with 10 percent, Denmark with approximately 9 percent and Mexico with 5 percent (Table 30).

Table 30

Diatomite: 2001 World Production by Major Producing Countries (thousand tonnes)

United States	735
China	350
Japan	190
Denmark*	185
Mexico	70
Other	420
Total	1,950

*Source: Dolley, USGS   * Much of the production is "molar", an impure mixture that includes diatomite.*

End Use

Diatomite, (in a great variety of grades), is primarily used as a filtration medium for beverages (especially beer and wine), but is also used in sugar and sweetener liquor, oils and fats, petroleum and chemical processing (including waste drycleaning fluids), pharmaceuticals, and water (potable). A growing application, is its use as an absorbent for industrial spills (oil and toxic liquids), and pet litter.

Another important broad category of its use is as a filler. Diatomite often serves as an extender and flattening agent in paints and coatings, a bulking and anti-caking agent in granular materials, a multi-effect component in plastics and an extender/absorbent carrier for dry pesticides, pharmaceuticals, catalysts, and other chemicals. It may also be used as an insulation material. Worldwide, its use was estimated in 1993 to be almost 50 percent for filtration applications, 25 percent for fillers, 17 percent for insulation and about 10 percent for absorption and other applications (Dolley, 2001). Diatomite at Lompoc in California, is also used to manufacture synthetic zeolite.

Quality and Specifications

Commercial diatomite products are offered in a great variety of grades. Principal factors are the size, shape, overall arrangement and proportions of the various types of frustules (factors that affect filtration rate, product clarity, and absorption capacity), and their content of silica and other impurities, such as iron clay, sand and organics. Other specifications such as brightness/whiteness and abrasive hardness are also important. Reduced free crystalline silica content, although normally low, is also a requirement of some environmental regulations, particularly for calcined products.

A major influence on diatomite grade, is the method used to process the mineral. These depend on whether they are:

- Naturally milled and dried;
- Plain ("straight") calcined (up to 1,000ºC);
- Flux-calcined (to 1,200ºC with the addition of up to 10 percent of sodium compounds, such as soda ash, salt, or sodium hydroxide).

Tables 31 and 32, illustrate physical properties of diatomite by use (adapted after Industrial Minerals HandyBook II, pg. 58)

Table 31

Diatomite: Typical Physical Properties by Use

	(Filler) Paper Fourdriner Celite 305	***(Filler) Paint, Semi-gloss Celite 499***	***(Filler) Plastic Polyethylene White Mist***	***(Abrasive) Car Polish Super floss***	***(Conditioning-agent) Fertilizer coating***
Loose wt., pcf	-	8.5	7.5	8.7	7.0
Wet density, pcf	24	22	23	24	17
Moisture, % max.	4.0	0.5	0.5	0.5	6.0
Retained on 150 mesh, %wt.	0.1	Trace	0	0	0.5
Retained on 325 mesh, %wt.	1.0	Trace	0.05	0.1	5.00
Oil absorption, %wt.	175	105	160	105	210
Colour	Grey	White	White	White	Buff
PH, max.	7.0	10.0	10.0	9.4	7.0
Resistivity	3,000	7,400	6,500	-	4.000
Refractive index	1.40	1.46	1.47	1.47	1.43
Surface area, m^2/g	10-20	0.7-3.5	0.7-3.5	0.7-3.5	10-20
Median particle size, µm	-	6.8	3.5	5.5	-

Table 32

Diatomite: Typical Physical Properties by Use

	Beer and Wine Standard Super-Cel (Calcined)	***Grape Juice Celite 501 (Calcined)***	***Industrial and potable water Celite 503 (Calcined)***	***Industrial wastes Celite 535 (Calcined)***	***Swimming pools Celite 545Flux (Calcined)***
Colour	Pink	White	White	White	White
Dry density, pcf	8.0	9.5	9.5	12.0	12.0
Wet density, pcf	18	18	18	19	19
Screen analysis, % -150 mesh	4	8	9	10	12
pH	7.0	10.0	10.0	10.0	10.0
Median pore size, µm	3.5	9.1	10.0	13.0	17.0
Permeability, d'Arcy	0.28	1.4	2.0	3.1	4.8

Market Trends

The diatomite market remained mature and stable at the beginning of the 21st century. Industry representatives expect the next five years to be similar to the past five years, although increased energy costs and possible global over-capacity may impede future expansion of the industry. The encroachments into filter applications by other technologies (ceramics, polymeric, and carbon membranes) are not of a major concern to producers, possibly because of cost factors. Disposal of diatomite waste, however, is a problem not fully resolved by recycling.

Emerging markets for diatomite include uses for biotechnology and in pharmaceuticals, and as a nontoxic insecticide. The problem of free crystalline silica associated with diatomite, particularly when calcined, continues to be of concern to producers and consumers (Dolley, 2001).

Price

Reported prices during 2002 for diatomite (by Industrial Minerals, No. 419) were:

- US calcined filter-aids, del Uk £370-410
- US flux-calcined filter-aids, del Uk £380-420

The USGS reports that the calculated weighted average unit value of diatomite sold or used by United States. producers during 2001, was about US$271 per tonne f.o.b. (Dolley, 2001).

Economic Factors

The world's largest deposits are near Lompoc, California where beds of up to 430 metres thick are mined on a large scale. In the United States, diatomite is mined by low-cost open pit methods because many occurrences are at or near the surface. In Europe, underground mining is fairly common (e.g., France) owing to deposit form and depth and topographic constraints. As a low-value commodity, access to transportation corridors and closeness to markets are important economic considerations for any future development.

Yukon Occurrences

There are no documented deposits of diatomite in the Yukon or recorded in Yukon Minfile 2001.

Exploration Guidelines

Examination of exposed sedimentary stratigraphic units in Tertiary basins may prove to locate deposits of diatomite.

DIMENSION STONE AND FLAGSTONE DIM

Chemical and Physical Characteristics

Dimension stone is natural stone, which has been selected and fabricated to specific sizes or shapes. In the many regions of western Canada, it means a rock or stone product that is cut or split on two or more sides and includes, tiles, facing stone, monument and ornamental stone, but does not include stone in structural applications.

Flagstone is a type of dimension stone usually of sedimentary origin (but may also be metamorphic), which splits into thin slabs from 1 to 5 centimetres (0.4 to 2 inches) in thickness.

The basic requirements for any building stone are durability, soundness, uniformity and chemical stability. Dimension stone should also be attractive and easy to process and shaped according to specifications, without producing uneconomical quantities of waste. Chemical stability means that the stone should not react with mortars or cement. When exposed to weather, it should not produce unsightly stains (rust for example), nor be susceptible to crystallization of soluble salts (Hora, 2002).

Various igneous metamorphic and sedimentary rocks are used as dimension stone, with the principal rock types described below:

Granite - commercial granites include all feldspathic crystalline rocks of mainly interlocking texture and with individual mineral grains that are visible to the naked eye. This category includes rock types such as gneiss, syenite, monzonite, granodiorite, anorthosite, and other intermediate rock types. Primary colours of granites are white, grey, pink, and red with green and brown as secondary colours. "Black granites" are not true granites petrologically but such mafic rocks (diabase, diorites, pyroxenites and gabbros), are included in this category. They range in colour from dark grey to black.

Limestone - commercial limestones are rocks of sedimentary origin primarily composed of calcium carbonate ($CaCO_3$) with or without magnesium. Included in this category are calcitic limestone, dolomite, dolomitic limestone, and travertine (a rock that is chemically precipitated from hot springs).

Marble - commercial marble includes metamorphosed limestones and serpentine rocks that are capable of taking a polish. An important member of this classification is serpentine marble, also known as "verde antique", which is composed of green-to-black serpentine (a hydrous magnesium silicate mineral), and may be crisscrossed by veins of lighter minerals such as calcite or dolomite.

Sandstone - commercial sandstone is a lithified sand, composed chiefly of quartz or quartz and feldspar of fragmental texture. Sandstone contains interstitial cementing materials, such as silica, iron oxides, calcite, or clay. Arkose (abundant feldspar grains), greywacke (abundant rock fragments), and conglomerates are included in this category. Other members of this category include bluestone (a dense, hard, fine-grained feldspathic sandstone, which splits easily along planes into thin, smooth slabs), and brownstone (feldspathic sandstone of brown to reddish-brown colour owing to abundant iron oxide).

Slate - commercial slate is a microcrystalline metamorphic rock formed by the recrystallization of clay sediments (shale, siltstone, or claystone). Characterized by excellent parallel cleavage, slates may be easily split into relatively thin slabs.

Greenstone - commercial greenstones are the result of the metamorphosis of basaltic rocks. Greenstone is named so because of the predominance of greenish minerals such as chlorite, epidote, or actinolite.

Basalt and Traprock - commercial basalt and traprock includes igneous rocks that are too fine grained to be termed black granite. The name traprock is derived from the term "trappa," meaning stairway - the characteristic terraced or steplike appearance of certain basalt lava fields. This category includes both extrusive rocks (such as andesite, basalt, or dacite) and intrusive igneous rocks (such as amphibolites, diabase, diorites, fine grained gabbros, peridotites, and pyroxenites).

Miscellaneous - this category includes dimension stone types that do not easily fit into the above categories. Examples are, soapstone or steatite (rocks that contain various amounts of talc). Additional miscellaneous dimension stone types may include pumice, schist, tripoli, tuff, porous or scoriaceous volcanic rock or any other rocks which are used as sized and shaped building stones.

Deposit Examples

Jackson Lake Quarry, near Whitehorse, Yukon; Johnson Creek Sandstone Quarry, Hudson Hope, Nelson Island Granite (92F/9E), Haddington Island Andesite (92L/11E), Anderson Bay, Texada Island Marble (92F/9E), British Columbia (Canada).

General Geology

Dimension stone is obtained from all three classifications of rocks – igneous, metamorphic and sedimentary. Deposits should have a well spaced and rectangular joint system allowing removal of commercial sized blocks (approximately twenty tonnes in weight) or be suitable for processing into ashlar, flagstone, or tile without an undue and uneconomical quantity of waste.

World Production

World dimension stone production was estimated to be approximately 61.5 million tonnes in 1999. Preliminary numbers indicate that this total remained unchanged for 2000. Although small-scale production probably occurs in the majority of the world's nations, dimension stone was produced and officially reported in 34 countries with the top five producing countries in 1999, in descending order by tonnage being: China, Italy, India, Iran and Spain. These countries accounted for about 72 percent of total world production (Dolley, 2000).

In Canada, the volume of dimension stone (granite, limestone marble, sandstone and slate) produced during 1999 was estimated at 104,026 tonnes valued at CA$732,369 (excluding stone used in the Canadian cement, lime and clay industries). The production of dimension stone is illustrated in Table 33:

Table 33

Dimension Stone

Produced in Canada During 1998

Commodity	***(000t)***	***(CA$000)***
Limestone	179	9570
Marble	14	887
Granite	163	27264
Sandstone	63	5536
Slate	18	5205

Source: Canadian Minerals Yearbook (1999)

End Use

Dimension stone is used as a decorative stone on buildings, and countertops, and also for monumental and memorial stone, flagstone, curbing ashlar and for other construction purposes.

Plate 4. Assorted 'Granite' Used to Construct an Attractive Fence, Whitehorse, Yukon Pla4

Quality and Specifications

Colour, durability (based on mineral composition, hardness and past performance), strength, grain texture, pattern and the ability of a stone to take a polish, are important market and selection criteria. The stone must also be free from features such as micro fractures or the presence of minerals that can lead to iron staining or efflorescence on exposed surfaces.

The physical standards for the use of stone in the building construction industry have been determined by the American Society of Testing and Materials International (ASTMI) (formerly the American Society of Testing and Materials (ASTM). This organization's standards are based on an exhaustive testing of materials and evaluation of all engineering criteria, which could affect the use of stone in construction, including: compressive strength, flexural strength, absorption, density, and freeze-thaw degradation. However, the importance of a stone meeting the ASTMI standards, depends upon its intended use. In some situations, particularly for interior use, meeting all standards is not essential. For example, a weakness in a stone can often be adequately compensated for, by cutting it thicker, or by incorporating it into a stronger structure. However, most dimension stone in the marketplace does meet the ASTMI standards and a stone that does not will often be rejected. Table 34 illustrates the basic physical requirements for granite and marble:

Table 34

Physical Requirements – Building Stone

Stone	***Minimum Density***		***Maximum Absorption by Weight***	***Minimum Compressive Strength***		***Traverse Strength***	
	Lb/ft^3	kg/m^3	(percent)	PSI	Mpa	PSI	Mpa
Granite	160	2560	0.40%	19,000	131	1,500	10.34
Marble	162	2595	0.75%	7,500	52	1,000	7.00

Source: adapted after American Society of Testing and Materials, 1984.

The ability of granite to take a good polish depends largely on the freshness of the silicate minerals present. If the silicate minerals have been altered, they will polish poorly. This applies especially to rocks containing kaolinized or sericitized feldspars, and chlorite altered pyroxene. Another problem arises when polishing granites that contain biotite. The biotite often flakes off, creating pits; this is especially true of coarse-grained biotite. Table 35 highlights some of the more common problems encountered with dimension stone:

Market Trends

A dimension stone market study by the British Columbia government identified a variety of market opportunities for developing a provincial industry (Page, 1989). In this report, market opportunities were identified for using grey, as well as coloured granites. These included several premium granites such as fine-grained black, medium to coarse grained mahogany, dark-red, gold, green and blue coloured granites. Market areas identified for these stones included British Columbia, Alberta, the America Pacific Northwest, California, Hawaii, Italy and Japan.

Today, there are a number of well-established flagstone and dimension stone producers supplying the existing markets in Western Canada and adjacent American states. Such products are distributed in pallets of approximately 1 cubic metre (around 2 metric tonnes), and are sorted by thickness and degree of processing, such as with or without sharp edges, random or square shapes, etc. Western Canadian stone products are complemented by imported stone types not available from local producers. The following are estimates of split stone production in British Columbia and Alberta (Hora, 2002):

Flagstone*

Kootenay Stone Centre	
Revelstoke flagstone Quarries	
Kettle Valley Stone Ltd.	
Thunderstone Quarries ltd.	
Total	approximately 12000 tonnes

Cut and Split Granite and Marble*

Garibaldi Group	
Margranite Industries Ltd.	
Adera Natural Stone Supplies Ltd.	
Quadra Stone Company Ltd.	
Matrix marble Corporation	
Total	approximately 5500 tonnes

* Amounts from each company are not reported for proprietary reasons.

Table 35

Some Deleterious Physical Features In Dimension Stone (Granite)

- The presence of sulphides which rust, causing stains and weakness in the stone.
- The presence of alteration minerals which weaken the stone, create absorption problems and polish poorly.
- The presence of cavities which weaken the stone and create absorption problems.
- A low density which suggests high porosity or cavities and hence strength or absorption problems.
- A high permeability (absorption) rate, which may result in problems with staining or physical degradation due to freeze-thaw, cycles.
- The presence of microfractures creates an obvious strength problem.
- Rocks that are poorly cemented or do not have interlocking crystal structures are weak.
- The presence of large crystals with a good cleavage, such as orthoclase, can be a source of weakness in a stone. The cleavage plane may be an important factor in the failure of the stone under stress.
- A high biotite content or large flakes of biotite cause polishing problems.
- The presence of quartz veins, streaks due to variations in mineral composition (flashes), or xenoliths (knots) are generally considered unattractive because they disrupt the uniform abstract pattern desired in granites. Their presence may also indicate strength problems.
- A high quartz content causes excessive wear on saw blades during cutting. In general, fabrication plants will not process a stone with a quartz content of greater than 30 percent.

Source: Page, 1991

The rest of reported production tonnage is in the form of small chips - waste from splitting the stone blocks - sold as landscaping stone, or for road maintenance, or possibly as raw material for cement manufacture.

Almost all producers sell up to 50 percent of their production to other parts of Canada, as well as to the United States.

A significant quantity of stone products is also imported. These are in part stone types not available from local producers, or different shapes and sizes produced elsewhere and required for special projects.

In recent years there has been competitive pressure on Western producers from very low priced imports from overseas, particularly from China.

It is estimated that including imports, the British Columbia market for flagstone and similar facing stone products is ten thousand tonnes per year (Hora, 2002).

No estimates were available for Alberta.

Price

Pricing rough blocks of dimension stone must take into account the value of producing the rough blocks and the cost of transporting them to finishing plants. Discussions with fabricators can identify recent prices for similar stone, and whether the company has had contracts to supply similar types and grades of stone. Transportation costs can be calculated based on discussions and estimates with transportation companies. Importantly, transportation rates can vary depending on the mode of transport, (that is the type of trailer, size of blocks, back-haul potential, turn-around time and contract volume).

There are a number of well-established flagstone/facing stone producers supplying the existing market in Western Canada and adjacent American states (Hora, 2002).

- Kootenay Stone Centre of Salmo is producing quartzite in a variety of brown, beige, yellow or green colours, in the thickness of 0.25 to 0.5 inch (0.8 to 1.25 centimetres), 1 inch (2.5 centimetres), 2 inches and 4 inches thick, at a price of $2 to $4 per square foot.
- Revelstoke Flagstone Quarries Ltd. of Revelstoke is producing a silvery grey, mica schist, in thickness of 0.5 inch, 1 inch, 2 inches, at a price of $4 per square foot.
- Kettle Valley Stone of Kelowna is producing lithified white and red/green banded volcanic ash, in thickness of 1 inch, 2 inches, at a price of $4 per square foot. Kettle Valley Stone also sells split basalt.

A variety of split granite is also produced in British Columbia in square shapes and in some areas competes with flagstone.

- Garibaldi Granite Group in Squamish, British Columbia is producing a variety of sizes of 2 and 4 inch thick slabs of white, grey and beige granite at $2.50 to $8 per square foot; a specialty product without sharp edges at $12 per square foot; and, 4 inch sawn basalt at $8 per square foot.
- Margranite Industries Ltd. is also producing about ten different colours of cut and polished or flamed granite tile in two sizes – 1 and 1½ foot squares. The price of stone tiles is from $12.75 to $14.95 per square foot.
- Matrix Marble Corporation of Duncan, British Columbia is selling black and white marble varieties as square paving blocks for $9 per square foot and tile for $12 per square foot.
- A stone marketed as the “Rundle Stone” or “Rundle Rock” consisting of a dark grey to black silty sandstone is quarried in Alberta near Canmore by Thunderstone Quarries Ltd. It is used in rough split pieces as a patio stone, or facing stone, and can be seen in Banff on many structures including the Banff Springs Hotel. It retails in Vancouver in 2-inch thick slabs for $6.89 per square foot.

Economic Factors

The physical and geological features of a quarry site determine the cost of production, but most successful modern quarries, have many features in common. It is essential that quarries be able to produce large blocks of consistent quality. Modern fabricating plants require rectangular blocks, with parallel sides cut to close tolerances, and weighing from 20 to 30 tonnes.

A quarry must be able to produce blocks of a consistently high, uniform quality with a low waste factor. This requires mobile, trackless equipment and the development of the quarry on a system of benches. Another important consideration is the tendency of stone in a quarry to split cleanly along predictable planes, allowing for efficient removal of quarry blocks. Other factors such as the steepness of the site, amount of overburden or waste removal required before production, as well as access to transportation, are major influences on the development and production costs.

The markets for quarry blocks and for finished stone products are different. Buyers of quarry blocks are fabricating plants, not architects nor consumers. Because there are no processing plants in the Yukon, a territorial quarry would have two options if they did not build their own plant. They could either have their blocks cut by one of the four finishing plants located in the British Columbia lower mainland (Table 36), or they could export their blocks to another jurisdiction. For more remote deposit locations, more uncommon colours that command premium prices may be essential for the quarry to be economical. Examples are black granite, green marble (serpentinite), or soapstone.

Table 36

Dimension Stone Processing Plants Which Potentially Could Serve a Yukon Quarry

Westcoast Granite Manufacturing Inc.	Delta, British Columbia
Matrix Marble Corporation	Duncan, British Columbia
Margranite Industries	Surrey, British Columbia
Garibaldi Granite Group Inc.	Squamish, British Columbia

Source, B.C. Mineral Exploration Review, 2001, pg. 16.

Table 37 lists some economic factors operators must consider when developing a quarry.

Table 37

ECONOMIC FACTORS AFFECTING THE OPERATION OF DIMENSION STONE QUARRIES

- The higher value of many premium or exotic granites is often a result of higher costs of production, not higher profits. This can be due to a high waste factor at the quarry or during the cutting operations.
- The prices paid to quarries for different types of granite do not show the same variation as do the prices of finished products.
- Transportation costs have a large influence in defining the market area of a particular stone.
- Development and operating costs appear to have a much greater influence on profitability than does the type of stone.
- The lower the profit margin for a quarry, the closer the relationship required between the quarry and a plant.
- The primary applications for granite dimension stone are usually large commercial projects such as exterior cladding for office towers. The types of granite chosen for these projects generally reflect conservative tastes in colour and texture. Supplying these types of projects may be the only way that many quarries can achieve sustainable and profitable levels of production.
- Sales support by the vendor (the fabrication plant or its agent) and reliability of the quarry have a bigger influence on market penetration than do small variations in price.
- A quarry and a plant must have a track record and be able to guarantee delivery of a uniform high quality product on schedule before they can win large commercial contracts. This requires that the quarry has proven and developed reserves ready for production and a good supply of blocks on hand. Plants must have two or more gang saws and sufficient resources to provide compensation in the event of inadequate performance. Potential quarries must consider an association with a successful plant, if they expect to supply large commercial projects.
- The ability of a quarry to produce large, rectangular blocks of optimum size for a given plant's saws has a large influence on the cost of production at that plant. This is a major factor in the demand for the quarry's blocks, and is more important than small variations in price for the rough stone. The size and shape of the blocks have become a very important consideration in the international market for quarry blocks, and is one of the primary reasons why European countries, such as Sweden, can successfully compete with third world countries.

Source: Page, 1991, pg. 5-6.

Yukon Occurrences

Although dimension stone and flagstone have been produced in the Yukon, as evidenced by a few buildings, monuments and other structures, there is no control or systematic documentation of such local stone production and furthermore much of it is not really a flagstone, but just irregular rubble, or "chips".

Yukon does have a wide variety of natural stone resources that potentially could meet industry standards as dimension stone or flagstone and the territory does have the potential to export some of this stone to both domestic and international markets. However, to evaluate these potential markets, an export market study is required to identify opportunities that may exist for Yukon produced dimension stone or flagstone.

Plate 5. 'Granite' Rubble Used to Construct Breakwater along the Yukon River, Whitehorse, Yukon Pla5

Exploration Guidelines

There are potentially many intrusive rocks in the Yukon that could be used for dimension stone. Any investigation of these rocks would require a systematic survey to determine their potential to host sufficient reserves of stone that meet or exceed the physical requirements set by the American Society for Testing Materials International (ASTMI). As well, the stone must be capable of taking a good polish, contain little or no sulphides and have a low porosity to prevent staining and water absorption. The market also requires that granites have a uniform colour, texture and pattern and that natural features such as mafic knots, veining, schlieren structures and inclusions are minimal, since these characteristics are not normally acceptable. Quarried blocks must be rectangular in shape and of sufficient size to meet cutting plant specifications. This requires that joint and fracture patterns at the outcrop must be sufficiently spaced, to permit the extraction of large blocks. One first positive indictor of a potential quarry site, is the presence of loose boulders several cubic metres in size. Deposits should be located near established transportation corridors to minimize shipping costs to markets and/or finishing plants.

FELDSPATHIC MATERIALS FEL

Feldspars

Feldspars are the earth's most abundant rock-forming minerals and are commonly found in igneous rocks. They are classified in two main groups, the alkali series and the plagioclase series. Alkali feldspars are in the compositional range of $KAlSi_3O_8$ and $NaAlSi_3O_8$, and the plagioclase series ranges from $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$. Plagioclase feldspars are more widely distributed and more abundant than potassic feldspars. The various feldspar species are described in Table 38.

Table 38

The Feldspar Series

Potash Fesldspars: KalSi3O8

Orthoclase	Monoclinic found in quickly cooled granites, granodiorites and syenites.
Microcline	Triclinic, found in more slowly cooled granites, granodiorites and syenites.
Sanidine	Monoclinic, high temperature, found as phenocrysts in rhyolites and trachytes.
Adularia	Mixed crystallography, low temperature, in hydrothermal veins.

Plagioclase Feldspars: NaAlSi3O8 (Ab) – CaAl2Si2O8 (An)

Albite	0-10% An, "soda spar", triclinic.
Oligoclase	10-30% An, triclinic, found in granodiorite and monzonite.
Andesine	30-50% An, triclinic, rare, found in andesites and diorites.
Labradorite	50-70% An, triclinic, found in gabbros and basalts.
Bytownite	70-90% An, triclinic, found in gabbros, not used commercially.
Anorthite	90-100% An, triclinic, rarer than albite, found in mafic-rich rocks.

Feldspathic Source Materials

Feldspathic material is found in economic deposits in nepheline syenite, phonolite, pegmatite, aplite, alaskite, leucocratic granite and feldspathic sand. A brief description of each follows:

<u>Nepheline Syenite</u> - contains the commercially important mineral, nepheline and a mixture of microcline and albite. Generally, syenites contain alkali feldspars; orthoclase, sanidine, microcline or anorthoclase with albite, nepheline, sodalite, amphibole, pyroxene, analcite, biotite, and calcite with accessory zircon, sphene, magnetite, muscovite, corundum and fluorite. Nepheline syenite is a difficult mineral to identify macroscopically but is more readily identified if cancrinite and sodalite are present. Nepheline syenite is generally considered igneous in origin, but may also be metamorphic. Its composition may also result from the re-melting of pre-existing alkaline rocks. Carbonatites are frequently associated with Nephelinitic rocks.

<u>Phonolite</u> - is the extrusive equivalent of nepheline syenite that may also be a potential source of feldspathic materials. Phonolites contain alkali feldspar (sanidine, anorthoclase or orthoclase), nepheline, rare plagioclase with sodalite, hauyne, analcite, sodium rich amphiboles or pyroxene, biotite, leucite, phlogopite and accessory sphene, apatite, corundum, and zircon.

<u>Pegmatites</u> - are defined as extremely coarse-grained igneous rocks found usually as dikes associated with a larger plutonic mass of finer grain size. The term pegmatite denotes texture only, not composition.

During the normal sequence of crystallization of a magma, the stage is reached where the residual fluid is rich enough in volatile materials to form coarse-grained rock, more or less equivalent in composition to the parent rock; this phase of crystallization produces pegmatites. Pegmatites consist chiefly of quartz and alkali feldspar (+muscovite/biotite). Being rich in volatiles and elements excluded from crystallization within normal silicate structures, they often contain abundant less-common minerals containing elements such as lithium, beryllium, niobium, tantalum, tin, uranium, thorium, tungsten, zirconium and rare earth elements.

<u>Aplite</u> - is a fine-grained, sugary textured, late-crystallizing rock composed of quartz and alkali feldspar. Pegmatites may be found with aplite within the same dike, with sharp or gradational contacts. Pegmatites and aplites in the same vein may be due to either simultaneous or sequential crystallization of both melt and water-rich phases, or from anatexis, the partial melting or 'sweating out' of granitic fractions, during high-grade metamorphism.

<u>Alaskite</u> - actually a muscovite granite, is mined for feldspar in North Carolina. Alaskite is usually defined as a leucocratic granite composed of alkali feldspar, quartz with very few mafic minerals.

<u>Feldspathic Sands</u> - are a mixture of approximately equal amounts of quartz and feldspar occurring naturally as an erosional product from granitic rock. The best feldspathic sands are found in stream systems where the entire basin drains only granitic terrain, and where only mechanical weathering has taken place.

Deposit Examples

Pegmatite - near Lumby; Feldspathic sand - Scuzzy Creek near Boston Bar; Nepheline syenite – Trident Mountain, British Columbia; Blue Mountain Deposit, near Nephton, Ontario; (Canada); Plagioclase feldspar - Spruce Pine, North Carolina; Potassium feldspar - Kings Mountain, North Carolina; Feldspathic sand - Bessemer City, North Carolina; Low-iron aplite - Montpelier, Virginia (United States).

World Production

Feldspathic Minerals

World production and consumption of feldspathic material was estimated at about 9.26 million tonnes in 2001. Production was dominated by Italy (2.6 million tonnes) , Turkey (1.2 million tonnes) and the United States (790,000 tonnes). During 2001, Canada imported 1,330 tonnes of feldspathic materials from the United States (Potter, 2001).

Nepheline Syenite

Canada and Norway dominated world production of nepheline syenite during 2001, although Russia also produced large tonnages, which were mostly used domestically to manufacture aluminum. Both the Canadian and Norwegian deposits are owned and operated by the same American company.

The Canadian deposit, located about 175 kilometres east of Toronto near Nephton, Ontario, produced about 650,000 tonnes in 1999. Of this amount, an estimated 70 percent of the raw material was consumed in glass applications, 15 percent was used in ceramics and 15 percent went into pigments and fillers. An estimated 60 percent of the output was shipped to American markets, 20 percent to Canadian markets and 20 percent to European countries (Potter, 2001).

End Use

Feldspathic minerals are used mainly as a source of aluminum and alkalis in the glass and ceramics industries, and as a filler in the paint, plastics and rubber industries. They also find use in the production of ceramic glazes, as match-flame retardant, abrasives and as arc stabilizers in welding.

Quality and Specifications

The most significant use of feldspathic minerals, which are a source of alumina, alkalis and silica, occurs in the glass and ceramics industries. These elements influence the rate and temperature of melting, the viscosity and fluidity of the melt, and the physical properties of the finished product. The ratios of melting alumina, sodium, potassium and silica are specified for each industrial use. Contaminants such as iron, copper and manganese must be virtually absent. Refractory minerals such as corundum, spinel or mica must be absent in the material used in glass manufacturing.

Tables 39, 40, 41, 42 and 43 compare typical analysis of feldspathic, aluminous materials, and nepheline syenite used in different commercial applications (Tables 40-43 adapted after The Industrial Minerals HandyBook II, pgs. 63-64).

.

Table 39

Typical Analyses, Feldspathic and Aluminous Materials (%)

(from Lefond, 1983)

	1	2	3	4	5	6
SiO2	67.54	67.04	71.84	79.20	63.71	61.40
Al2O3	19.25	18.02	16.06	12.10	21.89	22.74
Fe2O3	0.06	1.94	0.09	0.06	0.09	0.06
CaO	1.94	0.38	0.48	0.52	5.70	0.70
MgO	Trace	Trace	Trace	Trace	Trace	Trace
K2O	4.05	12.10	7.60	2.62	2.37	4.95
Na2O	6.96	2.12	3.72	4.80	5.60	9.54
Li2O	-	-	-	0.35	-	-
TiO2	-	-	-	-	0.43	-
LOI	0.13	0.30	0.20	0.35	0.21	0.60

1. *Soda flotation feldspar, Spruce Pine, NC*
2. *Potash flotation feldspar, Kings Mountain, NC*
3. *Dry-ground feldspar, Custer, SD*
4. *Feldspathic sand, Bessemer City, NC*
5. *Low-iron aplite, Montpelier, VA*
6. *Canadian nepheline syenite, Nephton, Ontario*

Table 40

A Comparison of Alumina Sources in Glass and Ceramics

	Nepheline Syenite	*Soda-Feldspar*	*Potash-Feldspar*
SiO2	61.40	67.54	67.04
Al2O3	22.74	29.25	18.02
Fe2O3	0.06	0.06	0.04
CaO	0.70	1.94	0.38
MgO	Trace	Trace	Trace
K2O	4.95	4.05	12.10
Na2O	9.54	6.96	2.12
LOI	0.60	0.13	0.30

Table 41

Specifications for Commercial Feldspar

	Glass F-20	*Glass C-20*	*Glass G-40*	*Pottery NC-4*	*Pottery C-6*	*Potter G-200*	*Pottery K-200*
SiO2	68.20	68.90	67.70	68.15	68.70	67.00	67.10
Al2O3	22.00	18.75	18.50	19.00	18.50	18.30	18.30
Fe2O3	0.10	0.07	0.1 max	0.067	0.07	0.08	0.07
CaO	5.60	1.85	0.90	1.60	0.90	1.02	0.36
MgO	Trace	Trace	Trace	Trace	Trace	Trace	Trace
K2O	3.00	3.85	4.10	4.00	4.10	10.50	10.10
Na2O	6.00	7.15	7.00	7.00	7.20	2.85	3.80
LOI	0.20	0.13	0.25	0.10	0.25	0.20	0.26
Screen analysis, cum. % retained on:							
	0	0	0				
16 mesh	0.10	0.40					
20 mesh	8.20	8.00					
30 mesh	12.00						
40 mesh		49.00	1.75				
50 mesh	85.50	81.00					
100 mesh	98.80	96.10	61.00				
200 mesh			97.50				

Table 42

Specifications for Feldspar Used as a Filler

	Minspar 3	***Minspar 4***	***Minspar 25***	***Minspar 7***
G.E. brightness	89.6	91.4	91.5	92.2
Wt./solid gallon (lb/gal)	21.61	21.61	21.61	21.61
Bulking value (US gal/lb)	0.0463	0.0463	0.0463	0.0463
Apparent bulk density (lb/ft^3)				
Loose	44	40	40	38
Packed	70	60	60	55
Moisture Content	0.1	0.1	0.1	0.1
PH	8.7	9.3	9.3	9.3
Oil absorption (rub out)	16-17	18-19	19-20	21-23
ASTM D-282-31				
Particle size distribution, % finer than				
74μ	99.6	100	100	100
44μ	96	99.95	100	100
30μ	87	94	99	100
20μ	72	88	96	100
10μ	41	60	70	90
5μ	19	30	35	55
Mean particle size, μ	12	8	7	4.8
Specific surface area (m^2/g)	0.8-0.9	1.0-1.2	1.2-1.4	1.5-1.6

Table 43

Chemical Composition of Commercial Nepheline Syenite

	Norway Glass grade	***Norway Amber Grade***	***Canada Glass grade (A30)***	***Canada Glass grade 333***	***Canada Ceramic grade A-200, 270, 400***	***Norway Ceramic grade***	***Canada Filler grade Minex 3&2***
SiO2	57.00	56.50	60.3	59.7	60.7	57.00	59.99
Al2O3	23.80	22.50	23.7	23.5	23.3	23.80	23.7
Fe2O3	0.10	0.40	0.1	0.4	0.07	0.12	0.08
TiO2	0.10	-	-				0.001
CaO	1.30	2.50	0.3	0.5	0.7	1.10	0.37
Na2O	7.90	7.50	10.4	10.2	9.8	7.80	10.6
K2O	9.00	8.20	5.0	5.0	4.6	9.10	4.8
MgO	n.a.	n.a.	Trace	0.1	0.1	n.a.	0.02
BaO	0.30	n.a.	-	-	-	0.30	n.a.
SrO	0.30	n.a.	-	-	-	0.30	n.a.
P2O5	0.10	n.a.	-	-	-	-	n.a.
F	<40ppm	<40ppm	n.a.	n.a.	n.a.	<40ppm	n.a.
Cl (Water soluble)	<0.15ppm		n.a.	n.a.	n.a.	<18ppm	n.a.
Cl (total)	<100ppm	<100ppm	n.a.	n.a.	n.a.	<75ppm	n.a.
LOI	1.2		0.3	0.6	0.7		0.37

Market Trends

Feldspathic Materials - Plastic containers have made significant penetration against glass especially in the food and beverage industries. Some baby foods, even beer have been marketed in plastic containers. In the developed world, glass containers are perceived to contain a high-quality product but by contrast consumers in the developing world see glass as containing a lower quality and less-attractive product than when in aluminum containers.

One of the challenges facing the feldspar industry, is increasing energy costs which are required when drying feldspar in its benefaction process. As well, the increasing trend of recycling glass containers, has reduced the quantity of new feldspathic materials in glass manufacturing. This increasing use of cullet or recycled glass has reduced the need for raw feldspathic materials. Recycling now accounts for approximately 33 percent of feldspathic materials consumed in the United States and as much as 90 percent in some European countries such as Switzerland (Harben, 1995, pg. 64).

North American companies are looking overseas for new markets. American Standard Company for example was optimistic about opportunities in existing feldspar markets in Eastern Europe (Potter, 2001).

Anorthosite is sometimes used as a source of silica and alumina in Portland cement manufacture if clays or shale are logistically not conveniently located.

Price

To follow are prices received for feldspar and nepheline syenite as reported by Industrial Minerals No. 419, during 2002.

Feldspathic Minerals
- Ceramic grade, powder, 300 mesh, bagged, ex-store UK£180-185
- Sand, 28 mesh, glass grade, ex-store UK£99
- Ceramic grade, sand, ex-works Italy US$22-25

Ceramic grade, s ton ex-works, USA
- 170-250 mesh, bulk (Na) US$60-75
- 325 mesh, bagged (Na) US$115-130
- 200 mesh (K) $125

Glass grade, bulk, s ton ex-works USA
- 30 mesh (Na) US$40-52
- 80 mesh (K) US$85-90

Nepheline Syenite

Canadian, s. ton:
- Glass, 30 mesh, bulk CL/TL, low iron C$32
- Glass, 30 mesh, bulk CL/TL, high iron C$29-30
- Ceramic, 200 mesh, bagged 1-ton lots C$85-90
- Filler/extender, bagged C$98-195

Norwegian, FOL UK Port:
- Glass grade, 0.5mm bulk £99
- Ceramic grade, 45µ, bulk £116
- Bags £148

Economic Factors

In the international market, trade in feldspathic minerals is mostly regional; European countries supply European markets. The same situation exists in North America. Japan and Korea are recognized as potential markets for British Columbia materials because of their relative proximity to these markets and their advanced industrialization (MacLean and White, 1991).

A market study completed by the British Columbia government in 1988 (McVay, 1988), concluded that approximately 1.5 million tonnes of feldspathic material are consumed in western Canada, the U.S. Pacific Northwest and northern California (Table 44).

Table 44

Consumption of Feldspathic Material in Canadian Western Provinces, Pacific Northwest and Northern California

	Material	*Tonnages Consumed (tonnes)*	*Alumina Contained*
Container Glass	Feldspathic sand	573,340	31,790
	Nepheline syenite	10,980	2,520
Fibreglass	Feldspathic sand	907,180	5,440
	Nepheline syenite	9,800	2,260
Ceramics	Nepheline syenite	1,810	420
	Feldspar	1,360	320
Total Alumina			42,750

Source: adapted after McVay, 1988.

Transportation costs are a major limiting factor for feldspathic materials. A Yukon deposit, which would meet industry quality and specifications for feldspathic materials, could potentially supply western Canada and the American Pacific Northwest, as well as Japanese and Korean markets. But this supply must be located near an existing transportation infrastructure, and preferably close to tidewater.

Yukon Occurrences

There are no reported feldspar-rich pegmatite or other feldspathic materials reported in the Yukon. A systematic study of Yukon pegmatite and other potential sources of feldspar is required to determine the Territory's potential to host a deposit which would meet industry standards for feldspathic materials and would have adequate reserves to meet potential markets.

Exploration Guidelines

Feldspathic Materials

Systematic sampling and documentation of known pegmatites, phonolites, feldspathic sands, alaskites, leucocratic granites and aplites in the Yukon to determine whether deposits meet the physical and chemical standards required for glass and ceramics applications.

Nepheline Syenite

Nepheline syenite of the sheet, gneissic and border phase of granite and syenite intrusive types, are most likely to have the required uniform composition and quality. Although documented nepheline syenite occurrences in the Yukon are rare, more detailed work in the future will likely identify new unreported nepheline syenites in the northward continuation of the cordilleran alkaline trend. These occurrences if found should be tested for their commercial applications in both the glass and ceramic industries.

FLUORSPAR FLU

Chemical and Physical Characteristics

Flurospar is the commercial name for the mineral fluorite (CaF_2). It is a transparent to translucent mineral often occurring in well-formed crystals ranging in colour from white to amber, green, blue, purple and black. Fluorite is semi-hard (4), heavy (SG 3.1), and has a vitreous lustre.

Fluorite is the only commercial source of fluorine.

Other fluorine containing minerals - cryolite, wellaite topaz, villiaumite, bastnaesite and fluorapatite are of no commercial importance. Only cryolite (formerly mined from an exhausted deposit in Greenland), was used as a source of aluminum metal.

Deposit Examples

Near the Liard Hot Springs (replacement along limestone and shale interface), Rock Candy Mine (BC Minfile 82ESE070), British Columbia; St. Lawrence, Newfoundland; (Canada); Zhejiang Province, (China); Buffalo Fluorspar mine, (South Africa).

General Geology

Fluorite forms in a wide range of temperature and pressure conditions and occurs in many geological environments. It may be associated with calcite and barite in low-temperature, carbonate-hosted lead-zinc deposits; with quartz in granite-related silver-lead-zinc veins; with chalcedonic quartz and gold, in epithermal vein systems; and with silver and lead, in manto-type replacement deposits in carbonate rocks adjacent to granitic intrusions. Commercial deposits are hydrothermal veins and replacement orebodies, in some base metal deposits (in Mexico, for example) fluorspar may be a co-product, or may be recovered from tailings.

Fluorine is also often enriched in carbonatites and related alkaline rocks, in specialized granites and complex pegmatite, and in skarn and greissen. Consequently, fluorite and other fluorine-bearing minerals are often associated with tungsten, tin, uranium, rare earth and “high tech” metals such as yttrium, niobium, tantalum, beryllium and zirconium etc. (Pell, 1992).

World Production

World mine production of fluorspar during 2001 was estimated at 4.510 million tonnes. The three leading producers included China (2.450 million tonnes), Mexico (635,000 tonnes) and South Africa (212,000 tonnes).

Canada did not produce any fluorspar during 2002. Reported imports according to Natural Resources Canada came mostly from Mexico, Morocco and China and consisted of 19,300 tonnes of metallurgical-grade fluorspar and 161,000 tonnes of acid-grade fluorspar (Miller, 2002).

End Use

Because of its attractiveness in massive form, fluorspar was used by the early Greeks and Romans for ornamental purposes, and for carving into vases, drinking cups and tabletops. Today, fluorspar is used in the manufacture of aluminum, crude oil hydro-cracking, insulating foams, refrigerants, uranium fuel, and as a metallurgical flux.

Quality and Specifications

Most fluorspar consumption and trade involves either acid grade, [greater than 97 percent calcium fluoride (CaF_2)] or subacid grade, which is 97 percent or less CaF_2. The latter includes metallurgical and ceramic grades and is commonly called metallurgical grade. Their quality and specifications are summarized in Table 45. Table 46 illustrates the chemical analysis of some acid-grade fluorspar.

Table 45

Fluorspar: Quality and Specifications

Acidspar	Minimum 97% CaF2 (96% if remaining impurities are within limits), < 1.50% SiO2, and 0.03 to 0.10% s as sulfide and/or free S. Other limitation include <10-12ppm As, average 100-550ppm P, limits on Pb, Cd, Be, CaCO3 and moisture. PS is 100 mesh (flotation product).
Ceramic-grade	Number 1 grade with 95-96% CaF2, medium grade with 93-94% CaF2, and Number 2 grade with 85-90+% CaF2; <2.5-3.0% SiO2, 0.12% ferric oxide, limited calcite, trace lead, and zinc sulphate.
Metspar	Minimum 60 effective percent fluorspar, <0.3% sulphide, and <0.50% lead. The effective percent is calculated by multiplying the silica percentage in the chemical analysis by 2.5 and subtracting the result from the calcium-fluoride percentage. Outside the USA the minimum requirement is 80% CaF2 with maximum 15% SiO2. It is usually required to pass through a 1 to 1.5 inch screen, but must contain less than 15% minus 1/16th inch material (or in briquette form).

Source: adapted after Industrial Minerals HandyBook II, pg. 68

Table 46

Chemical Analysis of Acid-Grade Fluorspar

	Mexico ***Fluorita de Mexico***	***USA*** ***Ozark Mahoning***	***Spain*** ***Fluoruros SA***	***China*** ***Typical***
CaF2	98.09	97.8	97.56	98.5
SiO2	0.32	0.62	0.98	0.8
CaCO3	0.75	1.33	0.75	
S, total	-	-	-	
S, sulphide	0.001	-	0.013	
As, ppm	4	2	10	3
P2O5, ppm	140	0.5	180	200
NaCl, total ppm	60	-	180	

Source: adapted after The Industrial Minerals HandyBook II, pg. 68

Market Trends

Fluorocarbon production from hydrofluoric acid (HF) is the single largest market that drives fluorspar demand. Demand for hydrofluorocarbons (HFCs) is benefiting from increases in auto sales, retrofits, and an emerging aftermarket. In the United States, HFCs and hydrochlorofluorocarbons (HCFCs) used as refrigerants in large cooling chillers, are in demand as the conversion from chlorofluorocarbons (CFCs) chillers to non-CFCs chillers continues (for environmental reasons).

The aluminum industry has experienced a 3.3 percent annual decrease in the consumption of AlF_3 because new smelters have much lower AIF_3 consumption rates. This trend however, is expected to reverse itself, especially since the largest increases in aluminum production are expected to occur in China and the Commonwealth of Independent States. These countries are expected to continue using older smelters in the foreseeable future. In the long term though, new smelting technologies could lower fluorspar demand, significantly in this industry.

The North American steel industry competes with imports and has large inventories. This is expected to cause an estimated 10 percent decrease in steel production and a similar decrease in fluorspar consumption in that industry.

Long-term growth is still expected in the cement market as some cement manufacturers are starting to use fluorspar in clinker production. Fluorspar can be added to limestone in the cement kiln as a fluxing agent, where it reduces the residence time, and increases production capacity (Miller, 2000).

Price

Prices received for fluorspar during 2002 reported by Industrial Minerals, No. 419 were:

• Metallurgical, min 85% CaF2, ex-UK store	£100-130
• Acidspar, Chinese wet filtercake, CIF Rotterdam	US$123-125
• Mexican, FOB Tampico, Acidspar filtercake	US$100-125
• Metallurgical	US$90-115
• Mexican, FOB Mexico Acidspar filtercake, As <5ppm	US$141-150
• South African acidspar dry basis, FOB Durban	US$105-125
• US Gulf port, Chinese, dry basis, acidspar	US$123-125

Economic Factors

In the St. Lawrence region of Newfoundland, mines produced 4.2 million tonnes of fluorspar from 1933-1978 establishing the district as one of the world's important fluorite producing regions. Most production from these mines came from vein systems. Estimated combined remaining reserves (from three major vein systems) are about 7.5 million tonnes, with a cut-off grade of 35 percent CaF_2 (Howse and Wardle, 2002).

Economic grades may vary depending on deposit type and mining methods employed. Large stratiform carbonate-hosted fluorite-barite-lead-zinc deposits in Illinois (USA), Mexico, and South Africa for example, are mined with CaF_2 grades of 15 percent and higher. Mineable vein deposits generally contain 25-80 per cent or more CaF_2. Fluorspar occurs as a major gangue mineral in many lead-zinc vein and replacement deposits and is economically recoverable as a by-product when fluorspar grades are 10 to 20 per cent (Pell, 1992).

Yukon Fluorite Occurrences

Fluorite occurrences are widespread throughout the Yukon. Fifty-six occurrences are described under mineralogy in Yukon Minfile 2001. However, only five are described as major commodity minerals (Table 47, Figure 4).

Table 47

Yukon Fluorite Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105L 058	105L/8	LITTLE FISHHOOK	CP	V	62º23’35”/134º03’34”
2	115H 042	115H/10	SNAP	TV	V	61º31’20”/136º31’47”
3	115O 081	115O/12	GUANO	YT	V	63º34’01”/139º58’54”
4	116B 006	116B/3	UNEXPECTED	TI	P	64º01’00”/139º04’30”
5	116O 057	116O/11	CARSWELL	DI	P	67º34’27”/139º16’56”

CP (Cassiar Platform); TV (Tertiary Volcanics); YT (Yukon Tanana); TI (Tertiary Intrusions); V (Vein), P (Porphyry)

Exploration Guidelines

Using geochemical analysis to find anomalous values of fluorine in water and silt samples is an effective exploration tool. Anomalous fluorine-in-water and fluorine-in-silt samples from regional geochemical surveys should be assessed and compared to known fluorite occurrences. Anomalous values in areas where fluorite occurrences are not reported, should be investigated to determine the sources of the anomalous fluorine values.

GARNET GA1

Chemical and Physical Characteristics

Garnet is a general name used to describe a suite of complex silicate minerals with similar crystalline structures, but varying chemistry. The general formula for the garnet mineral is

$A_3B_2 (SiO_4)_3$, where A, can be calcium, magnesium, ferrous iron, or manganese and B, can be aluminum, chromium, ferric iron, or rarely titanium. The six most common garnet minerals are almandine (preferred commercial industrial garnet), grossular, pyrope, spessartine, andradite (commercial garnet), and uvarovite.

Garnets range in colour from dark reddish-brown, pale green, deep crimson, brownish-red, dark brown green to emerald green. Depending on the garnet type, hardness ranges from 6.5-7.5 and specific gravity from 3.4-4.3. Garnet has a melting point of 1,250ºC, a high resistance to physical and chemical attack, and sharp sub-rounded to sub-angular chisel-edged fractures.

An important gem quality garnet is called “tsavorite”. This attractive green variety of grossular garnet, is discussed in this report under Gems.

Deposit Examples

Garnet Skarns - Crystal Peak, British Columbia (Canada); San Pedro, New Mexico, New York - by-product from wollastonite skarn (United States).

Beach Sands – Alluvial placer Stitt Creek north of Revelstoke, British Columbia (Canada); Emerald Creek, Idaho (United States); near Geraldton, (Western Australia).

Gem Quality Garnet (Tsavorite) – near Merelani, Lelatema Mountains, Tanzania. Also almandine and hessonite have gem quality varieties. Intrusive/metamorphic host rock – Gore Mountain, New York (United States).

World Production

World mine production of industrial garnet during 2001 is estimated to be 292,000 tonnes (Olson, 2002) with the main producing countries being Australia (125,000 tonnes), India (62,500 tonnes), the United States (52,500 tonnes), and China (25,000 tonnes). Additional garnet resources for small mining operations are located in Canada, Chile, the Czech Republic, Pakistan, South Africa, Spain, Thailand and the Ukraine (where most is consumed domestically).

General Geology

Garnet frequently occurs in nature in a large variety of rock types, typically in gneiss and schist formed at high-grade metamorphism or found in a placer deposit derived from these rocks.

Placer garnets are associated with heavy mineral sands in many parts of the world, while other sources include contact metamorphic rocks, crystalline limestones, pegmatites and serpentinites. Although occurrences of garnet are numerous, relatively few commercial deposits have been located.

Garnet skarn are hosted by carbonate or altered calcareous mafic volcanic sequences that are intruded by relatively oxidized plutons. Irregular zones of massive garnet may develop in exoskarns close to the plutonic contacts, with the shape of the deposits controlled partly by the morphology. Garnet skarn may occur in virtually any setting, and may be of any age (Ray, 1999).

End-Use

There are six principle end-uses for garnet including:

- As a blasting material, garnet is of a consistent size and so is used as an air blast abrasive. In some instances, garnet is used to replace silica sand in blast cleaning because of the perceived health hazard (garnet has no free silica).
- As a filtration material, this mineral's properties are useful for multimedia filtration systems, (typically layered from top to bottom: anthracite, silica sand, garnet, gravel) for cleaning of municipal water and for industrial waste separation.
- As a water jet cutting, garnet is a popular abrasive where (as abrasive slurry) it is fired through a nozzle at high pressure to cut steel, aluminum, glass and plastics.
- As a coated/bonded abrasives, garnet is used for coated papers and abrasive wheels due to its moderate melting point, little or no free silica content and resistance to physical or chemical attack.
- For polishing, high quality garnet powders are used for polishing glass, and in the production of faceplates, display screens, ceramics and semi-conductors.
- Some garnets (tsavorite garnet) are used as semi-precious gemstones (see the section on Gems, in this report).

Quality and Specifications

Almandite is the preferred industrial garnet due to a higher specific gravity (7.5) and resistance to degradation. Industry requirements specify a minimum garnet content limit of +97 percent of free silica. To follow, are typical chemical compositions and size ranges for garnet by end-use. Both tables from The Industrial Minerals HandyBook II, pgs. 71, 72 (Harben, 1999). (See Tables 48, 49).

Table 48

Typical Chemical Compositions of Garnet (%)

	W. Australia Beach Sands	*Tamilnadu, India Beach Sands*	*Idaho, USA Alluvial*	*New York, USA Hard Rock*	*Czeh Rep. Hard Rock*
SiO2	36.10	35.10	38.00	38	36.92
Al2O3	20.40	21.60	26.00	26	21.17
FeO	29.80				36.70
Fe2O3	1.70	32.90	30.00	30	
TiO2	1.80	0.55		1	0.06
MnO	1.05	0.53	2.00	1	0.37
CaO	1.55	1.84	2.00	1	0.87
MgO	6.00	7.40	2.00	1	3.92

Table 49

Size Ranges for Garnet by End-Use*

End Use	*Size ranges (mm)*
Sand blasting	1.1, 0.5, 0.6/0.4, 0.4/0.2, 0.3/0.15
Water filtration	2.5/1.7, 1.1, 1.4/0.6, 0.5, 0.6/0.4, 0.4/0.2
Water jet cutting	1.0/0.3, 0.25/0.18, 0.15, 0.18/0.85, 0.12/0.06
Coated abrasives	0.34/0.1, 0.08/0.036
Polishing/lapping	0.15/0.18, 0.10/0.15, 0.030, 0.010

* *Single grain size indicates mean particle size.*

Market Trends

Garnet consumption is influenced by the global economy and the industrial activity of the steel and glass industries. Consumption of garnet has been on the increase with the introduction of new regulations that discourage the use of silica sand for blasting. As a result, demand for garnet is expected to be between 3-5 percent over the next three years with abrasive blast cleaning and water jet cutting expected to be the two highest growth areas. Urban population growth and reduced water resources are increasing the demand for water filtration systems. However, in this market garnet faces competition from ilmentite. With recent worldwide increases in petroleum prices, there has been an increase in petroleum exploration and in the use of garnet blasting by the oil and gas industries for cleaning drill pipe. Possible increases in defense spending by the United States could also lead to increased demand for garnet since aircraft manufacturing and shipbuilding industries use significant amounts of garnet for jet cutting, blast cleaning and finishing metal surfaces.

There are significant stocks of garnet in Australia and India. Exports of garnet are expected to continue to increase from both of these countries, as well as from China (Olson, 2001).

Price

Growing exports from India have kept global prices in check. Prices vary widely according to type, source quantity purchases, quality and application. Examples of garnet prices reported by Industrial Minerals, No. 419 during 2002 were for Idaho almandine, 8-250 mesh, 20 tonne lots FOB mine, $US180-240

Economic Factors

To be economical, garnet skarn deposits should be greater that 20 million tonnes, with grades of greater than 70 percent garnet. The Mount Riordan (Crystal Peak) deposit in British Columbia for example, contains reserves of 40 million tonnes grading 78 percent garnet. The San Pedro deposit in New Mexico has reserves of between 22 and 30 million tonnes with 85 percent garnet.

Garnet should be free of inclusions, and possess a relatively high specific gravity, high angularity, and be present as discrete grains that can be processed by conventional benefaction techniques. Access to low cost transportation and a ready and reliable market for the product are essential components when guaranteeing the economic viability of a new mine.

Yukon Occurrences

There are no reported major garnet occurrences in the Yukon, although favorable geology suggests deposits are probable.

Yukon has extensive skarn deposits associated with Cretaceous intrusives. While the known garnet content is too low in these skarn to be considered for commercial production, they have never been systematically evaluated in terms of abrasives.

Potential garnet sources may also occur as a byproduct of placer mining operations, as the demand increases for higher quality abrasive products.

The potential for discoveries of gem quality garnet, is discussed under Gem in this report.

Exploration Guidelines

Garnet group minerals occur mainly in two belts in the Cordillera, the Omineca Crystalline Belt and the Coast Mountain Belt, with minor occurrences elsewhere. Within these belts, pelitic metasedimentary rocks containing small percentages of these minerals are extremely abundant (Pell, 1988). Investigation of pelitic metasedimentary rocks, which contain significant concentrations of garnet, are one exploration target in the Yukon.

Explorationists should also consider locating garnet skarn through the recognition of skarn environments and mineral assemblages. Geochemical signatures for garnet skarns may be weak for W, Mo, Zn and Cu anomalies. Gravity and possibly magnetic anomalies may be detected in geophysical surveys.

There is very little documented information regarding secondary placer concentrations of garnet minerals in the Yukon. However, areas in which hardrock enrichment occur also have good potential for placer accumulations. Knowing this should help in identifying areas that could be prospected for garnet placers. These secondary deposits may be economical with considerably lower concentrations of desired garnet mineral species, than higher concentrations required in hardrock sources (because of easier and less costly mining methods that could be employed) (Ray, 1999).

GRAPHITE GRA

Chemical and Physical Characteristics

Carbon (C) is known in three different conditions – scaly and crystalline as graphite, transparent and crystallized as diamond, and amorphous as lamp-black, charcoal, soot etc. It occurs as two important minerals - graphite, and diamond (See diamond in this report), both being of great industrial importance.

Graphite occurs naturally in metamorphic rocks such as marble, schist or gneiss. It is a soft mineral (1-2), is black in colour, opaque, has a metallic luster and, depending on purity, a specific gravity of between 2.20-2.30.

There are three principal types of natural graphite are lump - also called vein or crystalline graphite, crystalline flake, and amorphous.

Deposit Examples

Lump, vein or crystalline graphite: Calumet, Clot, Walker and Miller mines and St. Sauveur occurrences Quebec, (Canada); Dillon, Montana, (USA); Bogala Mine (Sri Lanka); deposits of South Kerala (India).

Crystalline flake graphite: AA prospect (092M 017), Black Crystal (82FN W260), British Columbia, (Canada); Asbury Graphite Mine and Peerless Mine, Quebec, (Canada); Black Donald mines, Ontario, (Canada).

Microcrystalline graphite: Kellog Mine, Moradillos, State of Sonora, (Mexico); Velké Vrbno-Konstantin (Czech Republic).

General Geology

Lump graphite deposits are most commonly found in Precambrian rocks but may occur in rocks of any age. Veins form in high-grade dynamothermal metamorphic environment where metasedimentary belts are intruded by igneous rock. Host rock can consist of gneiss, quartzites, clinopyroxenites, wollastonite-rich rocks and pegmatites. Associated rocks often include granitic and intermediate intrusive rocks, quartz-mica schists, granulites, aplites, marbles, anorthosites and amphibolites.

Veins range from a few millimeters to over a metre thick although commonly they are 0.3 metres thick. They form along joints, breccia zones, crests of folds and, along geologic contacts and foliations. Their origin is subject to debate but one hypothesis is that graphite crystallization may take place during the retrograde phase of regional or contact metamorphism as is suggested by the coexistence of low temperature minerals such as prehnite.

Lump graphite deposits are commonly associated with disseminated crystalline flake graphite deposits and occasionally with wollastonite deposits and abyssal pegmatites.

Crystalline flake graphite occurs in metasedimentary belts of granulite or upper amphibolite facies intruded by igneous rocks. Deposits are usually of Precambrian age but can be any age and are found in settings with favourable paleo-environment for accumulation of organic materials, i.e., such as intracratonic or continental margin-type basins. Host and associated rock types include marbles, paragneisses, quartzites, magnetite-graphite iron formations, clinopyroxenites, amphibolites and pegmatites.

Deposits are stratiform lens-shaped. Economic deposits are several metres to tens of metres thick and hundreds of meters in length. Low grade, large tonnage deposits are hosted by paragneisses and are stratabound. Higher-grade portions of these deposits are located in fold crests along lithological contacts or along other zones that acted as channels for retrograde metamorphic fluids.

Low-grade stratabound and stratiform deposits are believed to be a product of graphitization of the organic material within carbonates and shales with the crystallinity of graphite linked to the degree of metamorphism (Simandl and Kenan, 1999).

Microcrystalline (amorphous) graphite is usually (but not always) formed by the thermal metamorphism of coal. The designation amorphous is a misnomer as its relatively low degree of crystalline order and very fine particle size make it appear amorphous. It is usually of lower purity than the crystalline flake graphite and as a result commands a lower price.

Deposits are formed by contact or regional metamorphism of coal beds or other carbonaceous materials. Graphite occurs in beds or lenses up to a few metres thick and may be kilometres along strike and may be deformed (thickened) and repeated by folding, faulting, pinching or swelling.

Host rocks can consist of quartzites, phyllites, schists or metagreywackes and are usually found in Mississippian to Cretaceous or younger rocks. Graphite seams may grade into coal with increased distance from the heat source. The size, grade and mineral impurities in the graphite deposit are dependent on the characteristics of the original coal seams or carbonaceous sediments. Outcrops weather typically dull, porous and dark-grey to black.

Graphitization is an extreme form of coal maturation involving the following sequence:
peat>lignite>bituminouscoal>semi-anthratcite>anthracite>meta-anthracite>microcrystalline graphite.
Sources of heat in contact-metamorphism can include plutons, dikes or sills that intrude close to the coal bed (Simandl and Kenan, 1999).

World Production

The USGS reported world production of graphite in 2001 at an estimated at 675,000 tonnes. The five leading producers included China (250,000 tonnes), India (150,000 tonnes), Brazil (70,000 tonnes), Mexico (35,000 tonnes), and Canada from mines located in the Canadian Shield of Ontario and Quebec, (25,000 tonnes).

Sri Lanka accounted for nearly all the high-purity lump graphite with production estimated at 4,600 tonnes at 95 percent graphite in situ. (Kalyoncu, 2002).

End-Use

Lump graphite - powder metals, special refractories, copper graphite, electrical applications.
Crystalline graphite - mainly used in refractories, lubricants, brake linings, foundry moulds, pencils.
Microcrystalline graphite - is used in brake linings, steel making, foundry applications, lubricants, refractories, and pencils.

Quality and Specifications

Graphite has a high melting point (3600ºC) and is insoluble in acids. The price received for graphite is largely determined by carbon content and particle size distribution as well as ash content. Crystalline graphite ranges from chip or dust through to fine or amorphous lump, and to coarse or crystalline lump. Flake graphite is divided into coarse flake (-20to +100 mesh) and fine flake (-100 to +325 mesh).

Tables 50 and 51 illustrate some ash, chemical and specifications by applications for graphite (Harben, 1995, pg. 76).

Table 50

Ash Content of Some Natural Graphite (%)

	Canada	*China*	*Mexico*	*India*
Ash	23.5	16.9	3.8	11.8
SiO_2	64.8	49.7	51	56
Al_2O_3	13.9	19.7	14.5	20.3
Fe_2O_3	12.3	19.2	29.5	14.9
TiO_2	0.4	1.6	0.7	1.1
CaO	3.7	1.9	1.5	1.5
MgO	1.4	4.2	1.5	3
Na_2O	0.6	0.7	0.6	0.5
K_2O	2	2.6	0.7	2

Table 51

Graphite Specifications by Application

Application	*Average Carbon (%)*	*Average Flake Size*
Foundries		
Core & mold washes (F)	80-90	200 mesh
Core & mold washes (A)	70-80	200 mesh
Foundry facings (A)	40-70	53-75µm
Sintering	98-99	APS 5 µm
Refractories		
Crucibles, molds, ladles (F)	85-95	+150 µm
Refractory bricks (A)	70-80	-20mm & -600 mesh
Refractory bricks (F)	90-97	+180 to +150 µm
Mag-carbon bricks (F)	85-90	+150 to –710 µm
Al graphite refractories (F)	min. 85	-600 to +150 µm
Other Uses		
Brake linings	Min. 98	-75 µm
Batteries, dry cell	Min. 88	85%-75 µm
Batteries, alkaline	Min. 98	-75 to 5 µm
Carbon brushes	95-99	-50 µm
Conductive coatings (A)	50-55	
Explosives		-150 µm
Expandable graphite	min. 90	-2mm to +250 µm
Graphite foil	min. 90	
Lubricants	98-99	106 to 53 µm
Neutron moderator	99+	
Pencils (A & F)	80-82	Extremely fine

Market Trends

Natural graphite will continue to be consumed in high temperature application in the iron and steel industry and it is expected brake linings and other friction materials will steadily consume more natural graphite as automobile production increases.

Flexible graphite product lines such as grafoil (a thin graphite cloth), will continue to grow steadily but will consume relatively small amounts of graphite when compared to major end-use markets.

The use of hybrid and electric vehicles is expected to increase demand for high-purity graphite in fuel cell and batter applications. One prediction is demand for high-purity graphite will increase to more than 100,000 tonnes per year for fuel cell and batter applications (Crossley, 2000).

The global demand for graphite used in batteries is expected to double to 25,000 tonnes between 2000-2005.

Canada, Germany, Japan and the United States are aggressively promoting fuel cell development and some predictions for graphite used in fuel cells suggest consumption could reach 80,000 tonnes per year within 2-3 years.

China may increase it graphite production to take advantage of potentially increased profits but if the Chinese iron and steel industry expands its consumption of graphite then exports may decline and other producers (or new producers) may take advantage of increased demand for natural graphite.

Price

Prices received for graphite during 2002 are reported by Industrial Minerals, N. 419 to be:
CIF UK port

- Crystalline, large flake, 94%C US$570-750
- Crystalline, large flake, 90%C US$480-550
- Crystalline, medium flake, 90%C US$370-410
- Crystalline, small flake, 80/95%C US$270-500
- Amorphous powder, 80/85%C US$220-235

Economic Factors

Lump graphite

Veins contain 40-90 percent graphitic carbon before hand sorting. Since the deposits consist of narrow veins, underground mines are generally small scale and labour intensive. The only current source of lump graphite is in Sri Lanka, from where it is exported worldwide.

Crystalline graphite

Grade and tonnage of producing mines and developed prospects varies. The median grade and size is 9.0 percent and 2,400,000 tonnes respectively (Bliss and Sutphin, 1992). Depending on markets, large deposits containing coarse flakes can be economic with grades as low as 4 percent.

Microcrystalline graphite

Graphite mines are usually open pit, but if beds are of sufficient thickness and aerial extent, graphite can be mined using underground methods. The average size of economic graphite deposits is 4,900,000 tonnes (Bliss and Sutphin, 1992). Mines contain over 80 percent carbon but the average grade of some European deposits may be as low as 55 percent and in some instances beds are only partly graphitized.

Yukon Occurrences

Graphitic schist are common in many parts of the Yukon but no high-grade deposits or occurrences have been reported. Yukon Minfile 2001 reports 17 graphite occurrences but all are minor constituents of base metal deposits and no graphite grades and flake size are reported.

Crystalline flake graphite deposit, located near the southern tip of Bentick Arm, British Columbia, contains microscopic graphite veinlets, suggesting that similar graphite veins may also occur in the metasedimentary roof pendants of the Coast Plutonic Complex of Yukon.

Exploration Guidelines

Lump Graphite - ground electromagnetic methods (VLF in initial exploration stage, horizontal or vertical loupe at later stages) and resistivity can be used to locate large graphite veins.

Graphite veins in highly metamorphosed terrains can be associated with crystalline flake deposits.

Since graphite is inert and does not weather, boulder tracing and the use of electromagnetic mats may be effective.

Crystalline flake graphite - geochemical surveys may detect graphite concentrations in residual soils and stream beds. This method is not considered as effective as geophysical methods.

Geophysical surveys using airborne EM ground VLF, induced polarization, applied potential and self-potential surveys have been proven effective in outlining flake graphite deposits.

Crystalline flake graphite deposits can be spatially associated with kyanite, sillimanite, mica and garnet, high-calcium carbonate deposits, wollastonite skarn and pegmatites.

Microcrystalline graphite - geochemical signatures may be present in residual soils and positive vanadium and nickel anomalies and negative boron anomalies associated with graphite beds can be indicative of an occurrence, although each deposit may have its own geochemical characteristics. As well, graphite deposits may have associated radioactivity, as result of trace amounts of uranium.

Geophysical surveys using induced polarization (IP), resistivity, ground and airborne electromagnetic (EM), spontaneous potential (SP) and audiomagnetotelluric (AMT) surveys have been successfully used in exploration.

One of the primary exploration guides for microcrystalline graphite is the recognition of coal beds in stratigraphic sequences that have been intruded by igneous rocks (plutons, dikes, sills) and thus subjected to contact metamorphism. Another exploration target are coal seams that have been graphitized due to low to medium regional metamorphism (Simandl and Kenan, 1999).

GYPSUM GYP

Chemical and Physical Characteristics

Gypsum ($CaSO_4.2H_2O$) is white to grey in colour, soft (1.5-2) with a specific gravity of 2.38.
At room temperature it contains about 27 percent water by volume but loses more than half of its water content when heated to 160ºC. When heated to this temperature is referred to as calcined gypsum.

Anhydrite ($CaSO_4$), a light to bluish-grey mineral is not commercially important but is frequently associated with gypsum deposits. It is readily distinguished from gypsum by its hardness (3-3.5). Although associated with gypsum, anhydrite is not usually found in surface outcrops because of its rapid conversion to gypsum by meteoric water.

Deposit Examples

Bullion (Yukon Minfile 115B 009), Yukon; O'Connor River, Lussier River, Windermere, Falkland, British Columbia, (Canada); Appalachian Basin New York, (United States); Paris Basin, (France).

General Geology

Most commercial gypsum deposits in Canada, are of evaporitic origin and are Paleozoic (mostly Devonian) or Triassic in age. Most deposits consist of sedimentary beds of saline residues precipitated during the evaporation of seawater while in enclosed marine basins. Salt is a common associated mineral. Gypsum deposits in large sedimentary basins deposits of calcium and/or magnesium carbonates (limestone/dolomite), sometimes rock salt and in very concentrated brines with potassium and magnesium salts such as carnallite, kieserite or polyhalites. Both gypsum and anhydrite can occur in granular, compact or fibrous crystalline masses in thick (up to tens of metres) and extensive (over hundred of metres) sedimentary beds.

Most commercially exploited gypsum deposits have a gypsum content between 80-95 percent with the remaining material being either anhydrite or other impurities such as shale, limestone, dolomite or clays. Celestite ($SrSO_4$) and strontium ($SrCO_3$) which may also be found in evaporate deposits may be associated with gypsum.

A less common origin of gypsum deposits, which are usually smaller in size, is related to submarine volcanogenic massive sulphide deposits (VMS) as a more distal equivalent, similar to barite.

World Production

Gypsum is mined in more than 90 countries around the world with total world production estimated by the USGS during 2001 at 110 million tonnes. The world's five leading mine producers include the United States (18.8 million tonnes), Iran (11 million tonnes), Canada (9 million tonnes), Mexico (7.6 million tonnes) and China (6.8 million tonnes) (Olson, 2002).

In Canada, most gypsum producers are closely integrated in both mining and wallboard manufacturing. Six companies operate 11 mines and 13 wallboard plants. In Western Canada (Manitoba, Alberta and British Columbia), Georgia-Pacific Corporation and Westroc Industries Limited operate both open-pit mines and/or wallboard manufacturing plants in each province (Canadian Minerals Yearbook, 1999).

New wallboard plants in the United States such as the Lafarge plant in Kentucky use synthetic gypsum, which has a cost advantage over mined gypsum. Consequently, the use of synthetic gypsum will probably accelerate in use worldwide. Synthetic gypsum is the involuntary product of removing sulphur oxides from coal burning powerplants and similar sulphur containing smokestack and chemical industries.

End-Use

The primary use of gypsum in industrialized countries is for the production of wallboard. Other uses of gypsum include cement production, agricultural applications, smelting and glassmaking. There is no practical substitute for gypsum in Portland cement.

By-product (synthetic) gypsum is becoming increasingly important substitute for mined gypsum and a number of wallboard plants are using synthetic gypsum exclusively.

Developing countries mainly use gypsum for the production of cement. In 2000 the USGS estimated the world wallboard capacity at about 5.6 billion square metres at more than 250 plants worldwide. Of this amount, almost half is produced in the United States. In 1999, gypsum consumption in the United States totaled about 31.8 million tonnes well exceeding domestic production (Olson, 2000).

Quality and Specifications

Natural gypsum varies from 50-95 percent $CaSO_4$ with limestone or insoluble anhydrite as the main contaminant. Table 52 illustrates typical commercial grade specifications for gypsum.

Table 52

Commercial Grade Gypsum Specifications

	National Gypsum	*Georgia Pacific*	*US Gypsum*	*Japan*	*Germany*	*Agricultural Grade*
Gypsum, min. %	94	90	95	95	80-95	70
Ca sulfite, max %	0.5	-	2.0	0.25	0.25	
Total sol., max. ppm	-	-	600	1,000	-	
Sodium, max. ppm	250	200	75	-	600	
Chlorite, max. ppm	400	200	120	-	100	1.0
Magnesium, max. ppm	250		50	-	1,000	
Free water, max. %	1	10	10	10	10	10
PH	6-8	3-9	6.5-8	6.5-8	5-9	
Inerts, max. %	3.0	-	1	-	-	

Source: Industrial Minerals Handybook II, pg.79.

Market Trends

The Gypsum Association reports that the demand for wallboard has risen an average of 5 percent each year for the past 10 years. This trend is largely a result of demand by the United States and Canada's construction industry.

The USGS in its Minerals Yearbook review for 2000, suggests the use of mined gypsum may decline significantly in the United States as greater quantities of synthetic gypsum supplant it in wallboard manufacturing.

The development of wallboard plant construction in China suggests that China could become one of the world's leading gypsum wallboard markets in the near future. As well, the extent of wallboard capacity growth in regions of Asia, Europe, and Latin America indicates that wallboard manufacturing is likely to become more significant in these regions. In the past gypsum was largely used in these regions for the manufacture of cement or as a plaster product and not wallboard (Olson, 2000).

Price

Prices for gypsum in merchant markets are negotiated among buyers and sellers, and published figures are not always reliable. The USGS reports that during 2001 the price received for gypsum were: average crude, f.o.b. mine, per ton US$8.46; average calcined, f.o.b. plant, per ton US$16.84 .

Economic Factors

Gypsum sales are largely dependent on the construction/renovations industry and hence the state of the economy. Gypsum is in general, broadly available on a regional basis, and is considered a low-cost commodity consumed close to the point of production. Recycling waste wallboard from construction sites by separating the material into the gypsum and paper components is increasing largely because of the rising cost of disposal in land-fills. The resulting recycled gypsum will continue to replace natural gypsum at increased levels.

Crystalline silica has been classified as a probable carcinogen by the IARC and because of its content in both natural gypsum and anhydrite, it may come under the OSHA regulations. This will require labeling and other forms of warning and training. That may restrict gypsum's wide spread use. However, the main threat to natural gypsum is by-product gypsum manufactured from phosphoric acid, flue gas desulfurization or titanium dioxide plants. During 2001, synthetic gypsum accounted for more than 15 percent of the total American gypsum supply and this percentage is expected to increase (Olson, 2002).

Yukon Occurrences

Eight gypsum deposits/occurrences are described in Yukon Minfile 2001. Of these, two are listed as major commodities (Table 53; Figure 4). However, the reserve and quality estimates of all documented gypsum occurrences are not known.

Table 53

Yukon Gypsum Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105H 075	105H/11	MAXI	SB	SEDEX	61º39’01”/129º10’16”
2*	115B 009	115B/15	BULLION	WT	E	60º59’04”/138º38’53”
3*	115B 012	115B/16	KUL	AT	E	60º56’18”/138º21’34”
4	115G 001	115G/2	METALLINE	WT	E	61º01’11”/138º41’41”
5	115G 084	115G/2	BOCK	WT	UM	61º13’46”/138º53’30”
6	115G 085	115G/5	MAPLE	WT	SED	61º25’06”/139º33’55”
7	115G 086	115G/6	GYPSUM	WT	E	61º18’00”/139º27’43”
8	115H 038	11H/15	TAH	CPC	P	61º45’48”/136º46’27”

** Listed as a major commodity in Minfile 2001. SB (Selwyn Basin), WT (Wrangellia Terrane, AT (Alexander Terrane), CPC (Coast Plutonic Complex) ; E (Evaporate), UM (Ultra Mafic), SED (Sedimentary), P (Porphyry).*

Exploration Guidelines

Exploration programs for gypsum deposits should focus on sedimentary stratigraphic sequences conductive to gypsum formation, both evaporitic as well as VMS related. Most massive gypsum deposits are found as lenticular, stratified ore bodies. The O’Connor River gypsum deposit, located near the Yukon/British Columbia border would be a useful exploration model for discovering new gypsum occurrences in the Yukon. Other exploration models include Devonian evaporates near Windermere or Triassic gypsum deposits at Forgetmenot Creek in British Columbia.

The presence of sinkholes is potentially the first possible gypsum indicator.

KAOLIN KAO

Chemical and Physical Characteristics

Kaolin is a soft (2.6), earthy, non-plastic, usually white or nearly white clay (rock) composed essentially of clay minerals of the kaolin group, principally kaolinite [$Al_4SiO_{10}(OH)_8$].

It exhibits conchoidal or semi-conchoidal fracture and occurs in bedded or massive form. Depending on kaolin particle size and the presence of organic matter, some clay may be very plastic when moist.

Kaolin is also referred to as fireclay, underclay, high-alumina clay and china clay. By-products of the many different grades of kaolin include ceramic clay, ball clay, refractory clay, bauxite and silica sands. It remains white or nearly white when fired.

Deposit Examples

Sedimentary Deposit - Sumas Mountain (92GSE004) and (92GSE024), Blue Mountain (92GSE028), Giscome Rapids (93J020), near Prince George (Canada); Aiken, South Carolina, Andersonville, Georgia, (United States); Weipa, (Queensland, Australia); Jari, Capim (Brazil).

Residual Deposit - Lang Bay (92F137), British Columbia (Canada).

Hydrothermal - Monteith Bay (092L072), Pemberton Hills (092L308), British Columbia (Canada); Tintic, Utah, Terraced Hills, Nevada, (United States); Matauri Bay, Mahimahi and Maungarerux (New Zealand); Itaya and Taishu (Japan), Suzhou (China).

General Geology

Deposits may be sedimentary, residual or hydrothermal.

Sedimentary - most kaolin deposits are Upper Cretaceous to Eocene in age although some “fire clay and underclay" deposits are Late Carboniferous. Tectonic settings for kaolin deposits include low-lying coastal plains near continental edges, extension basins in orogenic belts, stable continental basins and back arc basins.

Kaolin occurs in beds, lenses or saucer shaped bodies. Their formation is controlled by the location of the sedimentary basin and the presence of weathered, granitic rocks adjacent to the basin, particularly rapidly eroding paleotopographic highs. Beds can be up to few metres thick but multiple beds have an aggregate thickness of up to 20 metres. Deposits can extend over several square kilometres in clastic sedimentary rocks that may also contain coal seams.

Post depositional weathering and leaching can produce gibbsitic bauxite and may improve cystallinity of kaolin particles and increase the size of crystal aggregates in some deposits.

Associated deposits can include peat, coal seams, paleoplacers, bentonites and lacustriane diatomite (Hora, 1999).

<u>Residual or Primary Kaolin</u> - residual or primary kaolinite deposits are formed through the alteration or kaolinization of feldspar-rich rocks such as granite, gneiss, syenite, arkose, and feldspar-rich volcanic ash by either weathering or hydrothermal processes. Most residual kaolin deposits occur in low temperature hydrothermal alteration zones along faults and fractures in granitoid feldspathic basement rocks. These hydrothermal actions may result in the formation of residual kaolin deposits adjacent to these active zones.

During the kaolinization process, kaolinite is formed by the hydrolysis of anhydrous aluminum silicates and about 25 percent by weight of the granite (for example) is lost, mainly in the form of alkalis (potassium, sodium, magnesium, and calcium) and silica. The mineralogical and chemical composition of the kaolin depends on the nature of the parent rock as well as the type and degree of alteration. These primary kaolin deposits may thicken considerably where shear and fracture zones act as a conduit for meteoric ground water (Harben and Kuẑvart, 1996).

Erosion may occur during periods of basin uplift, and which subsequently result in a cyclothemic sequence of clays, similar to those in coal measures (secondary kaolin), sandstone and conglomerates. In kaolin deposits, there may be a gradual decrease of kaolinization with depth.

<u>Hydrothermal</u> - kaolin and halloysite, with or without alunite and pyrophyllite, occur as veins and massive alteration masses in volcanic and granitic rocks. They represent past geothermal fields and hot springs arcs associated with volcanic activity nearby. Typically, the largest deposits occur in volcanic island arcs but may develop also in continental-based arcs and volcanic centres.

Clay deposits, are usually Tertiary to Quaternary in age (due to erosion and metamorphism of older deposits which are generally not preserved). They develop in feldspathic rocks and may occur without volcanic glass due to the circulation of hydrothermal fluids with low pH (3.5 to 5) and temperatures from below 100º to 400ºC. Halloysite forms at temperature approximately under 100ºC, kaolinite between 100º to 350ºC, and pyrophyllite between 300ºC and 400ºC. Alunite formation occurs under conditions as kaolinite. Newly formed silica compounds and alunite may precipitate in separate zones, but also as a cementing matrix of kaolinite and pyrophyllite. The deposits occur at a considerable depth, ranging from high temperature geothermal fluids at the paleosurface down into cupolas of intensive bodies at depth.

Circulating ground water may remove leachable elements (K, Na, Ca, Mg, etc.) and improve the quality of clay for a number of end uses. Residual weathering may overprint primary kaolin deposits resulting in superior quality ceramic clay.

Host rocks may include rhyolite, trachyte, andesite flows and volcaniclastic rocks and their hypabyssal equivalents as well as any basement feldspathic or sericite rich rocks. Alteration rocks consist of hydrothermal breccia and travertine and siliceous sinters.

Clay deposits are structurally controlled, cone or wedge shaped, although sometimes irregular shaped deposits result from variable host rock permeability controlled by fracture density and porosity of volcanoclastics. Many alteration zones spread out as they approach the surface or form large near surface zones on the flanks of volcanoes.

Associated deposit types can include epithermal Au-Ag, - low sulphidation HO_5, epithermal Au-Ag-Cu; high sulphidation HO_4, Hot Spring Au-Ag HO_3, Hot Spring Hg HO_2. Sulphur may occur in vents in some deposits.

In some cases, near surface leaching of alteration zones can produce altered zones containing more than 95 percent silica. Alunite deposits can be extensive and may represent a future aluminum resource (Hora, 1999).

World Production

The USGS reports the world production of kaolin was approximately 41.2 million tons 2001. The five leading producers included the United States (9 million tons), followed by Uzbekistan (5.5 million tons), Czech republic (6 million tons), United Kingdom (2.4 million tons) and the Republic of Korea (2.1 million tons).

Market Trends

Competition in the paper-filler and coating markets and increased fuel costs will continue to hamper the kaolin industry for the foreseeable future.

End Use

The principal source for kaolin is in the paper industry where it is used as both a filler and coating pigment. Other filler applications include use in rubber, paints, plastics and ceramics.

Quality and Specifications

Physical and chemical properties affect end use. Physical properties include brightness, particle size distribution, particle shape and rheology. Limonite staining is a negative feature.

Table 54 and 55 illustrate the quality and specifications of a few commercial applications for kaolin (Industrial Mineral HandyBook III, 1995). The chemistry and grades illustrated in both tables are for reference only and any potential producer should consult the standards required for specific commercial products (e.g. ceramics, refractories, plastics etc.).

Table 54

Chemistry of Commercial Clays

	Kaolin (Coarse coating) Georgia USA	*Kaolin (fine coating) Georgia USA*	*Kaolin (ceramic) Germany*	*Ball clay Tennessee USA*	*Brick clay Weald clay, UK*	*Plastic fireclay, USA*
SiO2	42.50	45.00	48.30	56.70	64.45	62.40
Al2O3	39.20	38.00	36.30	25.80	16.55	34.56
Fe2O3	0.58	1.00	0.50	1.10	2.13	2.01
TiO2	0.53	1.60	0.30	1.60		1.42
MgO	0.08	0.09	0.10	0.50	0.97	0.74
CaO	0.06	0.06	0.10	0.20	1.07	1.14
Na2O	0.03	0.29	1.60		0.34	1.58
K2O	0.02	0.13	0.10		2.30	0.88
S					0.21	
CO2					0.55	
H2O	13.30	14.00			4.69	
Organic content					0.70	
LOI				12.40	6.08	

Table 55

Typical Specifications for Commercial Paper-Grade Kaolin

	# 1 High Brightness Coating	***# 1 Standard Coating***	***Fine filler***
TAPPI Brightness, %	89.5-91.0	86.5-87.5	81-83
Particle size, %<2µm	90-92	90-92	82-95
Surface area, m²/g	13	13	22
325 mesh residue, max.%	0.01	0.01	0.3
Moisture, max.%	1.0	1.0	slurry
PH (28% solids)	6.0-7.6	6.0-7.9	6.0-8.0
Brookfield, 20 rpm, cps	350	350	n/a

Price

Industrial Minerals, No. 419 listed prices for kaolin in 2002 at:

- Ex-Georgia plant, s ton
- Filler, bult US$80-100
- Coating, bulk US$85-185
- Sanitaryware, grade, bagged US$64-74
- Tableware grade, bagged US$125
- Calcined, FOB US$335-395

Economic Factors

Very rich deposits in Georgia, USA contain 90-95 percent kaolinite. The Weipa deposit in Australia is 8-10 metres thick and contains 40-70 percent kaolinite. The Jari deposit in Brazil is reported to contain more than 250 million tonnes of commercial grade kaolin. Ball clay deposits in Tennessee and Kentucky consist of kaolin with from 5-30 percent silica. Individual deposits may be more than 9 metres thick and extend over areas from 100-800 metres long and 200 metres wide.

Residual deposits are mined mostly in Europe (i,e., the United Kingdom, France, Germany and the Czech Republic).

The high cost of processing required to meet industry specification and minimize transportation cost to the end user are the main limiting factors for kaolin use. Local producers compete for low value markets however, high quality products are shipped to users several thousand kilometres away (Hora, 1999).

Yukon Occurrences

China clay has the highest value but no deposits have been located because deposits either have not formed or were removed by glaciation. Possible exploration targets are the Bonnet Plume and Dawson basins.

Exploration Guidelines

Sedimentary Deposits

The most useful exploration guide for residual deposits is recognition of sedimentary basins with Upper Cretaceous and Eocene unconformity. Within these basins, kaolin may also occur with sediments, including coal seams. There is no apparent geochemical signature for kaolin but resistivity drill logs and refraction seismic survey may be useful in recognizing fire clay beds.

Residual Deposits

Deposits occur along Upper Cretaceous and Eocene unconformities in sedimentary basins.

Hydrothermal Deposits

Geochemical signatures may indicate a high aluminum content and reduced alkali content. Seismic techniques can distinguish dense unaltered rock from less dense clay altered zones. Resistivity methods can identify conductive clay zones from resistive unaltered rocks. Other exploration guides include the presence of siliceous sinters and association with geothermal fields.

LIMESTONE *LIM*

Chemical and Physical Characteristics

Lime is produced from limestone ($CaCO_3$), and/or dolomite $CaMg(CO_3)_2$. It is a general term referring to burned or calcined limestone, (burnt lime or quicklime) Its secondary products including hydrated lime (calcium hydroxide), which is also referred to as slaked lime. In the calcining process, quicklime (CaO or CaO·MgO) begins to form at the dissociation temperature of limestone. Temperatures are maintained sufficiently long until there is a complete breakdown of the limestone and a release of the carbon dioxide content. High-calcium quicklime containing mainly CaO and less than 5 percent MgO is the most common type of lime produced. However, dolomitic quicklime (or dolime) as well as its hydrated products are also produced. These products contain 35-40 percent MgO.

Deposit Examples

Gillies Bay and Blubber Bay, Texada Island, British Columbia, Pavilion Lake (between Lilloet and Clinton), Dahl Lake (near Prince George) British Columbia (Canada).

General Geology

Limestone is a sedimentary rock consisting of chiefly (greater than 50 percent) calcium carbonate, primarily in the form of the mineral calcite, and exists with or without magnesium carbonate. Common minor constituents include silica, feldspar, clays, pyrite, and siderite. Limestone is formed by either organic or inorganic processes and may be detrital, chemical, oolitic, earthy, crystalline or re-crystallized. Some limestone is fossiliferous and clearly represent ancient shell banks or coral reefs. Limestone is also a general term used commercially (in the manufacture of lime and cement) for a class of rocks containing at least 80 percent of the carbonates of calcium or magnesium and which, when calcined, give a product that slakes with the addition of water.

Dolomite is a basic constituent of sedimentary carbonate rocks (dolomites and dolomitic limestone) formed under diagenetic conditions by the action of sea-water on calcareous mud or by organogenetic formation.

World Production

The USGS estimates world lime production during 2001 at 115 million tonnes. The world's leading lime producers are China (22 million tonnes), the United States (18.7 million tonnes), Russia (8 million tonnes) and Germany (7.6 million tonnes). Canada produced an estimated 2.5 million tonnes of lime during 2001 (Miller, 2002).

End Use

Limestone and dolomite (and rarely marble) may be crushed for use as an aggregate, an ingredient for concrete, ballast, and for fill. It also has widespread use when white as high brightness limestone is ground and used as inert pigments or fillers in manufactured products. Still finer and purer grades are used in paper and plastics. In many industries, lime is used as the source of CaO, where it acts as a flux and scavenger, removing P, Si, Al and S in the reduction of iron ores. Hydrated lime is also used as a source of CaO in agriculture (for composting, soil liming, as a plant nutrient, as well as poultry and animal feed additive) and construction (soil stabilization, masonry mortar, plaster and stucco, sand-lime bricks, bituminous paving and whitewash). Significant quantities of lime is used in pulp and paper mills.

As a Cement - Portland cement is produced by burning in a kiln, at a temperature of 1,480ºC, a finely ground mixture containing about 75 percent $CaCO_3$, with clay minerals consisting of silica and Al_2O_3 and Fe_2O_3, with less than five percent magnesia, and containing a minimum of alkalies. After cooling, the kiln product becomes a fused complex of calcium silicates and aluminates in the form of rough spheres, termed "clinker". The "clinker" is then ground to a fine powder and mixed with 3-5 percent gypsum to prevent rapid setting. When combined with water, sand, gravel, crushed stone or other aggregates, the cement binds the materials together to form concrete.

Depending on its use, the $CaCO_3$ content in cement kiln feed mix can be as low as sixty-five percent, however the product must be low in alkalis having less than four percent MgO, 1.5 percent acid soluble residues and one percent each of F, K, Zn and Pb.

At the present time there is no cement production in the Yukon, although reserves of limestone, which potentially could meet commercial specification for cement production, have been well documented.

Quality and Specifications

Tables 56 and 57 illustrate the chemical composition and physical properties of calcium carbonate rocks and pigments respectively.

Table 56

Chemical Composition of Calcium Carbonate Rocks (%)

	USA Limestone (Filler)	*USA Limestone (Glass)*	*USA Limestone (Agriculture)*
$CaCO_3$	96.00	98.00	97.1
$MgCO_3$	1.50	1.30	2.0
SiO_2	1.20	0.15	Na
Al_2O_3	0.30	0.08	Na
Fe_2O_3	0.08	0.12	Na
H_2O	0.25	0	1-2.5
Brightness	96.00	-	-

Source: adapted after The Industrial Minerals HandyBook II, pg 38

Table 57

Physical Properties of Calcium Carbonate Pigments

	Natural Fine-ground limestone	*Natural Ultrafine-ground limestone*	*Precipitated Calcite*	*Precipitated Agragonite*
Specific gravity	2.71	2.71	2.71	2.93
Index of refraction, mean	1.58	1.58	1.58	1.63
Hardness, (Mohs scale)	3	3	3.0	3.5
Decomposition temp, ° C	800-900	800-900	800-900	800-900
Valley abrasion, mg	25	10	5	8
Brightness, % (GE)	95	96	98	99
Oil absorption, cc/100g	13	23	30	55
Surface area, m^2/g	3.2	9.6	6.8	8.5

Source: adapted after The Industrial Mineral HandyBook II, pg. 37

Market Trends

Lime has many uses, but only a few make up the bulk of its consumption. Lime demand by the steel industry is expected to increase as the economy strengthens. Overall, it appears that 2002 will see a small increase in lime production and consumption when compared with 2001, with better results expected in 2003. However, the nonferrous metallurgy in North America market continues to decline, and the lime industry still has over capacity problems, and suffers from stagnant prices.

Limestone is a substitute for lime in many applications, such as agriculture, fluxing, and sulphur removal. Limestone contains less reactive material, and is also slower to react. Limestone is considerably less expensive than lime (Miller, 2001).

Price

In 2001, despite attempts made by some commercial lime companies to raise prices (primarily because of higher fuel costs), the average for all types of lime sold increased only slightly to US$61.50 per tonne (Miller, 2001).

Economic Factors

Limestone is produced in virtually all countries. Lime is a high bulk low-cost commodity not usually shipped over great distances. The preferred location for a lime plant is close to principal market, adjacent to a source of high quality raw material, and near a supply of energy since lime production is energy intensive (consuming 6.7 million BTU per tonne of lime produced) (Downing, 1993).

Under certain conditions, limestone is shipped over long distances to regions where local supplies are not available. For example, limestone from Yucata, Mexico (having inexpensive production costs and limestone deposits located near tidewater), is transported by ship to the Gulf Coast of the United States, where there are no local limestone deposits but where a high demand exists (Miller, 2001). Texada Island limestone from British Columbia, is distributed to coastal customers from Alaska to northern California.

Yukon Occurrences

There is no Yukon lime production at this time. In the recent past Yukon's hard rock producers, United Keno Hill, Curragh and Erickson mines reportedly consumed approximately 10 thousand tonnes of lime annually, all of which was imported into the territory (Downing, 1993). In the future, major consumers in the Yukon may offset transporation costs by periodically running small lime kilns.

If future demand for lime warrants development of lime producing quarries, there are large accessible Triassic to Permian limestone beds in a belt running through southwest Yukon from Atlin to Carmacks (Wheeler and McFeely, Map 1712A). Curragh Resources and others have in the past staked claims over limestone deposits in the Carmacks area.

Exploration Guidelines

Careful sampling and chemical and physical analysis of limestone/dolomite deposits should be made in order to determine whether the deposit contains reserves that meet industry chemical and physical specifications.

Exploration efforts should concentrate on areas where existing transportation corridors and infrastructure is already established.

MAGNESIUM COMPOUNDS *MAG*

Magnesium (Mg) is the eighth most abundant element and constitutes about two percent of the Earth's crust, and is the third most plentiful element dissolved in seawater. Although magnesium is found in over 60 minerals, only dolomite, magnesite, brucite, carnallite, and olivine are of commercial importance. Magnesium and other magnesium compounds are also produced from seawater, well and lake brines and bitterns (Kramer, 2002).

Chemical and Physical Characteristics

Commercial magnesia (MgO) is derived from natural magnesite ($MgCO3$) or from magnesium sulfate and magnesium chloride contained in seawater or certain brines and bitterns. The most important commercially, is crystalline or sparry magnesite, which is semi-hard (3.5-4.5), translucent or transparent and has a vitrious or silky luster. Magnesite has a theoretical magnesia (MgO) content of 47.6 percent. Weathered outcrops are typically beige or pale brown and characterized by a "granola-like" appearance.

Hydromagnesite, or hydrated magnesium carbonate $[(Mg_4(OH)_2\ (CO3)_3\cdot\ H_2O]$ may contain up to 43 percent magnesia.

Brucite, magnesium hydroxide $[Mg\ (OH)_2]$ may contain up to about 69 percent magnesia. Dolomite is a double carbonate of calcium and magnesium ($CaCO_3\cdot MgCO_3$) which has a theoretical magnesia (MgO) content of 22 percent. Dolomite and brucite are secondary commercial sources.

Olivine, a double silicate of iron and magnesium ($Mg_2Fe_2SiO_4$), is a green to brown mineral used primarily as a foundry sand.

Deposit Examples

Sparry or Crystalline Magnesite Deposits - Mount Brussilof (BC Minfile 082JNW001), Marysville (BC Minfile 082GNW005), British Columbia, (Canada); Veitsch, Entachen Alm, Hochfilzen, Radenthein and Breitenau (Austria); Eugui (Spain); Ashan area, Liaoning Province (China); Satka deposit (Russia).

Ultramafic Hosted Talc Magnesite Deposits - Gisby, BC (Minfile 092HNW002), British Columbia; Deloro magnesite-talc deposit, Ontario, (Canada); Lahnaslamp mine (Finland).

General Geology

Mineral occurrences containing significant amounts of magnesia are common throughout the Canadian Cordillera. However, host geological environments are varied.

Sparry or crystalline - magnesite deposits are found in continental margin and marine platform settings, typically occurring in basins characterized by shallow marine depositional environments. They are stratabound and occur as stratiform lens-shaped zones of coarse-grained magnesite in carbonates but sometimes occur in sandstone or other clastic sediments.

Deposits are several hundred metres to several kilometres in length and up to tens of metres in width. They are usually associated with unconformity.

There are two theories of origin for magnetite deposits:

1) They occur as the replacement of dolomitized, permeable carbonates with magnesite, due to the interaction of metasomatic fluids; or,
2) They are a result of diagenetic recrystallization of magnesia-rich protolith deposited as chemical sediments in marine or lacustrine settings. Sediments in this type of deposit consist of fine-grained magnesite, hydromagnesite, huntite and other low temperature magnesia-bearing minerals.

In both models host rocks include magnesite rock, dolostone, limestones, shales and chert in association with sandstone, conglomerate and volcanic rocks or their metamorphic equivalents. Magnesite deposits can survive high-grade metamorphic environments because of their monomineralic nature (Simandl and Hancock, 1999).

Ultramafic-Hosted Talc-Magnesite Deposits - these deposits are found typically in accreted or tectonically transported seafloor and ophiolite slices or lenses in ancient greenstone belts. However, serpentinized ultramafic intrusions regardless of tectonic environment should be considered potentially favourable hosts.

Deposits related to regional fault systems cutting ultramafic host rock are commonly magnesite-rich. Deposits located within sheets of serpentinized peridotite, found along the periphery of ultramafic intrusions or near the borders of tectonically transported peridotite slices, are typically talc-rich.

Magnesium-rich silicate rock, provide a source of magnesium Permeable fault zones or serpentinite-siliceous rock contacts, control the location of talc formation. These deposits are commonly magnesite-rich and are linked to CO_2 and H_2O metasomatism (carbonatization and hydration) of ultramafic rocks by fluids following faults and contacts. The following reactions illustrate the concept.

$$\text{2 Olivine} + 1CO_2 + 1H_2O \rightarrow \text{1 Serpentine} + \text{1 Magnesite}$$

$$\text{2 Serpentine} + 3CO_2 \rightarrow \text{3 Magnesite} + \text{1 Talc} + 3\,H_2O$$

Associated deposit types include chrysotile deposits, magnesite veins and stockworks, podiform chromite deposits, famous “verde antiqe” dimension stone deposits and possibly nephrite and listwanite-related gold deposits (Simandl and Ogden, 1999).

Brucite Deposits - brucite, or brucitic carbonates, are documented in the Atlin area of British Columbia. Brucite is an alteration product of periclase, which is a relatively high-temperature magnesian mineral formed during metamorphism of magnesian limestones or dolomites. It is typically found in metamorphic aureoles, having formed as a result of the dissociation of dolomite. Periclase is typically rimmed or entirely replaced by brucite which in turn, readily alters to hydromagnesite.

The limestone-dolomite-periclase-brucite-hydromagnesite alteration sequence, illustrates the relationship of brucite to magnesian dolomite or limestone. Lower temperature alteration or limited magnesium results, in the development of magnesian limestone or dolomite. Higher temperatures, with sufficient magnesium, may result in the development of periclase and/or brucite.

Brucite and/or periclase contact metamorphic minerals are usually more limited in extent, although the contained MgO may be locally significant (Grant, 1987). The economic potential of burcite deposits is considered relatively small.

Hydromagnesite Deposits - hydromagnesite characteristically forms sheet-like bodies of limited extent within swampy areas or as a small depression in the overburden surface. They normally consist of an upper, relatively pure, white hydromagnesite horizon of 30-100 centimetres thick, with a characteristic, rough cauliflower-like weathered surface. A unit of yellow or cream-coloured granular hydromagnesite usually underlies this surface zone and normally exhibits an increase of calcium with depth.

Impure hydromagnesite, with a significant component of silica, clay or calcium, may underlie the yellow-cream horizon or it may lie directly on overburden sand or clay. The lower contact of the deposit is commonly gradational, with the underlying soil or fine clay.

Bedrock occurrences of magnesite, particularly ultramafic magnesite, may occur in nearby hydromagnesite accumulations (Grant, 1987).

World Production

Sparry or crystalline magnesite deposits account for 80 percent of world production. Significant quantities of magnesite are also produced from ultramafic-hosted deposits and fine-grained or nodular deposits. World magnesite production during 2001 is estimated at 3.09 million tonnes. Leading producing countries included China (720,000 tonnes), Turkey (570,000 tonnes), North Korea (300,000 tonnes), Russia (250, 000 tonnes), and Slovakia (250,000 tonnes) (Kramer, 2002).

End-Use

Magnesite is used in the production of magnesium metal, which in turn is used in the aerospace and automotive industries. Magnesite is also used to produce caustic magnesia for chemical and industrial applications, in the construction industry, for animal foodstuffs and environmental rehabilitation processes. Fused and dead-burned magnesia is used in high-performance refractories.

Magnesium compounds, primarily magnesium oxide, are used mainly as refractory materials in furnace linings for producing iron and steel, the nonferrous metals, glass and cement. Magnesium oxide and other compounds also are used in agricultural, chemical and construction industries. Magnesium metal's principal use is as an alloying addition to aluminum, and these aluminum-magnesium alloys are used mainly in beverage cans. Magnesium alloys are used as structural components in automobiles and machinery. Magnesium alloys can be used to remove sulphur from iron and steel in blast furnaces (Kramer, 2002).

Quality and Specifications

Specifications vary depending on origin and end-use. Table 58 illustrates chemical composition of some commercial magnesite.

Table 58

Chemical Composition of Commercial Magnesite (%)

	First Grade USA	*Second Grade USA (regular)*	*First Grade Mexico*	*First Grade Greece*	*First Grade Japan*	*Second Grade Japan*
MgO	96.60	98.00	99.000	97.00	98.60	99.58
CaO	2.30	0.70	0.700	1.85	1.00	0.18
SiO2	0.70		0.100	0.50	0.30	
Fe2O3	0.20	0.20	0.100	0.60	0.06	0.06
Al2O3	0.20	0.20	0.100	0.03	0.05	0.01
B2O3	0.02	0.02	0.003	<0.01	0.08	0.01
CaO:SiO2	3.00	1.00	7.000	3.70	3.00	0.67
BD, g/cc	3.42	3.32	3.400	3.42	3.41	3.46

Source: adapted after Industrial Minerals Handybook II, pg. 101

Market Trends

With current trends, to reduce the weight of vehicles in order to improve fuel economy and reduce harmful emissions, the automotive market for magnesium metal is expected to expand. With the introduction of the new 2002 model cars, industry executives estimate that the average magnesium content in the car will increase to 4.1 kilograms, compared with 3.9 kilograms in 2001 (Kramer, 2002).

Price

Industrial Minerals, No. 419 reported the following prices for magnesite during 2002.

- Greek, raw, max 3.5% SiO2, FOB East Mediterranean US$50-55
- Calcined, (natural) industrial, CIF £140-270
- Chinese, dead burned, 90-92% MgO, lump, FOB China US$95-115
- Chinese, dead burned, 94-95% MgO, lump, FOB China US$110-125

Economic Factors

Typical mine grades range from 90-95 percent $MgCO_3$, with reserves up to hundreds of millions of tonnes. The Mount Brussilof magnesite deposit in British Columbia is reported to have proven and probable geological reserves of 9.5 million tonnes grading over 95 percent magnesia and 13.6 million tonnes of 93 to 95 percent magnesia in the calcined product. Reserves were estimated at 17.6 million tonnes averaging 92.44 percent magnesia in the calcined product (Simandl et al, 1992).

Yukon Occurrences

There are no reported large occurrences of magnetite in theYukon, but the territory does have the geological potential for commercial deposits.

Exploration Guidelines

Exploration methods commonly used to locate magnesite occurrences include:

- Tracing magnesite boulders (exhibiting pinolitic textures)
- Geochemical analysis of stream-sediments for magnesite (grains).
- Recognition in the field of weathered textures, e.g. surface exposures of magnetite are beige, pale brown or pale grey and exhibit “granola-like” weathered textures.
- Recognition that deposits are associated with unconformity.

There are no reported geophysical signatures for sparry magnesite deposits but unserpentinized portions of host ultramafic rocks, commonly correspond to strong airborne and ground magnetic anomalies.

MAGNETITE MA

Magnetite (Fe_3O_4) and hematite (Fe_2O_3), are the primary forms of iron ore. Iron ore is a mineral substance which when heated in the presence of a reductant, will yield metallic iron (Fe). Other iron oxides include, geothite and lepidocrocite. In this report, magnetite and hematite are discussed.

Chemical and Physical Characteristics

Magnetite is an iron-black to brown, shiny, dense (SG 5.2), hard (5.5-6.5), mineral with an opaque metallic luster, black streak and strong magnetic properties for example, lodestone.
Hematite is an opaque, hard (5.5-6.5), very heavy (SG 5.2) red to reddish-brown mineral. It is commonly found in massive, granular masses, and is often oolitic, botryoidal or concretionary in appearance.

Deposit Examples

Magnetite – Whitehorse Copper Mine tailings, Yukon; Texada Island, Brynnor Mine near Kennedy Lake, British Columbia, Sept-Iles, Quebec (Canada); Broken Hill (Australia); Brucutu Mine, Minas Gerais, (Brazil); Kiruna district (northern Sweden); Thabazimbi Mine (South Africa); Iron Mountains, Montana (United States).
Hematite – Crest Property, Snake River Iron Formation, Yukon (Canada).

General Geology

Magnetite is ubiquitous to most rocks in the earth's crust. It is most common in basic to ultrabasic and metamorphic rocks as a primary phase, and is often found in sedimentary rocks as a trace or minor component. Magnetite is found in several types of mineral deposits in the Yukon. The most common is skarn, in which magnetite varies from the main component to a trace mineral. Iron skarns are common and often large. Other types of magnetite occurrences are usually smaller, and may include differentiated magmatic, stratabound, ultramafic and placer deposits. Some porphyry copper deposits contain recoverable quantities of magnetite.

From a production standpoint, only the skarn bodies have been mined in the Canadian Cordillera; e.g., the Taku deposit on the Queen Charlotte Islands, which produced over 20 million tonnes of iron ore (Hancock, 1988). The Craigmont mine presently produces magnetite from tailings. Magnetite is also associated with corundum in natural emery.

Hematite, a common accessory mineral of many igneous rocks, especially lavas, forms under oxidizing conditions, as compared to magnetite. It is rare in plutonic rocks but common in pegmatite and hydrothermal veins. Hematite often forms under sedimentary conditions through diagenesis of limonite and usually retains its concretionary and oolitic forms. Hematite remains stable in low-temperature metamorphic environments, where it often replaces magnetite. It can also occur as a sublimation product of volcanic exhalations.

World Production

Metallurgical production - Annual world production of iron ore is about a billion tonnes with most of it concentrated in a few countries. In 2001, the seven largest producing countries included (China, 220 million tones), Brazil (200 million tonnes), Australia (160 million tonnes), Russia (88 million tonnes), India (72 million tonnes), United States (60 million tonnes) and Ukraine (55 million tonnes) produced more than 80 percent of the world total.

Canada during 2001 produced an estimated 35 million tonnes of iron ore from mines in eastern Canada (Kirk, 2001).

Non-metallurgical production -Based on USGS data, total world production of natural iron oxide pigments has been estimated at 441,000 tonnes. Leading producing countries include India (ochre), 285,000 tonnes, United States (finished natural iron oxide pigments), 81,000 tonnes and Spain (ochre and red umber) with 22,000 tonnes (Kirk, 2001).

M-Seven Industries Inc. in British Columbia produces between 60-70 thousand tonnes per year of magnetite from the Craigmont Mine tailings. This source supplies most coal mines in western Canada with material for heavy media use in wash plants (B.C. Mineral Exploration Review, 2001).

Market Trends

The iron ore industry in North American is totally dependent on the steel industry for sales. This dependence is not forecast to change in the near future. With iron ore prices having declined over the past number of years, there is no reason to expect that this trend will reverse itself. As a result, mergers and acquisitions are expected to continue, causing major changes in the structure of the iron ore industry in the near term.

Iron ore is the only source of primary iron. In some operations, ferrous scrap constitutes as much as seven percent of the blast furnace burden. Scrap is extensively used in steel making and in iron and steel foundries (Kirk, 2000).

End Use

Iron ore is a mineral substance which, when heated in the presence of a reductant, will yield metallic iron (Fe). Worldwide, nearly all iron ore is used in steel making (98 percent).

There are a wide variety of grades of different types of iron oxides, which are consumed, in non-metallurgical applications. The three main categories are:

Pigments - ready-mix concrete, automotive topcoats and primers, highway paint, cement blocks and roofing tiles, and in rubber and plastic compounds.

Magnetic - magnetic tapes, dual and non-component toners, magnetic fluids, magnetic storage media and magnetic links.

Chemical and other - air bags, pet food, glass, hard and soft ferrites, catalysts, cosmetics, foundry sands, pharmaceuticasl, batteries, and fuel cells, grit-blasting, abrasive, water filtration media, ballast material, animal feed, fertilizers, high density additive in concrete and in heavy media separation.

Finely ground magnetite for example, is used in a slurry of controlled density as a heavy medium in coal preparation plants to separate low ash coal from waste rock. This is an important end use for magnetite produced from mine tailings, e.g. Craigmont Mine, British Columbia.

Quality and Specifications

Magnetite has frequently been overlooked as a secondary economic mineral. Only the high-grade orebodies have been mined. It is readily separated from other ores. Commonly, wet or dry drum magnetic separators are used. Further classification of wet magnetite fines after milling has been achieved by cyclone separation (Kilbourne Engineering, 1986).

Table 59 illustrates the quality and specifications of iron oxide by use in non-metallurgical applications.

Table 59

Quality and Specifications of Iron Oxides By Use (Non-metallurgical)

Pigments (for use in paints)	Natural iron oxide is categorized as A, B, C, D by Fe2O3 content, i.e. red > 95, 70,50 and 10%; yellow >83,70,50,10%; brown>87,70,and 30%; black>95 and 70%; and grey MIO>85%. Other factors include soluble and volatile matter, CaO water soluble chlorite and sulphates; bulk density; oil absorption; opacity, relative tinting strength; specific surface area; particle size (e.g. –10 or 50 microns).
Ferrites (hard)	Minimum 98% Fe2O3, maximum 0.3% SiO2, 0.25% SiO2, 0.25% Cl, 0.5% MnO2, 0.2% Al2O3, 0.1% Cr2O3 and 1% moisture with 85% -325 mesh.
API	SG >5 and –200 mesh.
High-density aggregate	Minimum 65% Fe, maximum 5% Al2O3+SiO2, water absorption < 4%, low alkali and sulphide reactivity, angular to subangular particle shape, and SG 4.5-5.1
Pet foods	Maximum 5ppm As, 20ppm Pb, and 3ppm Hg
Pharmaceuticals and cosmetics	Maximum 3ppm As, 10ppm Pb, 3ppm Hg

Source: adapted after Industrial Minerals HandyBook, pg. 87.

Price

The estimated price received for iron ore during 2001 was reported by the USGS at US$25 per tonne. This is substantially down from the US$31.14 per tonne received in 1998.

Industrial Minerals, No. 419 reports iron oxides used in non-metallurgical applications in August 2002 were:

Spanish ochre

- Standard (53µ) FOB Spain US$125-135
- Micronised, FOB Spanish port US$215-225
- Ochre, FOT Cartersvill, CL/TL, short ton, cents per pound: Light (No 404) US$0.21, Medium (No 548) US$0.17.

Economic Factors

Synthetic iron oxides for non-metallic uses have taken over many of the markets once served by natural iron oxides.

Magnetite is a subsidiary component of many mine ores, for example in asbestos, copper and base metal mines. The tailings of these mines could be an important source of magnetite. Many mines had magnetite concentrations in the order of ten percent, such as the Cassiar Mine in northern British Columbia (Hancock, 1988).

Yukon Occurrences

Magnetite - Tailings from the abandoned Whitehorse Copper mine (Minfile 105D 053), is probably the best readily available source of magnetite in the Yukon. The mine worked a copper skarn, and contained appreciable magnetite, however no values were reported. Tailings at the mine were stockpiled during the length of the mines operation from the early 1900's until 1982. Dowling reported that Dennison Mines Ltd. evaluated the tailings as a potential source of magnetite for the Quintette Coal mine located in Northeastern British Columbia but the results of this work are not known.

Magnetite in skarn is referenced in Yukon Minfile 2001 (under minerology) but not as major, minor or trace minerals. Values for reserve estimates are not reported. A systematic survey of Yukon skarn deposits is required, to evaluate magnetite potential in the territory.

Hematite – The Crest Iron Deposit (Minfile 106F 008) located near the Yukon/Northwest Territory border contains an estimated 5.6 billion tonnes of iron ore averaging 46 percent Fe, 25 percent SiO_2 and 0.35 percent P_2O_5. The deposit is in the Snake River Iron Formation which lies near the base of the late Proterozoic Rapitan Group of rocks. Beneficiation studies in 1964 indicate the material can be beneficiated by selective agglomeration methods. Material containing 54.6 percent Fe and 0.39 percent P_2O_5 was treated to provide concentrate containing 65.9 percent Fe, less than 0.02 percent P_2O_5 and 5.3 percent SiO_2 with 85 percent of the iron being recovered in the concentrate.

The Pagisteel deposit (Minfile106D 049) has reserves of 9.1 million tonnes and grading of 29.2 percent soluble iron. There is good potential for additional discoveries of iron, in the Snake River Iron Formation.

Exploration Guidelines

Skarn deposits account for the greatest volume of magnetite mineralization in British Columbia and by extension, are probably the best potential source of economic deposits of magnetite in the Yukon. This is suggested by skarn deposits referenced in Yukon Minfile 2001, many of which reported magnetite as a primary mineral.

The most common method of detecting magnetite, is by ground and/or airborne magnetometer geophysical surveys. Frequently geophysical anomalies of 10,000 gammas (10,000 nanoteslas) above background levels, are reported over magnetite bodies. As well, pulse electromagnetic surveys and induced polarization (IP) surveys have proven to be effective methods for detecting significant magnetite occurrences, especially when in association with sulphides. Importantly, the proportion of magnetite to sulphides, increases in the skarn associated with mafic intrusions. Most iron skarn are associated with more mafic intrusions as compared to, for example, a tin-molybdenum skarn that is generally related to granitic plutonism. Precious metal content commonly decreases sharply, with an increase in the amount of magnetite. However, precious metal content locally increases, with copper enrichment (Hancock, 1988).

When prospecting, a hand magnet provides an excellent method for establishing the presence of magnetite.

MANGANESE MINERALS MAN

Chemical and Physical Characteristics

Manganese does not occur naturally in its metallic form but rather it is obtained from mixtures of manganese minerals which include pyrolusite (MnO_2), braunite ($2Mn_2O_3 \cdot MnSiO_3$), manganite ($Mn_2O_3 \cdot H_2O$), hausmannite (Mn_3O_4), bementite [$Mn_8Si_6O_{15}(OH)_{10}$], rhodochrosite ($MnCO_3$) and rhodonite ($MnSiO_3$).

Pyrolusite, the most important ore of manganese, is a soft, iron-black or dark steel-grey, tetragonal mineral while the silicate rhodonite, a pale-red, rose-red or flesh-pink to brownish-red or red-brown mineral, often marked by black streaks and veins of manganese oxide, and is valued as an ornamental stone.

Psilomelane is a general field term for mixtures of manganese minerals or for a massive, hard botryoidal, colloform, and heavy manganese oxide, whose mineral composition is not specifically determined.

Deposit Examples

Molango (Mexico); Charco Redondo (Cuba); Urcut (Hungary); Nikopol (Ukraine); Groote Eyulandt (Australia).

General Geology

Tectonic settings for sedimentary manganese deposits are interior or marginal basins that rest on stable cratons. Commonly, they form in shallow marine depositional environments (15-300 metres), and in sheltered sites around islands along some areas of a continental shelf or interior basins. The Black Sea and stratified fjords, such as the Sannich Inlet or Jervis Inlet in British Columbia are considered modern analogies (Emerson 1982; Grill, 1982).

Many manganese deposits are located within transgressive stratigraphic sequences near or at black shale pinchouts. Generally, they formed during the lower to middle Paleozoic, Jurassic, mid-Cretaceous and Proterozoic periods. Deposits may consist of manganite, psilomelane, pyrolusite, rhodochrosite and/or other manganese minerals, which are believed to have accumulated as rims around paleo-islands in oxygen depleted (anoxic) basins. Precipitation is thought to have taken place at the interface between anoxic seawater and near surface more oxygen-rich, waters. In this model, extreme iron fractionation is caused by a low solubility of iron in low Eh environments where iron precipitates as iron sulphide. A subsequent increase in Eh and/or pH of manganese-rich, water produces manganese-rich, iron depleted chemical sediments. The manganese oxide facies is preserved on oxidized substrates, while carbonate facies are preserved either in oxidized or reduced substrates, in slightly deeper waters.

Manganese deposits may also occur in association with VMS deposits, where mafic volcanics are present. The Big Bull mine on the Taku River is an example of this deposit type. This type of deposit was also mined in eastern Cuba until the late 1960's.

The origin of manganese-bearing black shales in deep marine basins (oxygen depleted), are thought to occur when a high accumulation rate of organic matter in sediments, promotes the development of anoxic conditions below the surface. This results in surface layers that are enriched in manganese oxyhydroxides and when buried, they release diagenetic fluids, which are supersaturated with manganese carbonates that precipitate Ca-Mn carbonates. Sedimentary manganese deposits can then be transformed into manganese-silicates during metamorphism as illustrated by:

$$\text{Rhodochrosite} + SiO_2 = \text{Rhodonite} + CO_2$$

These manganese silicates although valuable as ornamental stones, are not considered a potential source of manganese metal ores.

Manganese enriched zones can range up to 50 metres thick, may extend over 50 kilometres along strike and occur in the form of a "bathtub-ring" or a "donut" shape. Some deposits may consist of a landward oxide facies and a basinward reduced carbonate facies, with ore bodies represented as discrete portions of these zones (Force et al, 1999).

World Production

Leading producer countries of manganese ore include: Australia, Brazil, China, Gabon, Ghana, India, Kazakhstan, Mexico, South Africa, and Ukraine (Table 60).

Table 60

Manganese Ore: Estimated 2000 World Production, By Country (Thousand metric tons)

Country	*Range (Mn %)*	*Gross Weight*	*Metal content*
Australia	37-53	1,614	787
Brazil	30-50	2,000	920
China	20-30	4,000	800
Gabon	45-53	1,743	804
Ghana	30-50	896	287
India	10-54	1,550	590
Kazakhstan	20-30	1,136	280
Mexico	27-50	418	156
South Africa	30-48+	3,635	1,578
Ukraine	30-35	2,741	930
Others	-	467	147
Total	-	20,200	7,280

Source: Jones, 2000

End Use

Manganese (Mn) is essential to iron and steel production by virtue of its sulphur-fixing, deoxidizing, and alloying properties. It is used to scavenge sulphur and oxygen from molten steel. This metallurgical use supplied either by manganese ore concentrates and/or ferromanganese and sillicomanganese derived from the ores, accounts for 95 percent of the manganese consumption.

Manganese is also an important component for many nonmetallurgical products including its use in batteries, as an additive in animal feed and fertilizers; a colourant for bricks, cements, pottery and porcelain tiles; and as an oxidizer in photographic developing processes, in medicines, and as a slag former.

Quality and Specifications

Ore is divided into manganese ore (greater than 35 percent Mn) and manganiferous ore (5-35 percent Mn) which can still be further divided into ferruginous manganese ore (10-35 percent Mn) and manganiferous iron ore (5-10 percent Mn).

Table 61 illustrates the quality required for several grades.

Table 61

Quality and Specifications of Manganese Ores

Metallurgical-grade	Minimum 48% Mn and maximum 6% Fe, 11% Al2O3 + SiO2, 0.18% As, 0.19% P, and 0.3% Cu+Pb+Zn
Chemical-grade	Minimum 35% manganese
Battery-grade	Categorized by manganese dioxide content of 70-85%. Dry-cell EMD is minimum 92% MnO2 with maximum 2% H2O, 0.02% Fe, 0.0005% Cu, and 0.0009% Pb
Fertilizer and feed grade	30-60% Mn.
Ferrites	Very low levels of CaO, K2O, Na2O, BaO and SiO2
Hydroquinone	80-88% MnO2 and –300 to 325 mesh

Source: The Industrial Minerals HandyBook II, pg. 106.

Tables 62 illustrates the chemical composition of commercial manganesse concentrates:

Table 62

Chemical Composition of Commercial Manganese Concentrates (%)

	Gabon Battery	*Ghana Carbonate N grade*	*Australia Met. Lump*	*Australia Siliceous*	*Australia Chem.*	*Netherlands Glass Mangalox A*	*Netherlands Ceramics-Mangalox B*
Mn	54.85	30.8	49	43	52		
MnO2	83.64	Nil				79	69
MnO	3.04	39.77				1	3
Fe		1.04	3.3	7	3		
Fe2O3	2.64					3	5.5
SiO2	1.06	12.68	6	13	3.5	3.5	5
Al2O3	4.67	2.15	4	7	3.5	4.5	9
CaO	Trace	4.75				0.05	0.2
MgO	0.05	3.5				0.35	0.2
BaO	0.37	Trace	0.7	0.7	1.5	2.8	0.4
TiO2	Trace	0.1				0.3	0.3
S						0.01	-
SO3	0.025	0.15				-	0.05
P2O5	0.19	0.137				-	0.25
P	0.08	0.06	0.09	0.075	0.08	0.09	-
As2O3	Absent		0.025				
Cu	0.03	Trace					
CuO						0.06	0.07
Pb	Absent	Trace					
Zn	0.01						
ZnO		0.07				-	0.06
SnO		0.005					
K2O	056	0.17	1.7	1.4	0.8		
Na2O	0.05	0.05					
Co	0.095						
CoO						0.04	0.15
Ni	0.05						
NiO						0.05	0.1
NiO						0.02	-
CO2	0.41	33.68					
Mo + H2O	2						
Water of crystal	0.12				3	5	
Insolubles	0.12						

Source: Industrial Minerals HandyBook II, pg. 106

Market Trends

The 2000 supply of manganese alloys was estimated at 7.1 million tonnes (Jones, 2000). In response to highly competitive markets in North America and Europe, much of the manganese ore mining is being integrated with alloy production. As a result, the bulk of manganese units for the steel production, is now being supplied in the form of alloys. There is also a new tendency to have the ore processed in China and the Commonwealth of Independent States (CIS).

The global demand for manganese is almost entirely governed by the levels of steel production. Some non-metallurgical uses for the mineral (such as battery production) may be higher than for the demand for steel, but this will have only a minor effect on overall manganese demand.

Statistics from the American Iron and Steel Institute indicated that American raw steel production increased in 2000 by about four percent. It is probable that manganese consumption increased by about the same percentage. The forecast for the United States, is for manganese consumption to reach 800,000 tonnes by 2005 up from an apparent consumption of 680,000 tonnes from 1988 to 2000. This forecast however, is contingent on American raw steel production maintaining an annual growth rate of approximately 1.4 percent which, given the recent downturn in the American economy, may not be realized (Jones, 2000).

Globally, the International Iron and Steel Institute (IISI) through 2000 to 2005 (in its 2000, midterm steel consumption forecast) projected an annual growth rate of two percent for the world’s overall consumption.

Price

Industrial Minerals, No. 419 listed manganese in August 2002 at: battery grade MnO_2, unground, 78-85% CIF at US$225-240; chemical grade 74-84% MnO_2, unground, bulk CIF US$140-250; chemical grade 74% MnO_2, 200 mesh, bulk ex-works at US$275-342

The average price, based on production costs, insurance, and freight (c.i.f.) to American ports, of metallurgical-grade ore containing 48 percent manganese, was assessed at US$2.39 per tonne unit. The price of a tonne of ore is obtained by multiplying the unit price by the percentage of manganese content of the ore, that is, by 48 when the manganese content is 48 percent (Jones, 2000).

Deposit Criteria and Economic Factors

The average manganese deposit contains 6.3 million tonnes at 30 percent MnO but some may exceed 100 million tonnes (South Africa, Australia, Brazil and Gabon) (Force et al, 1999).

Yukon Occurrences

Eight manganese occurrences are described in Yukon Minfile 2001 (Table 63; Figure 4). Of these, two are described as rhodonite, and these are listed as major commodities. See under Gems (rhodonite) in this report. The other reported occurrences are reported as minor or trace.

Table 63
Yukon Manganese Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105C 017	105C/11	EVE**	YT	S	60º42’26”/133º20’07”
2	105N 004	105N/9	ROGUE	SB	?	63º34’08”/132º20’35”
3	106D 016	106D/3	RAMBLER	SB	V	64º04’34”/135º15’40”
4	115K 086	115K/10	OLGA**	CPC	V	62º31’36”/140º57’11”
5	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36”/140º55’14”
6	1150 113	1150/14	BRONSON	YT	?	63º58’44”/139º28’40”
7	115P 061	115P/15	BIG	?	?	63º50’29”/136º58’07”
8	116B 041	116B/4	FRESNO	YT	V	64º13’13”/139º52’41”

** *Described as rhodonite in Minfile 2001. YT (Yukon Tanana), SB (Selwyn Basin), CPC (Coast Plutonic Complex), NST (Northern Stikine Terrane); S (Skarn), V (Vein), ? (Deposit type unknown).*

Exploration Guidelines

Good exploration targets for manganese sedimentary deposits are shallow, marine stratigraphic sequences of black shale or other sedimentary rocks, which were deposited near the onset of marine regressions. High manganese concentrations are enhanced in depositional environments characterized by weak clastic sedimentation. Manganese carbonates occur basinward from the manganese oxide ore. Many sedimentary manganese deposits formed during periods of high sea levels are contemporaneous with an adjacent anoxic basin. If manganese oxides are the exploration target, sequences containing shellbed-biogenic silica-glauconite are favourable. Evidence of severe weathering of the landmass adjacent to and contemporaneous with the favourable sedimentary settings, is also considered a positive factor. In Precambrian terranes, sequences containing both black shales and oxide-facies iron formations, are the most favourable.

Manganese-enriched beds are a good geochemical target. Mn/Fe ratio is a local indicator of the basin morphology that may be reflecting separation of Mn from Fe by precipitation of pyrite. Some of the largest manganese deposits, including Groote Eylandt in Australia coincide with, or slightly post date _^{13}C positive excursions and these anomalies may be indicative of favourable stratigraphic horizons for manganese exploration.

Generally geophysical exploration is not effective although Supergene cappings may be a target for the self-potential (SP) method (Force et al, 1999).

MICA MIC

Chemical and Physical Characteristics

The mica group represents 34 phyllosicate minerals that have a layered or platy texture. The commercially important micas are muscovite and phlogopite.

All micas belong to the monoclinic crystal system ranging from colourless to black. Individual sheets are, chemically resistant, translucent, hydrophilic, dielectric, insulating, reflective, refractive, lightweight, flexible, elastic and durable.. Layering in the univalent (potassium, sodium) micas imparts perfect basal cleavage, allowing crystals to be split into very thin sheets that are tough and flexible. Layering in the divalent, or brittle, micas, also results in perfect basal cleavage; the greater bond strengths, however, make them more brittle, and less flexible.

Vermiculite, a hydrated magnesium iron mica-like aluminum silicate (originally phlogopite or biotite), is platy, green or golden-yellow-to-brown crystals. Flakes of raw vermiculite concentrate are micaceous in appearance and contain interlayer water in their structure. When the flakes are heated rapidly at a temperature above 870ºC, the water flashes into steam, and the flakes expand into accordionlike particles (up to 8-12 times original size). This process is called exfoliation, or expansion, with the resulting lightweight material being chemically inert, fire resistant, and odorless.

Deposit Examples

Scrap and flake mica - Marietta deposit, Quebec; Bisetts Creek, Ontario (Canada); Spruce Pine, North Carolina; Black Canyon, Arizona (United States).

Sheet mica - India.

Vermiculite - Sowchea Creek vermiculite (093K 101), British Columbia, (Canada); Libby vermiculite deposit, Montana; Enoree and Woodruff, South Carolina (United States); Natkruit Mine, Northern Transvall (South Africa).

General Geology

The three commercially important micaceous minerals include vermiculite, muscovite, and phlogopite.

Vermiculite - major vermiculite deposits occur mainly within zoned ultramafic complexes or carbonatites. Smaller or lower-grade deposits are hosted by dunites, unzoned pyroxenites, peridotites or other mafic rocks cut by pegmatites and syenitic or granitic rocks.

Vermiculite deposits hosted by carbonatites and ultramafic complexes are commonly related to rifting within the continental platform, or marginal to the platform in geosynclinal settings. Most deposits are derived from rocks of Precambrian to Jurassic age. Deposits post-date emplacement of intrusive host and regional metamorphism. Their age may be linked to periods of intense weathering, which show up as erosional surfaces, or inconformaties.

Deposits may occur in variable shapes, a function of geometry, which is often a result of fluid access. Lenticular or planar deposits occur along serpentinized contacts between ultramafic rocks and metamorphic country rocks. Individual lenses may be up to seven metres thick and 30 metres long. Smaller lenses may be found along fractures with the margins of pegmatites crosscutting ultramafic lenses within high-grade metamorphic terranes. The degree of alteration generally diminishes with depth, with economic grades rarely extending more than 40 metres below the surface.

Vermiculite can form from a variety of mafic minerals, but biotite or Fe-bearing phlogopite are considered key components and vermiculite is probably in part a low-temperature alteration of biotite. One theory is that vermiculite forms by supergene alteration due to the combined effect of weathering and circulation of meteoric fluids.

Ore controls include the existence of a suitable protore (commonly dunite or pyroxenite rock) containing abundant biotite or phlogopite which may be of late magmatic to hydrothermal origin. The maximum depth extent of the ore zone depends on the permeability, porosity, jointing and fracture system orientation, which permit the circulation of meteoric fluids (Simandl et al, 1999).

Phlogopite - a magnesium-bearing mica, is usually associated with magnesum-rich rocks such as metamorphosed dolomite or limestone or ultrabasic igneous rocks. It is thermally stable up to 900ºC to 1000ºC. Muscovite, an aluminum-rich mica is a primary mineral in acidic igneous rocks, and commonly occurs in granites, pegmatites and aplite.

Major Muscovite deposits - are associated with granitic pegmatites, which normally contain 1-2 percent muscovite, and rarely contain up to ten percent. It is terminally stable up to 500ºC (For information about mica genesis see under Sillimanite in this report). Sericite is a very finegrained form of muscovite. It may form as a metamorphosed deposit of kaolinitic clays.

World Production

Mica - the estimated world mine production of mica is 280,000 tonnes with Russia (100,000 tonnes), the United States (95,000 tonnes), Republic of Korea (30,000 tonnes) and Canada (17,000 tonnes) being the leading producers (Hedrick, 2002).

World sheet mica is estimated at approximately 5,000 tonnes annually, of which approximately 80 percent is supplied by India. Other producers of sheet mica are China, Argentina, Brazil, South Africa and Madagascar (Industrial Minerals, No. 402, 2001).

Vermiculite - the estimated world mine production of vermiculite during 2001 was 470,000 tonnes with South Africa (162,000 tonnes), the United States (150,000 tones), China (50,000 tonnes) the leading producers (Potter, 2002).

End-Use

Sheet mica - is used principally in the electronic and electrical industries. Its usefulness in these applications is derived from its unique electrical and thermal insulating properties as well as its mechanical properties, which allow it to be cut, punched, stamped, and machined to close tolerances. Its uses include applications in optical filters, furnace windows, high pressure gauge glass, transformers, condensers, rheostats, fuses and insulating material in vacuum tubes.

Ground mica - often referred to as scrap or flake mica, is the waste from the production of mica sheets or from the processing of kaolin and feldspar. Consumption is dependent on the grade, that in turn, is determined by the grinding technique used, and the resulting particle size. The main use for ground mica is as a filler and extender for finishing seams and as blemishes in gypsum wallboard. It is also used in paints as a pigment extender, and to promote adhesion. These two uses account for about 75 percent of all dry ground mica consumption.

Unexfoliated vermiculite concentrate - is used in fire rated wallboard, and to reduce slag build up in coal fired boiler-tubes and in drilling mud. When heated (to 870ºC), vermiculite becomes exfolited and expands from 8 to 12 times its original size.

Exfoliated vermiculite - a very light thermal insulating material used in plant nurseries as a bedding material, and as a component for insulating plasters, cements and lightweight aggregates, or loose insulation in attics, walls etc.

Quality and Specifications

Sheet mica is graded on the basis of colour and visual quality, and on the usable rectangle that can be cut from a single lamina.

Ground mica may be dry ground (APS 1.2 millimetres to 150 µm , wet ground APS 90-45µm), or micronized (APS less than 53µm). Tables 64 and 65 illustrate the chemical composition of mica and the grade and size of mica by use.

Table 64

Chemical Composition of Mica (%)

	Muscovite	***Phlogopite***
SiO2	44-47	37-43
Al2O3	30-38	12-17
Fe2O3	0.2-5	0.2-2
K2O	8.5-11.5	8.5-11.5
Na2O	0.1-0.8	0.3-0.8
TiO2	0-0.9	0-1.5
BaO	-	0-0.7
MgO	0.3-1.5	23-29
CaO	0.1	0.1-0.5
Li2O	0.1-0.8	0-0.1
F	0-0.15	0.5-5.0
P	Traces	Traces
S	Traces	Traces
LOI	4-5	1-3

Source: adapted after Industrial Minerals HandyBook II, pg. 110

Table 65

Grade, Sieve Size and Typical Use for Ground Mica

Grade	*Sieve size (mesh)*	*Typical uses*
Course flakes	6	Oilwell drilling, artificial snow
Medium-coarse flakes	10	Christmas ornaments, display material
Fine-coarse flakes	16	Concrete block fillers, refractory bricks, gypsum wallboards
Coarse-fine powder	30	Metal annealing, absorbent in explosives, disinfectants, automotive components
Medium-fine powder	60	Welding electrodes, cables, foundry works, pipeline enamels, lubricants, adhesives
Fine powder	100	Texture paints, acoustical plaster, ceiling tiles
Superfine powder	325	Paints, plastics, rubber products, paper, cosmetics.

Source: adapted after Industrial Minerals, March 2001, pg. 19

Tables 66 and 67 illustrate the Commercial grade and chemical analysis of vermiculite.

Table 66

Commercial Grade of United States Vermiculite

Grade	Density lb./ft^3	US sieve size (Tyler Mesh)	Approximate maximum size (millimeters)
1	4-7	3-10	6.700
2	4-8	8-14	2.400
3	5-9	10-35	1.600
4	6-10	28-65	0.600
5	8-11	35+	0.400
		Micron	0.180

Source: Industrial Minerals HandyBook II, pg. 194

Table 67

Chemical Analysis of Commercial Vermiculite (WT%)

	United States Enoree, SC	*United States Louisa, VA*	*South Africa Palabora*	*Brazil Piaui Eucatex*
LiO2		0.01	0.03	0.10
Na2O		1.72	0.80	0.50
K2O	4.42	6.63	2.46	23.60
MgO	20.04	16.38	23.37	3.80
CaO	0.75	1.12	1.46	0.20
BaO	0.12			
MnO	0.07	0.14	0.30	
FeO			1.17	
Al2O3	17.36	12.85	12.08	10.20
Cr2O3	0.05	0.23		
Fe2O3	8.45	8.80	5.45	5.80
SiO2	38.66	38.34	39.37	45.10
TiO2		1.66	1.25	0.70
H2O (total)	8.71	10.66	11.20	10.20

Source: adapted after Industrial Minerals HandyBook, II pg. 193

Market Trends

Mica - the major markets for ground mica are mature and relatively stable. Growth is tied mainly to the demand for residential building materials and for vehicle production. Demand for dry-ground mica is expected to grow annually by up to 1-3 percent through to 2005, unless there is a downturn in new housing developments or vehicle manufacturing. Demand for wet ground mica is also expected to grow, to meet increasing demand for pearlescent paints and cosmetics.

Sheet mica remains in short supply, but expected to remain as level as it has been, since the 1980's (Hedrick, 2000).

Vermiculite - although horticultural and related applications have consisted of the largest end uses of vermiculite in the United States in recent years, other uses appear to be growing, including as an intumescent (swelling) material in gaskets and other materials. Other uses are as fillers in coatings and binders as well as insulation in buildings, and friction brake applications. Production of vermiculite by China is expected to increase with that country probably becoming a major supplier in the future (Potter, 2000).

Price

Prices for micas vary depending on grade and type. The current price of North American mica ranges from US$230-400 per tonne for dry ground and US$535-1,400 per tonne for wet ground. Sheet mica varies from less than US$1.00 per kilogram for low-quality mica to more than US$2,000 per kilogram for the highest grade.

Vermiculite is a relatively low-end priced commodity with transportation costs high, in comparison to unit values. The mineral is also subject to substitution by glass fibre, perlite, peat and sawdust. Prices quoted for vermiculite (Industrial Minerals No. 419, 2002) were:

- South African, bulk, FOB Rotterdam US160-260
- Raw, ex-US plant, bulk s ton US$130-200
- South African, crude bulk FOB barge, Gulf coast, s ton US$140-250

Economic Factors

The grading, classification and preparation of sheet mica is a highly specialized industry and is critical in the successful development of a producer. Grading and classification is divided into two parts, visual and electrical methods. Visual methods include size grading (width and thickness) quality (clarity, staining inclusions etc.) and degree of flatness. “Books” of mica are cobbed at the mine site to remove obvious impurities such as quartz and feldspar, and then split with a blade into sheets 0.5 centimetres thick.

Vermiculite deposits of over 35 percent (greater than 65 mesh) are considered high-grade. Tonnage for major deposits are in the order of several million (tonnes) but small deposits of high-grade biotite schist-hosted deposits ranging from 20-50 thousand tones, have been successfully mined in South Carolina (Simandl et al, 1999).

In some deposits, muscovite could be recovered as a by-product from some porphyry Cu or Mo operations.

Yukon Occurrences

There are no documented or reported commercially significant occurrences of micas or vermiculite in the Yukon. Yukon Minfile 2001 mentions 12 biotite, 19 muscovite and one phlogopite in various mineral occurrences, but these mica occurrences were not evaluated for their quality, quantity or economic potential.

Vermiculite is not listed as a mineralogical component or commodity in Yukon Minfile 2001.

Exploration Guidelines

There is no apparent geochemical signature for mica in metasediments. Regional geophysical data, such as electromagnetic (EM) or radiometric methods may be used as indirect tools to trace favourable metasedimentary units, if marker horizons or igneous intrusion have distinctive signatures. Another exploration tool is to delimit areas where metamorphic conditions, which were needed to form hydrous aluminum silicates, were reached. Identifying favourable lithologies with special attention to crests or folds and metasediment-intrusive rocks are also a useful guide. Panning along streambeds for concentrations of mica flakes, may also be indicative of, a nearby occurrence.

Ultramafic rocks that host large vermiculite deposits (usually in the cores of ultramafic or alkaline complexes – usually pyroxenites and carbonatites) are commonly characterized by strong magnetic anomalies detectable by airborne surveys. Since vermiculite is an alteration product of ultramafic rocks, vermiculite zones are expected to have a negative magnetic signature.

Vermiculite may be detectable in soil samples and a portable torch may be used to identify vermiculite in hand specimens since it exfoliates when exposed to fire, and forms golden flakes when heated. An excellent time to prospect for vermiculite is after a forest fire (Simandl et al, 1999).

Alteration envelopes of VMS deposits particularly in metamorphic units may be major sericite resources.

OLIVINE OLI

Chemical and Physical Characteristics

Olivine is a mesosilicate, with a general composition of $(Mg, Fe)_2 SiO_4$, which describes a group of minerals that form a solid-solution series with fayalite (Fe_2SiO_4) and forsterite (Mg_2SiO_4) being the end members. For industrial purposes, fosteritic olivine is preferred, because of its higher magnesium and lower iron content. Forsteritic olivine is light green to yellow-green, has a glassy to vitreous lustre, a hardness of 6.5-7 and a specific gravity of 3.27 to 4.37 (increasing with iron content).

Olivine minerals readily weather to form serpentine or chlorite and are essential minerals in ultramafic rocks but appear as accessory minerals in mafic rocks. In outcrop, massive olivine weathers a characteristic dun to red-tan colour. On fresh surfaces, dunite or peridotite is light to dark green, with either a sugary, or granulated texture.

Deposit Examples

Tulameen Ultramafic Complex, British Columbia, (Canada); Twin Sisters olivine deposit, Washington State, Burnsville, North Carolina, (United States); Aaheim, (Norway).

General Geology

Olivine is a dominant mineral in ultramafic rocks, and an accessory mineral in mafic rocks. As a major rock-forming mineral, it occurs as granular crystal aggregates, or massive bodies in dunite (more than 90 percent olivine) and peridotite (harzburgite). As an accessory mineral in gabbro, lherzolite, wherlite, websterite, pyroxenite and basalt, olivine commonly occurs as free grains of small crystal aggregates. It also occurs as an alteration mineral in magnesian skarns and in magnesian carbonate rocks. However, the most significant source of olivine, is from dunite and related, partially serpentinized bodies.

In outcrop, massive olivine weathers a characteristic dun to red-tan colour. On fresh surfaces, dunite or peridotite is light to dark green with either a sugary or massive texture. Accessory minerals include orthopyroxene (enstatite), clinopyroxene (augite), and rarely, plagioclase. Alteration minerals commonly present are serpentine (antigorite and lizardite), chrysotile (asbestos), talc, magnesite, magnetitie, brucite and sericite.

World Production

The largest producer of unweathered olivine is Norway, which supplies approximately 3.5 million tonnes annually. The estimated world total is four million tonnes. If weathered material is included (serpentine), then world production is estimated at 8 million tonnes annually (Industrial Minerals, September 2001). Of this amount, the majority is consumed in Europe. Other countries producing lesser amounts of olivine and serpentine are the United States, Japan, South Korea, Taiwan, Spain, Italy, Brazil and Mexico.

Some synthetic olivine is produced in Quebec, Canada by calcining chrysotile asbestos mine tailings.

End-Use

Approximately 90 percent of the world's annual production of olivine is used as a slag conditioner. When olivine is added to blast furnaces as lump, sinter or as pellets, it improves the sintering capacity, and reduces energy consumption, as well as the volume of slag produced. Principle competing materials used in this process are dolomite and limestone, however, these have been generally replaced by olivine in Europe.

Olivine sand is used as the raw material in forsterite bricks, refractory monolithics and mortars and as sandblasting and molding sand. It also is used in castings for steels as it produces very clean surfaces, is easy to use and can be recycled. Additionally it may be used as a high-density aggregate for ballast and covering material, as a coarse ballast for heat storage, as a component in underwater pipes and cables, and as a raw material in the manufacture of fire retardant mineral wool.

Peridot, a gem variety of olivine, which is transparent and pale green, is used to make jewelry.

Quality and Specifications

At present there are few firm specifications for olivine in the marketplace since most are defined by the customer, to fit individual applications. However, there are a few general considerations. Almost pure olivine is required for smelting and foundry use. The general test for olivine alteration is loss-on-ignition (LOI), with acceptable levels below two percent. High magnesium levels are preferred, with a minimum of 45 weight percent MgO (most olivine produced averages 50 weight percent). Finally, other oxides should comprise less than 15 percent weight in total, with iron content being less than ten percent.

There are no general specifications for use in refractories, abrasives, aggregates and construction material. Compositions, grain sizes and allowable impurities, are highly variables depending on each customer. Details are worked out between the customer and producer, on a product by product basis. A relatively low LOI is a critical factor, as it indicates the presence of hydrated minerals such as serpentine and chlorite.

Sizes range from lump or aggregate (10 to 45 millimetres) to sand or flour (-200 or -325 mesh). Tables 68 and 69 illustrate the chemical composition of commercial olivine and size range for blasting.

Table 68

Comparison of Chemical Analyses of Some Commercial Olivine

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
MgO	47.5	43-44	49.0	47.7	46.4	46.9	48.09	47.1-48.9
SiO2	40.4	24-35	42.6	40.8	42.5	40.8	40.28	39.3-40.0
Fe2O3	9.0	7.6-7.7	6.0	7.5	8.0	9.4	*9.13	*9.25
Other oxides	2.5	0.7-0.8	1.8	1.9	2.4	3.2	1.51	0.84-3.46
Loss On Ignition	0.8	?	0.6	2.0	0.5	0.6	?	0.92

Source: White, 1987
1 Ste. Anne des Monts, Quebec Canada (Teague, 1983)
2 Leoben, Austria (Teague, 1983)
3 Aaheim, Norway (Teague, 1983)
4 Norddal, Norway (Teague, 1983)
5 Burnsville, North Carolina, U.S.A. (Teague, 1983)
6 Hamilton, Washington, U.S.A. (Teague, 1983)
7 Twin Sister, Washington, U.S.A. (Olivine Corp., unpublished report)
8 Tulameen Ultramafic Complex, B.C., Canada (Findlay, 1969)
** Total iron calculated as Fe2O3*

Table 69
Olivine for Blasting

Grade	*Size Range (mm)*	*Surface profile on mild steel*
AFS 20	1.7-0.355	Medium
AFS 30	1.0-0.18	Fine
Special	1.0-0.15	Fine
AFS 60	0.5-0.125	Less than fine
AFS 90	0.25-0.09	Less than fine

Source: Industrial Minerals HandyBook II, pg. 121

Market Trends

Olivine's largest market as a slag conditioner, is generally thought to increase, as a result of a greater use of olivine in pellet production. Its use as olivine sand in refractory production, replaces more costly raw minerals, such as calcined magnesia.

Olivine, is considered to be environmentally friendly in its use as a dry sand (blasting sand) and as a foundry sand. However, while its industrial qualities give it an advantage over competitive raw materials such as silica sands, any increase in use will probably be dependent on healthy steel and foundry industries.

Price

Prices for olivine are negotiated directly between the customer and the producer. They are product specific and the price to the customer varies as transportation costs become more significant. In North America, the two major producing companies are AIMCOR in North Carolina and Olivine Corporation Ltd. in Washington State (Twin Sisters deposit). Prices reported for typical applications during August 2002 were (Industrial Minerals, No. 419);

- Bulk, crushed (for blast furnace), CIF £9-13
- Dry, graded refractory aggregate, bulk, ex workds £50-55
- Foundry sand, bagged, ex-workds £54-58
- Foundry sand, bulk, ex-works £45-58
- Sand for furnish spray, bagged £70-76

US ex-works/mine:

- Foundry grade, AFS 30-180, bulk US$60-110
- Bags US$ 77-125
- Flour, bags US$117
- Aggregate, bulk US$50-78

Economic Factors

Olivine as an abrasive and foundry sand, has an advantage over crystalline silica, because of the absence of free silica. The latter has been classified as a probable carcinogen by the International Agency for Research on Cancer (IARC).

Possible substitutes and alternatives to olivine as a refractory include andalusite, bauxite, chromite, sillimanite, zircon; as a foundry material: calcined bauxite and alumina, chromite, fireclay, perlite, pyrophyllite, silica sand, vermiculite and zircon and as a slag conditioner; dolomite.

Markets for new sources of olivine will be largely dependent on the iron and steel/ferrous and nonferrous foundries, which are driven by the economy and technological changes.

Yukon Occurrences

There are no commodity or mineralogical occurrences of olivine reported in Yukon Minfile 2001. Dunites have been mapped in the Kluane mafic-ultramafic belt (Hulbert, 1997) and on Dunite Mountain in the Quiet Lake area (105F). Other occurrences of fresh dunite could occur in ultramafic rocks described under deposit-types in Yukon Minfile 2001. However, careful sampling, chemical analyses and physical testing of collected samples would be required to assess their commercial potential for olivine applications.

Exploration Guidelines

Sampling and documentation should be made of fresh (LOI) deposits of unserpentinized dunite and peridotite (harzburgite) in mafic and ultramafic occurrences. Peridot should be prospected in and around the necks of Miocene basalts and basalt tephra (e.g. Mt. Timothy, Lightning Peak in British Columbia).

PEAT PEA

Chemical and Physical Characteristics

Peat is defined as "a heterogeneous mixture of more or less decomposed plant material and inorganic minerals that have accumulated in a water-saturated environment and in the absence of air. Its structure ranges from nearly pure plant remains, to a fine amorphic, colloidal mass" (Lappalainen and Sopo, 1998).

Deposit Example

Peat bogs occur throughout the Yukon; and in northern Canada subarctic and boreal regions; Fraser Delta, British Columbia, Rivière-du-Loup region on the south shore of the St. Lawrence River, Quebec (Canada); peat bogs (Ireland). Alberta, Saskatchewan and New Brunswick are important producers.

General Geology

Peatlands are situated predominately in shallow wetland areas of the Northern Hemisphere, where large deposits developed from the gradual decomposition of plant matter, under anaerobic conditions. They can be considered to be sedimentary rocks composed of slightly metamorphosed organic material (vegetation) with decomposition processes controlled by drainage and temperature. Peat, forms in waterlogged terrain, when the production of plant materials, exceeds the rate of decomposition. Examples of wetland conditions include fens, and bogs, and some swamps, marshes and open shallow water environments. In Canada, Peatlands cover approximately 12 percent of the total land area (Tarnocai, 1984).

Peat deposits are classified within organic and cryosolic orders (Canadian Soil Survey Committee, 1978). In order to be considered a deposit, a peat layer has to be at least 60 centimetres thick when the material is fibric, and 40 centimetres thick, if it is mesic or humic. Some deposits exceed ten metres but the average depth of peat deposits are from three to five metres in fens and bogs, to below three metres when associated with marshes.

World Production

World peat production was estimated at 27.4 million tonnes in 2000. Leading producers include Finland (7,400 tonnes), Ireland (5,500 tonnes), Germany (2,980 tonnes), Belarus (2,100 tonnes), Russia (2,000 tonnes), and Canada (1,229 tonnes) (Jasinski, 2000).

In the United States, the Alaska Department of Natural Resources estimates Alaskan peat production during 2001 was about 36,000 cubic yards (approximately 27,500 cubic metres), and worth an estimated US$180,000. The mining of peat in Alaska during 2001 employed 32 people with seasonal work (Swainbank and Szumigala, 2002).

Although Canada has an estimated 40 percent of the world's peat deposits, Canada produces only about 4.5 percent of the worlds supply. Of the estimated 1,229 million tonnes produced in 2000, all were used for horticultural purposes (Jasinski, 2000).

In 1997, sales of Canadian peat were valued at greater than $200 million dollars, creating more than

3000 person-years of employment, particularly in many rural communities where other employment opportunities, were limited (Hood, 2002).

Today more than eight million cubic metres of peat are produced in Canada, with most provinces contributing. Currently there are more than 60 companies producing horticultural-grade peat moss in Canada, although 90 percent of the production comes from only 14 producers. Of the amount produced, 78 percent of Canadian sphagnum peat moss is sold in the United States, and ten percent to Japan, with ten percent consumed domestically. About two percent is exported to Australia, the Caribbean, the Middle East and Southeast Asia (Hood, 2002).

End Use

Peat is an important source of energy in Ireland, Scandinavia and the former Soviet Union.

Sphagnum peat is also an important horticultural product. When added to a soil it increases its organic content and its ability to retain water and nutrients, and it improves aeration (Tarnocai, 1984).

In Canada, peat is used mainly in greenhouses, gardens, landscaping and in the manufacture of peat pots, pellets and growing plates. As long as liming, fertilizing and watering is done in a controlled environment (for example in a greenhouse), sphagnum peat is an excellent horticultural product. Sphagnum peat can also be used as an effective filtration and absorption agent because of its high surface area, porosity and exchange capacity. It has been used to remove suspended solids from effluents, and to chemically remove heavy metals, pigments and toxic materials from industrial effluents, as well as absorb oil spills.

Quality and Specifications

The most comprehensive and widely used system of classifying peat material is the modified von Post system illustrated in Table 70 in which peat is classified by using the recognizable features of the original plant constituents. The degree of humification, indicated by the letter "H" is divided into 10 categories ranging from living organic materials (non-humified) to fully humified organic material. The three main types are usually considered: fibric (von Post H1-4), mesic (von Post H5,6) and humic (von Post, H7-10).

Table 70

Modified von Post Classification for Peat

H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.
H2	Almost completely undecomposed peat which, when squeezed releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material is present.
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but for which no peat passes between the fingers. Plant remains are still identifiable, and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very muddy water with a very small amount of amorphous granular peat escaping between the fingers. The structure of plant remains is quite indistinct, although it is still possible to recognize certain features. The residue is strongly pasty.
H6	Moderately to strongly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is strongly pasty but shows the plant structure more distinctly, than before squeezing.
H7	Strongly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very strongly decomposed peat with a large quantity of amorphous material and very dry indistinct plant structure. When squeezed, about two thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
H9	Almost fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed, almost all of the peat escapes between the fingers as a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Source: adapted after Buteau, 2002

<u>Non-Energy Peat</u> - slightly humified, sphagnum peat (H1 to H4) because of its internal structure, has high water-holding capacity, high cation-exchange capacity, high pore space, relatively high permeability, compressibility and capability of retaining its original structure, even after compression to a tenth of its original volume.

<u>Energy Peat</u> - requires a high degree of humification, high bulk density, relatively low ash content, low content of potential pollutants such as sulphur, and high calorific value. Sphagnum peat, with a degree of humification of H4 or greater, and sedge peat with H3 humification, have the necessary characteristics, although dense well-decomposed peat of at least H5 is technically and economically superior (Maynard, 1988).

Market Trends

The outlook for horticulture and its associated business is bright because of global demand for plants, flowers, ornamental trees, and natural turf. The outlook for the North American peat industry will likely be governed by several variables, including future wetland environmental regulations, the ability to permit new bogs, growth and competition from recycled yard wastes, and other natural organic materials. The overall viability of the greenhouse industry will have an impact on peat production. As well, domestic competition within the peat industry and the degree of market penetration with flowers and ornamental plants from abroad, will affect the growth of the industry in North America (Jasinski, 2000).

The Canadian peat industry appears to have a bright future with the development and production of value-added products such as composting materials, biofilters and organo-mineral fertilizers, and the development of new harvesting systems. Of great importance is a commitment by the industry to develop a progressive and innovative environmental policy that leads to a modern and sustainable industry (Buteau, 2002).

Plate 6. Peat Bog Located Approximately 30 Kilometres West of Whitehorse Near the Alaska Highway Pla6

Price

The U.S. Geological Survey reported the average unit value per tonne of peat was at US$26.85 in 2000. Packed peat sold at a higher value. On a unit-value basis, packaged sphagnum moss was valued at US$68.42 per ton, f.o.b. plant; hypnum moss, US$52.47 per ton; reed-sedge, US$24.33; and humus, US$17.86 per ton.

Economic Factors

The U.S. Department of Energy defines fuel grade peat as having an energy value of at least 8000 BTU (4440 kilocalories/kilogram), containing less than 25 percent ash. These deposits are at least 1.5 metres deep and cover an area of 80 contiguous acres per square mile (12.5 hectares per square kilometre).

Mining can be carried out by either dry or wet methods. Extensive site preparation, such as draining and grading must be done before the dry methods (milled and sod mining) can be used. Climate greatly affects this method because field drying is required to produce peat containing between 25 to 50 percent moisture. Wet mining requires less site preparation, because there is little movement of equipment on the peatland surface.

The feasibility of mining peat is highly dependent on climatic factors such as precipitation, temperature, amount of sunshine, wind, and length of frost-free periods. Amount and distribution of rainfall are important especially for dry mining methods, where long dry periods are needed to operate. Temperature and amount of sunshine have direct implications for field drying of milled peat. Steady, moderate winds are most favourable for evaporation. The duration of the frost-free period, is an indication of the length of the peat production period, provided other climatic parameters are favourable. Perennially frozen peatlands are often difficult to work, using existing mining techniques (Maynard, 1988).

Environmental Considerations - two obvious environmental considerations regarding the development of peat deposits for commercial use must be considered. They include the effect of draining peatlands on the water table and the subsequent change of habitat. Developers need to assess these and other environmental factors through the use of environmental impact studies, prior to development (Maynard, 1988). Experience from New Brunswick indicates that a depleted peat bog can regenerate itself within a couple of decades.

Yukon Occurrences

There has never been a comprehensive systematic study of potential commercial peat resources in the Yukon. In 1997, a National Wetland Classification System identified four wetland/peatland regions in the Yukon, which might host commercially significant peat deposits (Table 71).

Table 71

Wetland/Peatlands Found in the Yukon	
Low Arctic	**Low and high center lowland polygons.** Polygonal peatlands overlay shallow deposits of mesic sedges and brown moss peat with the average thickness of high centre polygon deposits (bogs) being up to 1.5 metres. Low centered polygons remain below 0.5 metres (fens). Peat mound bogs are rather small, and found in minerotrophic environments. The peat thickness can reach up to 1.5 metres and the active layer can be 0.4 metres deep. The upper peat layer is formed by fibric sphagnum material, and the lower one by mesic brown moss and sedge remains. Basin fens will occupy large depressions in which mesic sedge peat deposits averaging one metres depth, can be found. Finally, mesic sedge peat layers of 0.2 metres will occur under snowpatch fens.
Low Subarctic	**Peat plateaus; palsas; ribbed and horizontal fens.** Peat deposits underlying peat plateau bogs and polygonal peat plateau bogs have an average thickness of two metres. Upper peat layers are formed by fibric sphagnum remains, while lower layers gradually change from mesic to almost humic material, with remains of sedges and different brown mosses. Palsas bogs are in the range of 100 metres in diameter and can reach up to seven metres in height. The peat deposit thickness averages around 2.5 metres with an active peat layer of up to 0.5 metres. Northern ribbed fens are characterized by small peat deposits (<2.0 metres) of carex peat.

Table 71 (cont'd)

High Boreal	**Domed, flat, basin and plateau bogs; horizontal and ribbed fens.** The typical pattern shows an upper layer of fibric peat, followed by a mesic one and a humic layer at the base of the deposit. The average depth of the deposit is also quite constant. All the fens have an average depth of about 1.5 to 2.0 metres, while bogs, can reach up to 3.5 metres. The maximum depth of peat deposits is in the range of six metres for fens, and 11 metres for bogs.
Pacific	**Flat and basin bogs; horizontal and ribbed fens.** Basin bogs are characterized by a very complex peat accumulation process. The thickness of the deposits varies from 2-10 metres. The shore bogs and floating bogs occur at the margin of small lakes. They are quite common and extensive, with peat depths of up to two metres. Flat bogs are associated with mesic sphagnum deposits (1.5 metres in average thickness), and domed bogs with fibric sphagnum deposits overlying woody peat. Sedge peat can range between 3-4 metres thick.

Source: adapted after Buteau, pgs. 278-282

Exploration Guidelines

Assessing peatlands can be carried out at various levels of detail (Table 72).

Table 72

Levels of Investigation for Peat Resource Assessments (after Monenco Ontario Ltd., 1981)	
Level 1	**Preliminary Peatland Survey Using Maps and Information from Literature** Purpose is to provide preliminary maps of peatland distribution everywhere that resource surveys have been carried out. Characteristics and quality of peat can be obtained from existing literature.
Level 2	**Peat and Peatland Survey by Aerial Photography and Other Remote Sensing Techniques** Purpose is to identify all peat deposits by using aerial photographs as the main source of information. There are two uses for this level of inventory: small-scale photography can be used to map peatlands in areas where no other inventory data exists; and larger scale photography can be used to gather more detailed information on peatlands mapped at Level 1. Photo-interpretation combined with selective field checking, provides data to infer ranges of peat thickness and distribution of peat types which can be used to calculate preliminary figures on the overall peat resource.
Level 3	**Detailed Ground Surveys** Purpose of this step is to select a number of deposits for final development. It usually follows a Level 2 survey (but may be done concurrently) and concentrates on areas found suitable for further investigation. Work involves sampling on a semi-detailed grid pattern to obtain data relating to the suitability of the deposit for development. Information collected includes size of deposit, distribution, quantities and qualities of peat types, basic chemical and physical properties, and drainability. Access and land ownership are also important factors to determine at this stage.
Level 4	**Site-specific, Project-orientated Assessments** Purpose is to establish a proper drainage plan and the most efficient mining plan. Work involves a detailed grid sampling assessment of peat thickness and distribution of peat types and an accurate surface elevation survey. A large number of samples (e.g. one core per 10 hectares) needs to be taken for chemical and physical analyses, to facilitate the planning of the mining sequence.

(adapted after Maynard, 1988)

PERLITE PER

Chemical and Physical Characteristics

Classical perlite is a hydrated ryholitic volcanic glass, usually with a pearly, vitreous luster, grey to bluish-black and a characteristic concentric or "onionskin" fracture. Granular perlite, common in high-volume commercial deposits, is lighter than the more classical perlite, which is microvesicular, highly fractured and white to grey in colour. Perlite is distinguished from other hydrous volcanic glasses such as obsidian, pumicite and volcanic ash by a relatively high combined water content of between two and five percent. When heated to temperatures of around 510ºC, perlite will expand to form a white, porous, lightweight material. When crushed then heated quickly to higher temperatures of between 900ºC to 1100ºC, perlite can expand up to 20-40 times its original volume.

Deposit Examples

Frenier deposit (BC Minfile 0920 072), Francois Lake (BC Minfile 093K 001), British Columbia (Canada).

General Geology

Perlite is one of the natural volcanic glasses that contain waters in excess of the original magmatic amount. It is a hydrated volcanic glass formed by the weathering of obsidian by gradual incorporation of ground water into the high-silica glass (Austin and Barker, 1998). Because of its relative instability, most perlite deposits are less than 50 million years old ranging from Tertiary to Quaternary in age. A typical commercial deposit of perlite may have a variety of textures with grading ranging from pumicious to obsidian. This grading is thought to be related to depth of burial and consequential cooling history.

World Production

Estimated world production of mined perlite during 2001 was 1,710,000 tonnes with the United States (588,000 tonnes), Greece (360,000 tonnes), Japan (250,000 tonnes), Hungary (150,000 tonnes), and Turkey (150,000 tonnes) being the largest producers. However, owing to a lack of reliable figures, the world total does not include several producing countries such as China, which was probably the largest or second largest producer in the world during 2001(Bolen, 2001).

Presently, Canada has no producing perlite mines and imports are largely from the United States with American imports estimated at 43,000 tonnes during 2000 (Bolen, 2002).

Market Trends

The total consumption of expanded and processed perlite in the United States is expected to slightly increase during 2002. The demand in Canada for horticultural perlite is expected to grow although new mines have opened over the last 5 years in the United States. This will likely restrain price increases for most grades of processed perlite (Bolen, 2001).

A market study prepared by for the British Columbia Geological Survey in 1994, concluded that markets for expanded perlite in Western Canada and the U.S. Pacific Northwest were stable and that there would continue to be a strong regional demand for high-quality raw perlite ore. The study estimated a total market use of 44,700 tonnes per year in the region, at an estimated value of C$5.4 million (Gunning et al, 1994).

End Use

Perlite, mostly in its expanded form, is used in a variety of construction, horticultural and manufacturing processes such as high-to-medium-temperature insulation, lightweight aggregate, in fillers, soil conditioners, filter aids and as a carrier for agrochemicals in pesticides and herbicides. End use is dependent on the expanded mineral’s properties of low bulk density, high brightness, chemical inertness, high absorption, low conductivity and non-flammability.

In the United States, the largest segment (69 percent) of the market for expanded perlite exists in construction end products such as insulating board, acoustical ceiling tile and pipe insulation (Austin and Barker, 1998).

Quality and Specifications

To maintain industry quality and performance standards, perlite is classified according to results from a series of chemical and physical tests established by the Perlite Institute and the American Society for Testing Materials International (ASTMI). Testing includes sieve analysis of fine materials, fractional density of expanded perlite, testing for pH, furnace yield, percent non-expandable and perlite ore expandability. Physical tests that would normally be performed in establishing expanded perlite product quality, include expanded bulk density, furnace yield, dry brightness, sieve analysis and percent non-expandable. Specialized tests include compacted density and compaction resistance.

Tables 73 and 74 illustrate the chemical analysis of perlite and processed properties of a commercial grade perlite.

Table 73

Chemical Analyses of the Typical Perlite

	Typical Perlite*	Frenier Deposit**
SiO2	71-75%	71-78%
Al2O3	12.5-18%	11-14%
K2O	4-5%	4-5%
Na2O	2.9-4%	1-3%
CaO	0.5-2%	0.5-1.5%
Fe2O3	0.5-1.5%	N/A
MgO	0.1-0.5%	0.01-0.5%

Source: adapted after White, 2002

** Perlite Institute Inc. presented as an indication of the analyses that can be expected from a commercially operated perlite deposit. ** Aurun Mines Ltd. product information bulletin 111-P.*

Table 74

Typical Processed Frenier Perlite (trade name "Aurolite")*

Form	Fine granulites
Colour	White (brightness = 750)
Size	4 mesh (4.8mm) and finer
Refractive index	1.5
True density	2.3g/cc (140pcf)
Bulk density	0.04-0.16 g/cc (2.5-10pcf)
Softening point	870-1090ºC
Fusion point	1260-1340ºC
Specific heat	840J/Kg deg.K
Thermal conductivity	0.04W/m deg.K
Solubles, water	<0.1%

*Source: White, 2002 * Aurun Mines Ltd. Product Information Bulletin 111P.*

Price

During 2001, processed perlite sold at an average value of US$36.53 per tonne. The average price for expanded perlite was US$211 per ton during the same period. By use, the average prices per ton during 2001 were fillers (US$404 per ton), cavity fill insulation (US$365 per ton), low-temperature insulation (US$363 per ton), and for use as a filter aid is (US$321 per ton), (Bolen, 2001).

Economic Factors

The Frenier deposit located near Clinton, in south central British Columbia operated from 1983 to 1986 producing a total of 6,500 tonnes of perlite. Company reports indicate proven reserves of perlite at 450,000 tonnes and probable and possible reserves exceeding one million tonnes. This type and size of deposit is a good exploration target for the Yukon. Importantly, because perlite is a relatively low value product, any deposits located in the Yukon would almost certainly need to be located near an established infrastructure, in order to be economical.

Yukon Occurrences

There are no perlite or volcanic glass occurrences reported in Yukon Minfile 2001. However there are Tertiary to Quaternary volcanic rocks exposed throughout the Yukon (Wheeler and McFeely, 1991) and a systematic investigation of these flows could determine their potential, as a source of perlite.

Exploration Guidelines

Units equivalent to British Columbia Eocene rhyolite-dacite-anesite volcanics are potential perlite hosts. A good prospecting technique when exploring for perlite is to test Tertiary to Quaternary volcanic glass occurrences for their expandability properties. This can be simply done by heating ground perlite with a portable propane torch and noting its expandability. Good quality perlite will expand up to 15-20 times its original volume, when heated using this technique.

PHOSPHATE PHO

Chemical and Physical Characteristics

Phosphate rocks are a primary source of the essential agricultural nutrient phosphorus (P).

Phosphate rock deposits are concentrations of calcium phosphates. The phosphate mineral is one of the members of the fluorapatite-chlorapatite-hydroxylapatite series, with a general formula $Ca_5(PO_4.CO_3)3$ (F,OH,Cl). It may be igneous or sedimentary.

Apatite ($3CaP_2O_8CaF_2$) is the most common mineral group of phosphate minerals. A generally green mineral found in all rock types (igneous, sedimentary and metamorphic), apatite occurs in hexagonal, prismatic crystals in granular masses in igneous rocks and colloform and botryoidal crusts in sediments. Apatite is hard (5), heavy (SG3.16-3.22), transparent to opaque with a vitreous to subresinous lustre. It varies considerably in colour from yellow, green, brown, occasionally red or blue, to colourless. The colour is often due to the presence of rare earth elements, of which certain apatite deposits are a significant source.

Guano deposits consist of bird droppings with commercially exploitable deposits containing 70 to 90 percent phosphate of lime.

Deposit Examples

Phosphatic iron formation: Road River Group, Rapid Creek-Big Fish River phosphatic iron formation, Blow River Formation, Richardson Mountains, northern Yukon; Apatite deposits, Grenville terrain of eastern Ontario and southwestern Quebec; apatite deposits in carbonatite complexes, Ontario and Quebec, Sedimentary deposits, Fernie Formation, British Columbia (Canada); Sedimentary Marine Phosphorites: Hardee County, Florida, North Carolina, Idaho, (United States); apatite from the Palabora carbonatite, (South Africa); Hubei Province, (China); Guanos of Nauru, Ocean, Angaur and Makatea Islands.

General Geology

Phosphate is produced from three sources: marine sedimentary deposits, igneous apatite (carbonatites and related alkaline intrusions) and guano-derived deposits resulting from the accumulation of corpolites. Approximately 80 percent of phosphate production is from bedded sedimentary rocks and most of the balance is from alkaline igneous rocks or carbonatites (Butrenchuk 1987).

Phosphate rock - The term phosphate rock applies to any rock containing more than 20 percent P_2O_5, and deposits consisting of residual concentrations of phosphates. One of the most important types of sedimentary deposits are 'land pebble' deposits which result from the marine reworking of phosphatic limestone, to produce resistant phosphate pebbles that accumulate in gravel beds. Such deposits occur in Florida and supply most of the United State's phosphate demand. Phosphatic marls and limestone are sedimentary beds with high phosphate content. They are usually of too low a grade for commercial exploitation, but may be used locally for fertilizer. Marine phosphate beds are chemical accumulations of phosphate formed in enclosed marine basins. They occur in the western United States and are important commercially. Non-commercial but similar deposits are in the Fernie area of southeastern British Columbia.

Apatite - deposits are concentrations of the mineral apatite which may occur in pegmatites and veins, in carbonate-alkaline(carbonatite) complexes, and in magmatic segregations in gabbro and nephelinites.

Weathering of low-grade accumulations may result in residual deposits of commercial interest (e.g. Cargill deposit, Ontario).

Guano - deposits are formed when phosphatic solutions from bird droppings react with coral to form tricalcic phosphate. The phosphates accumulate in hollows between pinnacles of resistant coral rock (Downing, 1993).

World Production

Annual global production of phosphate rock during 2001 was estimated at 128 million tonnes with the three leading producers consisting of the United States (34.2 million tonnes), Morocco and Western Sahara (22 million tonnes) and China (20 million tonnes) (Jasinski, 2002).

End-Use

Phosphates are used to manufacture wet-process phosphoric acid and superphosphoric acid, which are used as intermediates in the manufacture of granular and liquid ammonium phosphate fertilizers and animal feed supplements. More than 50 percent of the wet-process phosphoric acid produced, is used in the form of upgraded granual diammonium and monammonium phosphate fertilizer, triple superphosphate fertilizer, and merchant grade phosphoric acid. Elemental phosphorus is also used to produce high-purity phosphoric acid and phosphorus compounds, these are used in a variety of industrial and food-additive applications.

Quality and Specifications

The purity of mined phosphates is graded according to either the bone phosphate of lime (BPL-tricalcium phosphate) content or the P_2O_5 content, which ranges from 4 to 42 percent. The percentage of P_2O_5 content can be calculated by multiplying the BPL percentage by 0.4576; while BPL can be calculated by multiplying the P_2O_5 percentage by 2.1853.

The P_2O_5 content is the main method for quantifying grade. Table 75 illustrates the chemical composition of some commercial phosphate concentrates.

Table 75

Chemical Composition of Some Commercial Phosphate Concentrates (%)

	Florida, USA 77% BPL Sedimentary	***Idaho, USA Sedimentary***	***Finland Siilinjärvi Igneous***	***Brazil Goiasfertil Igneous***	***Nauru Calcined Guano***
P2O5	35.31	32.3	35.3	37.04	39.92
CaO	50.10	45.85	N/A	49.77	54.42
CO2	2.98	2.1	6.9	0.86	2.04
MgO	0.23	0.17	1.3	0.16	-
K2O	0.08	0.61	0.04		Trace
Na2O3	0.4	0.46	0.1		0.45
Al2O3	1.02	2.13	0.2	0.54	
Fe2O3	1.03	0.95	0.5	2.39	
SiO2	3.05	9.87	0.5	1.66	0.4
F	3.87	2.99	2.5	2.02	2.62
SO3				0.16	
SrO				0.96	
BaO				1.05	
TiO2				1.84	

Source: adapted after The Industrial Minerals HandyBook II, pg. 132

Market Trends

More than 90 percent of phosphate rock is consumed for fertilizer and used in animal feed supplements. World demand for phosphate fertilizers will continue to expand in relation to increased world population and food requirements, with the largest growth occurring in the developing nations. For the 2002 to 2005 period, phosphate consumption is expected to increase by 3.6 percent annually (Janinski, 2002).

Price

Industrial Minerals, No. 419 reported the following prices for phosphates during August 2002.

- Morocco, 75-77% BPL, FAS Casablanca US$48.50
- Morocco, 70-72% BPL, FAS Casablanca US$46
- Tunisia, 65-68% BPL, FAS Sfax US$30-33

Economic Factors

Both sedimentary and igneous deposits of phosphate have widely differing mineralogical, textural and chemical characteristics. Sedimentary phosphate deposits generally contain higher impurity levels - especially toxic elements such as cadmium and arsenic. The rock is typically 26 to 31 percent P_2O_5.

With more than 90 percent of all phosphate rock mined in the United States being used in fertilizer and in animal feed supplements, agricultural demand dictates the direction of this industry.

Yukon Occurrences

Phosphate minerals were first identified in the Richardson Mountains (NTS 117A) in 1962 by F.A. Campbell, who identified lazulite (now Yukon's official gemstone) from specimens that were collected by B. Cameron from creek gravels at the junction of Blow River and Rapid Creek.

These minerals contained in the Rapid Creek Formation, are described by Young and Robertson (1984), as an unusual sedimentary phosphatic iron formation that comprises the upper and youngest portion of the Lower Cretaceous flyschoid sequence. The phosphate was deposited in the Blow Trough, a straight or arm of the ancient seas, which extended southward from the Arctic Beaufort-Mackenzie Basin between the rising Old Crow Landmass on the west and the Cache Creek High on the east. It may have been connected with the Pacific waters to the south and west (Young and Robertson, 1984).

The Rapid Creek phosphatic iron formation in the Richardson Mountains consists of cyclicly interbedded Lower Cretaceous sideritic mudstones and shales, montmorillonitic shales, phosphatic mudstones, pelletal phosphorites and carbonates, which were deposited in a shallow marine environment. Sections containing numerous siderite beds are up to 450 metres thick, and contain 15 to 25 percent iron and 13 percent P_2O_5. Some individual layers contain up to 20 percent P_2O_5. The major phosphate minerals are satterleyite, and arrojadite. Phosphate mineralization at the Big Fish River area is confined to recrystallized spherulitic replacements of ammonites and pelecypods and oblate concretionary phosphate nodules.

In Yukon Minfile 2001, three major phosphate occurrences are reported which include the DRIFTWOOD phosphate/strontium occurrence (Minfile 116O 059) as being underlain by Ordovician to Lower Devonian Road River Group shale. Samples at site, assayed up to 12.4 percent P_2O_5. No reserve estimates were given. Also documented in Minfile were the BIG FISH deposit (Minfile 117A 038), and RAPID deposit (Minfile 117A 027), described as hosting siderite and phosphatic ironstone in shales of the Rapid Creek Formation. Assayed samples from both deposits reported grades of 14 percent P_2O_5. Reserve estimates were not available.

Exploration Guidelines

For sedimentary phosphate deposits, exploration should be done and evaluations made of concentrations of rock phosphates (of greater than 20 percent P_2O_5) in sedimentary units, (i.e., the Rapid Creek phosphatic iron formation).

For igneous sources of phosphate, evaluation of carbonatites for apatite content should be made. Geochemical signatures may include concentrations of phosphate minerals in soils and stream sediments. Magnetic and radiometric expression and anomalous radon gas concentrations may indicate primary targets (guidelines for locating carbonatites are discussed under Rare Earth in this report). A basic indication of phosphate presence is a bluish-white staining on outcrops of sediments.

Apatite in placer deposits may also be indicative of phosphate deposits.

POTASH POT

Chemical and Physical Characteristics

The term potash denotes a variety of mined and manufactured salts, all containing the element potassium (K) in water-soluble form. The main commercial potash minerals are illustrated below in Table 76.

Table 76

Main Commercial Potash Minerals

Mineral	*Formula*	*K*	*KCl*	*K_2O*
Carnallite	$KCl\cdot MgCl_2\cdot 6H_2O$	14.07	26.83	16.95
Kainite	$4KCl\cdot 4MgSO_4\cdot 11H_2O$	15.71	29.94	19.26
Polyhalite	$K_2SO_4\cdot MgSO_4\cdot 2CaSO_4\cdot 2H_2O$	12.97	-	15.62
Sylvite	KCl	52.44	100	63.17
Sylvinite	KCl+NaCl	-	-	10-35
Langbeinite	$K_2SO_4\cdot 2MgSO_4$	18.84	-	22.69

These minerals are often intercrystallized and mixed with other evaporite minerals, including halite (NaCl), anhydrite or gypsum ($CaSO_4$) and epsomite ($MgSO_4\cdot 2H_2O$).

Deposit Examples

Williston Basin, Saskatchewan; Kings County, New Brunswick, (Canada); Southeastern New Mexico (United States); Qaidam Basin, Qinghai Province, (China); Pozo Almonte, (Chile); Stassfurt, (Germany).

General Geology

Potassium is present in most rocks in combination with aluminum and silica as orthoclase feldspars, and as muscovite and biotite micas. Feldspars are readily weathered. The released potassium is carried away in solution to the sea. Evaporation of sea-water in enclosed basins, results in the concentration of the chlorides and sulphates of potassium and magnesium as saline residues. In Canada for example, the potash deposits in the Williston basin of southern Saskatchewan consist of the main potassium minerals sylvite (potassium chloride), kainite (potassium chloride and magnesium sulphate), and polyhalite (sulphate of potassium, magnesium and calcium) in association with thick beds of rock salt and gypsum/anhydrite.

Potash is also recovered from brines of the Dead Sea, from the Searles Marsh in California and from the Saldura Marsh, in Utah.

World Production

Estimated world resources of potash, total more than 250 billion tonnes. During 2001, the estimated total world production was 25.3 million tones, with Canada, the world's largest producer, supplying an estimated 8.8 million tonnes (Searls, 2002).

End Use

Potash is primarily (approximately 95 percent) used as an agricultural fertilizer (plant nutrient) because it is a source of soluble potassium, one of the three primary plant nutrients (the other nutrients are fixed nitrogen and soluble phosphorous).

Potassium chloride, sourced from sylvite, and also known as muriate of potash (MOP), is the most common source of potassium for fertilizers. It has a K_2O content of 60 percent minimum. Other forms of potash include potassium sulphate (sulphate of potash), with a 50 to 54 percent K_2O content; potassium magnesium sulphate (sulphate of potash-magnesia), with a 22 to 30 percent K_2O content; potassium nitrate with a 46 to 47 percent K_2O content; and potassium carbonate. Some of their end uses are illustrated below in Table 77.

Table 77

Potash- End Use

Potassium sulphate	***Medicine, glass, accelerator for gypsum products, food preservatives, bleaching agent.***
Potassium nitrate	Explosives, pyrotechnics, glass and ceramics, plastics.
Caustic potash	Batteries, soaps, textile bleaching, printing inks, water treatment.
Potassium permanganate	Bleach, catalysts, saccharin manufacture, zinc refining.
Potassium carbonate	Specialty glass, e.g. television tubes, optical glass.

Quality and Specifications

Potash concentrations are based on K_2O content derived from the following calculations:

$$KCl \times 0.61 = K_2O$$

$$K_2O \times 1.64 = KCl$$

$$K_2O \times 1.2046 = K$$

Tables 78 and 79 illustrate potash products and the K_2O content of different grades of potash (adapted after The Industrial Minerals HandyBook II, pgs. 135, 136).

Table 78

Potash Products

Fertilizer	***Nutrient Content***	***Source/Production***
Potassium Chloride KCl Chloride or Muriate of Potash (MOP)	60-62% K_2O	Natural product is sylvite (KCl)
Potassium Sulphate K_2SO_4 Sulphate of Potash and Magnesia (SOPM)	50-53% K_2O	Reacting potassium chlorite with various sulphate-bearing minerals such as langeinite ($2MgSO_4 \cdot K_2SO_4$) in New Mexico and Kieserite ($MgSO_4 \cdot H_2O$) in Germany or with sulphuric acid.
Potassium Nitrate KNO_3	44-46% K_2O	Produced synthetically
Potassium Magnesium Sulphate $K_2SO_4 \cdot MgSO_4$ SOPM	22% K_2O 18% MgO 22% S	Natural product is langbeinite

Table 79

K_2O Content of Different Grades of Potash

Grade	*Min. K_2O equivalent wt %*	*Mesh (Tyler)*	*Millimetres*	*Type of potash*
Granular	61, 50, 22	-6 to +20	3.35-0.85	Muriate and sulphates
Blend	60	-6 to +14	3.35-1.18	Muriate
Coarse	60	-8 to +28	2.4-0.6	Muriate
Standard	60, 50, 22	-28 to +65	1.2-0.21	Muriate and sulphates
Special Standardized	60	-35 to +150	0.4-0.11	Muriate and sulphates
Soluble/Suspension	62	-35 to +150	0.4-0.11	Muriate
Chemical	63	N/A	N/A	Muriate

Market Trends

Demand for potash depends on the health of agriculture industries in the developed countries with large-scale operations like those in Canada and the United States.

Based on data from the first half of 2001, potash consumption in Asia, Europe, and North America declined between four to nine percent, while potash consumption in Africa, the Middle East and Latin America (which used about 22 percent of total world consumption) increased to between eight to ten percent. However, the use of fertilizers will increase over the long-term with population growth, and the need for more efficient food production and nutrient balance (Searls, 2002).

Price

Industrial Minerals No. 419 reported the following prices for potash in August 2002:

- Muriate of potash, bulk, 60%K2O Std, CIF UK port £86-89
  Granular, CIF UK port £101-105
  Std, FOB Vancouver US$128
- FOB Saskatchewan, bulk, s ton,
  Standard US$85; Coarse US$88; Granular US$90
- FOB Carlsbad, bulk, s ton,
  Coarse US$95; Granular US$101

Economic Factors

There are no substitutes for potassium as an essential plant nutrient. Manure and glauconite are low-potassium-content sources that can be profitably transported only short distances to the crop fields.

Yukon Occurrences

There are no reported potash deposits in Yukon Minfile 2001. There is virtually no possibility of deposits occurring in the Yukon as the environmental conditions required to form deposits have not occurred.

RARE EARTH ELEMENTS RAR

Chemical and Physical Characteristics

The Rare Earth Elements (REE) are a moderately abundant group of 17 elements which include scandium, yttrium, and 15 lanthanides.

Lanthanides comprise a group of 15 elements with atomic number 57 through 71 that include the lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Cerium, is more abundant than copper (with an average concentration in the Earth's crust of 50 ppm). Cerium is the most abundant member of the group at 60 ppm, followed by Yttrium at 33 ppm however, they rarely make economic concentrations. Generally, Ce and Y minerals are disseminated in some intrusive rocks, and they may occasionally be concentrated in some placer deposits.

The principal economic rare-earth ores are lateritic ion-absorption clays and the minerals bastnäsite, loparite, and monazite.

Scandium (Sc), whose atomic number is 21, is the lightest rare-earth element. It is the 31st most abundant element in the Earth's crust, with an average crustal abundance of 22 ppm. Scandium is a soft, lightweight, silvery-white metal, similar in appearance and weight to aluminum. It is represented by the chemical symbol Sc, and has one naturally occurring isotope.

Yttrium (Y), whose atomic number is 39, is chemically similar to the lanthanides and often occurs in the same minerals, as a result of its similar ionic radius. It is represented by the chemical symbol Y and has one naturally occurring isotope. Yttrium's average concentration in the Earth's crust is 33ppm and is the second most abundant rare earth, in the Earth's crust. Yttrium is a bright silvery metal that is soft and malleable, similar in density to titanium.

Deposit Examples

Magmatic (Carbonatites): Aley (REE, niobium, 094B027), British Columbia, (Canada); Mountain Pass, REE, California, (United States); Palabora (apatite), (South Africa).

Replacement Veins: Rock Canyon Creek, (Fluorite, REE 082JSW018), British Columbia, Canada; Bayan Obo (REE), China;

Residual: Araxa, Catalao and Tapira (niobium, phosphate, REE, Ti), Brazil.

Placer: By-product of garnet, ilmenite and cassiterite mining.

General Geology

Carbonatite-Associated Deposits (magmatic, replacement and residual)

Carbonatites are igneous rocks with greater than 50 percent carbonate minerals. They range in age from early Precambrian to Recent, and intrude all classifications of rocks at varying depths. In the Canadian cordillera, carbonatites are mostly upper Devonian, Mississippian or Eocambrian in age. They are usually associated with continental environments, and rarely oceanic environments (as in the Canary Islands) and are thought to be related to large-scale, intra-plate fractures, grabens or rifts that correlate with periods of extension, and may be associated with broad zones of epeirogenic uplift.

Typically, carbonatites occur as dikes or plugs with subcircular or elliptical cross sections and can be up to three to four kilometres in diameter. Intrusive carbonatites occur commonly within alkalic complexes or as isolated sills, dikes or small plugs that may not be associated with other alkaline rocks. Carbonatites may also occur as lava flows and pyroclastic rocks however these do not host economic deposits of REE. Only intrusive carbonatites are associated with economic concentrations of REE which can occur as either primary igneous minerals, replacement deposits (veins) or as residual weathering accumulations from either igneous or replacement, deposits. Host rocks include calcite carbonatite (sovite), dolomite carbonatite (beforsite), ferroan or ankeritic calcite-rich carbonatite (ferrocarbonatite), magnetite-olivine-apatite ± phlogopite rock, nephelinite, syenite, pyroxenite, and peridotite.

Ore mineralogy for magmatic deposits may consist of bastnäesite, pyrochlore, apatite, anatase, zircon, baddeleyite, magnetite, monazite, parisite and fersmite. Replacement vein mineralogy includes fluorite, vermiculite, bornite, chalcopyrite and other sulphides, and hematite. Residual deposits include anatase, monazite, xenotime, pyrochlore and apatite. Intrusive deposits are a result of fractional crystallization with tectonic and local structural controls influencing the forms of metasomatic mineralization. The depth of weathering and drainage patterns control residual deposits.

Rare-earth elements and Yttrium are concentrated in all alkaline rocks. In carbonatites they are present mainly in the form of the cerium subgroup, or light rare earths. Concentrations of rare-earth elements may be contained in common minerals such as calcite, dolomite, pyrochlore, fluorite, apatite, sphene and zircon. Rare-earth carbonate and fluorocarbonate minerals such as bastnäesite and parisite, or phosphate minerals such as monazite or xenotime, may also be present in alkaline suites and contain rare-earth elements. Yttrrium, although not strictly a rare earth, is commonly grouped with them since its chemical properties are similar to the heavy rare earths. Uranium ores and some phosphates may also be anomalous in heavy REE and Y concentrates.

Commercial production of rare-earth elements is from primary bastnäesite, monazite placers and beach sands, primary monazite, carbonatite occurrences, uranium ores and phosphatic rocks.

Associated deposit types include nepheline and sodalite syenite. REE and zircon placer deposits can be derived from practically all intrusive rocks. Wollastonite occurrences are in some cases reported in association with carbonatites. Kimberlites and lamproites (common host rocks for diamond) may occur along the same tectonic features as carbonatites, but are not related to the same magmatic event.

Carbonatites should be evaluated for a variety of mineral substances as illustrated by the Palabora carbonatite which provides phosphate (primary and possibly hydrothermal), Cu (hydrothermal), vermiculite (alteration) and also Zr, U, and Th as byproducts.

While extrusive carbonatite rocks are known to contain anomalous REE values, like the Mount Grace pyroclastic carbonatite in British Columbia, they are not known to host REE in economic concentrations (Birkett and Simandl, 1999).

World Production

World mine production of rare earth during 2001 was estimated at 85,500 tonnes with leading producers including China (75,000 tonnes), the United States (5,000 tonnes), India (2,700 tonnes), Commonwealth of Independent States (former USSR) (2,000), Malaysia (450 tonnes), and Sri Lanka (120 tonnes). Currently, one mining operation in California accounts for all North American production of rare earth elements. Molycorp, a wholly owned subsidiary of Unocal Corporation, mined bastnäesite, a rare earth fluorocarbonate mineral, by open pit methods at Mountain Pass, located in California (Hedrick, 2002).

End Use

Rare earth elements (REE) have a variety of applications as illustrated in Table 80 (adapted from The Industrial Minerals Handybook II, pg. 147).

Table 80

Major Uses of Rare Earth Elements

	Mixed REE	*La*	*Ce*	*Pr*	*Nd*	*Pm*	*Sm*	*Eu*	*Gd*	*Tb*	*Dy*	*Ho*	*Er*	*Tm*	*Yb*	*Lu*	*Y*
Metallurgy, ferrous	X	X	X														X
Metallurgy, nonferrous	X	X	X	X	X			X									X
Magnets	X	X	X	X	X		X		X								X
Ceramics	X	X	X	X					X				X				X
Electronics	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X
Metallurgical Catalysts	X	X	X		X		X		X		X				X		X
Catalysts	X	X	X		X		X		X						X		
Optical	X	X	X	X	X	X	X	X	X	X		X	X	X			X
Medical							X	X	X	X				X			X
Pharmaceuticals		X	X		X				X					X			
Nuclear fuel			X														
Nuclear control and shielding			X				X	X	X		X	X					X
Hydrogen storage		X	X	X	X												
Crygenics		X															
Batteries		X			X												X

Quality and Specifications

Ore and product grade are variable and measured in rare-earth oxide (REO) and/or Y_2O_3 content as illustrated in Table 81.

Table 81

Quality and Specifications of Ore and Product Grade Rare Earths

Bastnasite	Contains 60% unleached, 70% leached and 90% leached and calcined REO.
Monazite	Contains 55%, 60% or 66% REO.
Xenotime (Yttrium Group)	Has a minimum of 25% Y2O3 concentrate which may be upgraded to yttrium concentrate with minimum 60% Y2O3.
Products include mixed rare earth chlorides (minimum 45% REO), mixed rare earth fluoride (minimum 78% REO), mixed rare earth oxide (minimum 96% REO).	From these concentrates the individual rare-earths are separated to form compounds such as the acetate, carbonate, nitrate, oxalate and sulphate alloys such as mischmetal.

Source: Industrial Minerals HandyBook II, pg. 149

Table 82 illustrates rare earth contents in bastnasite, monazite, xenotime and rare earth laterite minerals.

Table 82

Rare Earth Contents of Major and Potential Source Materials

Rare Earth	*Bastnasite, Mountain Pass, CA, USA*	*Monazite, North Capel, Western Australia*	*Xenotime, southeast Guangdong, China*	*Rare earth laterite, Longnan Jiangxi Province, China*
Cerium	49.10	46.00	3.00	0.4000
Dysprosium	Trace	0.7000	9.10	6.70
Erbium	Trace	0.2000	5.60	4.90
Europium	0.1000	0.0530	0.2000	0.10
Gadolinium	0.2000	1.49	5.00	6.90
Holmium	Trace	0.0530	2.60	1.60
Lanthanum	33.20	23.90	1.20	1.82
Lutetium	Trace	Trace	1.80	0.4000
Neodymium	12.00	17.40	3.50	3.00
Praseodymium	4.34	5.00	0.6000	0.7000
Samarium	0.8000	2.53	2.20	2.80
Terbium	Trace	0.0350	1.20	1.30
Thulium	Trace	Trace	1.30	0.7000
Ytterbium	Trace	0.1000	6.00	2.50
Yttrium	0.10	2.40	59.30	65.00
Total	100.0000	100.0000	100.0000	100.0000

Source: adapted after Hendrick, 2002

Market Trends

The use of rare earth elements is expected to grow especially in automotive pollution catalysts, permanent magnets, rechargeable Ni-MH batteries, fibre optics, medical applications and in magnetic refrigeration alloys.

Recently companies have shifted away from using naturally occurring radioactive rare-earth ores because the cost and space to dispose of radioactive waste products has increased, severely limiting the use of low-cost monazite and other thorium-bearing rare-earth ores. This has had a negative impact on monazite-containing mineral sands but future long-term demand for monazite, is expected to increase because of its abundant supply, and its recovery as a low-cost byproduct.

World markets are expected to continue to be very competitive based on lower wages and fewer environmental and permitting requirements in producing countries. China is expected to remain the world's principal rare-earth supplier.

As research and technology continues to advance the knowledge of rare earths and their interactions with other elements, the economic base of the rare-earth industry is expected to grow. For example, in the United States, a team of scientists is studying the properties of the magnetic refrigeration group of gadolinium-silicon-germanium alloys. Any new discoveries could have important economic implications for some rare-earth elements (Herick, 2000).

Price

The competitive pricing policies in the rare-earth industry cause most rare-earth products to be quoted on a daily basis (Table 83). Industrial Minerals, No. 419 price quotes for August, 2002 were:

- Bastnaesite concentrates, 70% leached per pound REO - US$2.25
- Yttria (99.99% Y2O3) kg - US$13-16

Table 83

Rhodia Rare Earth Oxide Prices In 2000

Product (oxide)	*% Purity*	*Standard package (kg)*	*Price (US dollars/kg)*
Cerium	96.00	25	19.20
Do.	99.50	900	20.85
Dysprosium	99.00	3	120.00
Erbium	96.00	2	155.00
Europium	99.99	1	990.00
Gadolinium	99.99	3	130.00
Holmium	99.90	10	440.00
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	3,500.00
Neodymium	95.00	20	28.50
Praseodymium	96.00	20	36.80
Samarium	99.90	25	360.00
Do.	99.99	25	435.00
Scandium	99.99	1	6,000.00
Terbium	99.99	5	535.00
Thulium	99.90	5	2,500.00
Ytterbium	99.00	10	230.00
Yttrium	99.99	50	88.00

Source:Hedrick, USGS

Economic Factors

Carbonatites are the main source of niobium and an important source of REE. The Mountain Pass carbonatite in California reports bastnesite grade seven to eight percent total rare-earth oxides.

Special rare-earth tariffs for Canada and Mexico were implemented by the North American Free Trade Agreement (NAFTA) in 1994. Under the agreement, tariff rates for most rare-earth products from both countries were granted duty free status. Tariff rates for most other foreign countries were negotiated under the Generalized Agreement on Tariffs and Trade Uruguay Round of Multilateral Trade negotiations.

Yukon Occurrences

There were no reported exploration programs for REE in 2001 (Yukon Exploration Geology 2001). Four rare-earth occurrences are documented as minor commodities in Yukon Minfile 2001 (Table 84; Figure 4).

Table 84

Yukon Rare Earth Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/ Longitude*
1	105F 080	105F/8	NOKLUIT	CP	S	61º29’21”/132º10’27”
2	105F 081	105F/8	GUANO	YT	S	61º29’28”/132º24’56”
3	95C 051	95C/5	VISTA	SB	S	60º21’46”/125º48’32”
4	105D 169	105D	MATT	CPC	V	60º00’18”/135º22’25”

CP (Cassiar Platform), YT (Yukon Tanana); S (Skarn); SB (Selwyn Basin); CPC (Coast Plutonic Complex)

The NOKLUIT occurrence reported 1.2 percent REE (Th, Ce, La, Nd, Y) and 0.5 percent niobium in a chip sample across a 10 metre wide silicified and carbonatized zone in a dike.

The GUANO occurrence reported 0.13 percent REE elements and 0.09 percent niobium across 50 metres. Grab samples report 5.5 percent REE and 2.15 percent Nb_2O_5.

A few rare earth occurrences have been discovered in the southeast part of the territory. On the VISTA property (95C 051) in southeast Yukon, a Cretaceous nepheline syenite intrudes Paleozoic shale and carbonates. The syenite is enriched in radio-active and REE elements and reported samples contain more than 2 percent REE.

Anomalous REEs have also been recorded from uranium and copper bearing breccias on the MATT claim in the Wind River-Bonnet Plume River areas (Minfile 105D 169). No values of REE were reported.

Exploration Guidelines

In the Canadian Cordillera, carbonatites and related alkaline rocks are found in a broad zone parallel to and encompassing the Rocky Mountain Trench in British Columbia (Pell, 1987). Two northwest-trending belts, the Rocky Mountain Fold and Thrust Belt (Foreland Belt) and the Omineca Belt can be defined within this broad zone. By extension, the Rocky Mountain trench extends into the Yukon as the Tintina Trench, as do both the Foreland and Omineca belts. These belts are good exploration targets for new occurrences of carbonatites and related alkaline rocks, which may host REE.

Carbonatites weather relatively easily, and in flat topography are commonly associated with topographic lows (although some such as the ALEY carbonatite are located on a mountain ridge). They are found over broad geologic provinces but individual intrusions may be isolated and difficult to locate. Fenitization or widespread alkali metasomatism of quartzo-feldspathic country rocks in the immediate vicinity of carbonatite complexes however, can increase the size of the target during regional exploration programs.

Gamma anommalies and geochemical signatures provided by U-Th (radioactivity) which are associated with fluorite and barite within carbonatites, may be considered as indirect REE indicators. As well, resistant niobium or phosphate minerals in soils and stream sediments and F, Th and U in waters, are good geochemical indicators.

Geophysical targets can include magnetic and radiometric expressions. On occasion, anomalous radon gas concentrations establish primary targets (Birkett and Simandl, 1999).

ROCK SALT ROC

Chemical and Physical Characteristics

Rock salt (NaCl), also known as halite or sodium chloride is a white coloured compound essential to human and animal life. Salt (or halite), contains approximately 39 percent sodium (Na) and 61 percent chlorine (Cl). Halite is soft (2), very light, and displays perfect cubic cleavage. It is transparent to translucent with a vitreous lustre.

Deposit Examples

Williston Basin, Alberta, Manitoba, Saskatchewan, Mississippian Windsor Group, Nova Scotia, Southwestern Ontario, (Canada); Stassfurt (Germany); Wieliczka (Poland); Cardona (Spain).

General Geology

Halite (rock salt) occurs as a precipitate in sedimentary deposits caused by the evaporation of saline waters, usually saline lakes. Rock salt deposits are often interbedded with clay. As it is remarkably plastic under pressure and has a low density, rock salt in deep deposits tends to push its way upward towards the surface, forcing overlying sediments into domelike arches and forming so-called “piercement structures”. Gypsum, anhydrite and occasionally native sulphur, are concentrated at the top of these domes. In some salt domes, sulphur may be a source of Frasch sulphur.

World Production

The estimated world production of salt in 2001 was 214 million tonnes with the United States (45.1 million tonnes), China (32 million tonnes), Germany (15.8 million tonnes), India (14.5 million tonnes) and Canada (12.5 million tonnes) being the world's leading producers (Kostick, 2002).

End Use

The chemical industry consumes about 42 percent of total salt sales, with salt in brine representing about 92 percent of the type of salt used for feedstock. Chlorine and caustic soda manufacture is the main consuming sector within the chemical industry. Salt for highway de-icing accounts for 36 percent of American demand, with the remaining markets for salt in declining order; distributors, seven percent, industrial applications, six percent, agricultural, four percent, food, three percent, and primary water treatment, one percent.

Salt has nutritional, preservative, and binding properties, colour development and taste properties (used in food processing, canning, meat packaging, baking, flour processing etc.), and medical properties (saline solutions). Salt's freezing point depressant of about -6°C makes it a useful de-icing agent. It can also act as a flux (high-purity aluminum alloy), and as a alkalinity contributor to pulp and paper, as well as to oilwell drilling fluid.

Quality and Specifications

Tables 85 and 86 illustrate the quality and specifications of commercial salts (adapted after the Industrial Minerals HandyBook II, pg. 152.

Table 85

Chemical Analysis of Some Industrial Salt

	China	***Mexico***	***Australia (Shark Bay)***	***India***
Moisture	2.77	2.19	1.99	4.71
NaCl	95.65	97.73	97.45	95.76
Na	37.63	38.24	38.35	36.59
Cl	58.28	59.04	59.21	56.92
SO4	0.55	0.18	0.15	0.78
Ca	0.17	0.07	0.05	0.20
Mg	0.12	0.02	0.03	0.22
K	0.02	0.02	0.01	0.08
Insolubles	0.33	0.03	0.02	0.54

Table 86

Quality and Specifications of Salt by Use

Chemical grade	Minimum 95.5% NaCl, maximum 2.5% moisture, 0.1% Ca, Mg, and K, and 0.5% insolubles.
Food grade	Minimum 97.5% NaCl, maximum 1ppm As, 4ppm heavy metals (as Pb), 2% Ca and Mg, 0.0016% Fe and (for iodized salt) 0.010% to 0.006% iodine.
Specialty salt	Minimum 99.95% NaCl, 0.02-0.06% CaSO4, maximum 0.02% CaCl2, 0.01% Na2SO4, 0.4 ppm Cu, 1.5ppm Fe, 20ppm insolubles, 0.1% surface moisture.
Highway salt	Mined rock salt varies by origin and may contain up to 5% gypsum, shale, dolomite, and quartz and is acceptable for de-icing.

Market Trends

Salt is a low cost bulk mineral that does not bear transport costs well, and tends to be sold close to the country of production. Supplies of salt are more than adequate to meet any surge in demand, for the foreseeable future. Environmental concern over the adverse effects of chlorine (Cl_2) has reduced demand for salt (the most common source of chlorine).

Demand for salt in the Northern hemisphere is influenced by the weather as harsh winters increase salt demand for road de-icing purposes, and may cause local shortages (Kostic, 2000).

Price

The four types of salt that are produced, have unique production, processing and packaging factors that determine the selling prices. Generally, salt sold in bulk is less expensive than salt that has been packaged, pelletized, or pressed into blocks. Salt sold in brine is the least expensive, because mining and processing costs are less. Vacuum pan salt is the most expensive, because of the higher energy costs involved in processing and guaranteeing the purity of the product. Prices for year 2000 are illustrated in Table 87 (Kostic, 2000).

Table 87

Average Value of Salt by Product Form and Type (U.S. Dollars per tonne)

Product Form	*Vaccum and Open Pans*	*Solar*	*Rock*	*Brine*
Bulk	50.58	21.16	19.28	5.70
Compressed pellets	130.97	112.28	XX	XX
Packaged	128.05	71.56	62.34	XX
Average	113.95	50.46	20.67	5.70
Pressed blocks	101.18	93.52	91.14	XX

XX - Not applicable.

Economic Factors

The main types of commercial salt are: rock salt extracted from underground mines; vaccum pan salt produced by the mechanical evaporation of brines; brines derived from solution mining; and rock salt produced by solar evaporation of seawater or other brines.

Yukon Occurrences

No salt deposits have been reported in the Yukon and none are listed in Yukon Minfile 2001.

Exploration Guidelines

May be associated with evaporitic gypsum deposits.

SILICA AND QUARTZ SIL

Chemical and Physical Characteristics

Silica is the term used to describe any compound that is composed almost entirely of silicon dioxide (SiO_2). The element silicon constitutes approximately 26 percent of the earth's crust. Silica has a hardness of seven, is inert and resilient, and has a conchoidal fracture.

Quartz is the most common polymorph of silica found in nature, and accounts for about 12 percent of surficial terrestrial rock. Quartz crystals may exhibit excellent clarity, colour, and crystal shape. High purity quartz may be referred to as lasca.

Tripoli (amorphous silica) is an inert, porous, and friable microcrystalline silica with a hardness of (7), a specific gravity of 2.65, brightness of 84-91, and average particle size of 0.1-0.5µm . It is white (dry) to grey (wet) with an index of refraction of 1.550 and oil absorption of 17-20 percent.

Novaculite is a porous white to grey, light brown to black rock, comprising closely packed sharp anhedral quartz grains with a hardness of seven, and a specific gravity of between 2.63-2.64.

Flint is a compact cryptocrystalline chalcedonic silica that is inert, has a hardness of 7, a specific gravity of 2.62, and conchoidal fracture.

Silex is a fine-grained siliceous rock (greater than 90 percent SiO_2), with similar properties to flint.

Deposit Examples

Moberly mine, Horse Creek mine, Monteith Bay quarry, British Columbia (Canada).

General Geology

Silica deposits have formed during all geological periods, and are classified as primary, secondary or replacement.

Primary deposits are found as veins and pegmatites. Secondary deposits occur as sandstone and quartzite. Replacement deposits occur as siliceous solutions that metasomatically replaced host rocks, resulting in the formation of silicified zones.

World Production

World mine production, reserves and reserve bases are not available, but the global reserve base for lascas, is thought to be large. Limited resources of natural quartz crystal suitable for direct electronic or optical use are available throughout the world. World dependence on these resources will continue to decline however, because of the increased acceptance of cultured quartz crystal as an alternative material. Use of cultured quartz crystal will mean an increased dependence on lascas, for growing cultured quartz (Dolley, 2002).

British Columbia reported silica production during 2001 at 107,000 tonnes from three mines and quarries. Most of this material was exported to markets in the Pacific Northwest region (BC Mineral Exploration Review 2001).

End Use

In Canada, the three major markets for silica are glass, fiberglass and foundry sand. Micronized silica, depending on particle size, is used as filler in paint, plastics and rubber and as an adhesive in putty, caulks and sealants. Quartz crystals, because of their piezoelectric properties and shape, are used in electronic instruments, mineral specimens and as gems whereas lump-quartz/quartzite is used in manufacturing of silicon metal and ferrosilicon. Lascas is a high purity SiO_2 used in the production of cultured quartz monocrystals. Tripoli is used as a filler/pigment (in paint, rubber, plastics, adhesives and sealants); and as an abrasive (for scouring powders, polishing compounds, tooth polishes). Tripoli contributes durability, weatherability and chemical resistance to floor, marine, highway and other specialty paints. In adhesives, sealants, plastics, and rubber, tripoli contributes whiteness, opacity, and rigidity. Its low oil absorption allows for a high level of loading, without increasing the viscosity. Novaculite makes an excellent abrasive (metal sharpening and grinding media); and as refractory and light-weight aggregate. Flint and silex are both used as grinding agents for metal sharpening and for ball-mill lining. Silica sand is used to manufacture glass and ceramics, and as foundry and blasting sand.

Table 88

Chemical Composition of Silica Glass Sands (%)

	USA New Jersy	*USA Illinois*	*USA Oklahoma*	*USA California*	*France Fontainebleau*	*UK Loch Aline*
SiO2	99.66	99.81	99.73	92.76	99.65	99.73
Fe2O3	0.025	0.017	0.020	0.127	0.02	0.013
Al2O3	0.143	0.055	0.090	3.779	0.08	0.057
TiO2	0.027	0.015	0.012	0.034	NA	NA
CaO	0.007	<0.01	<0.01	0.060	NA	NA
MgO	0.004	<0.01	<0.01	0.017	NA	NA
K2O	-	-	-	2.734	-	-
Na2O	-	-	-	0.114	-	-
LOI	0.130	0.100	0.140	0.373	0.13	0.04

Quality and Specifications

Table 88 illustrates the chemical composition of silica glass sand. Table 89 describes the quality and specifications by use for silica and quartz (Harben, 1995).

Table 89

Quality and Specifications By Use

Glass-grade silica	Minimum 98.5-99% SiO2 with Fe2O3 of <0.04% (flat glass), 0.03% (flint container), 0.18% (amber container), and 0.3% (fibreglass), 0.2-1.6% Al2O3, with limits on alkalis, colourants (Ni, Cu, Co) and refractory minerals (chromite, zircon, rutile). First grade optical glass: minimum 99.8% SiO2, < 0.1% and 0.02% Fe2O3.
Ceramic-grade silica	(-200 mesh) >97.5% SiO2, <0.55% Al2O3 and 0.2% Fe2O3.
Filtration sand	Free of dust, clay, mica, organic matter. Grains angular or round. Uniform size.
Foundry sand	(-200 and –200 mesh), minimum 98% SiO2 with limits on CaO and MgO to reduce the acid demand value (ADV) which is a measure of the binder required.
Flux sand	(Iron and steel) lumpy >90% SiO2.
Frac or proppant sand	Well rounded with only minor impurities such as clay, feldspar, and calcite (<0.3% solubility in HCl). Common screen sizes: 3.35x1.70mm; 2.36x1.18mm; 1.70x0.850mm; 0.425x0.212mm; 0.212x0.106mm.
Ground silica, silica flour	<0.10% Fe2O3, <0.38%Al2O3, <0.10%K2O. Flour has an APS of 60µm and both require a brightness of 89%+.
Feedstock	>99.4%-99% SiO2, <0.1% Fe2O3, <0.15%Al2O3, no P or As, <0.2% CaO, MgO, and LOI with lumps >2.54cm diameter and minimum softening point 1,700ºC with decrepitation point of 950ºC.
Tripoli	98-99.5% SiO2, 0.025-1% Fe2O3 with particle size 99% -74µm to 99%-10µm.
Flint	97.4% SiO2, 0.035% Al2O3, trace Fe2O3, 0.46% CaO, 0.18% MgO, 1.3% LOI, 10µm APS (Ceramics) and 1½, 2½-3 inch and 3-4 inch (grinding pebbles),
Lascas	Average 15-20ppm Al, 2-5ppm Fe, 2-25ppm Na, 2-10ppm K, 1ppm Ca, Mg, Li, Ti and are divided into Grade 1:>90% clear to the unaided eye and essentially free of crystal faces; Grade 2: 50-60% clear to the unaided eye, contains minor air and water inclusions but is essentially clear of crystal faces; Grade 3: translucent to light; Grade 4: opaque quartz of milky white appearance.

Market Trends

A very common commodity worldwide, silica is produced and consumed in most countries. This combined with its relatively low price, minimizes international trade. Often, production of silicon and ferrosilicon is more dependent on the availability of low-cost energy, than on the availability of silica. However, silica, which only meets certain specifications (such as monocrystals), is less common, and such products may be traded internationally to large markets where a local source of the commodity is lacking.

Recent trends indicate that demand for quartz crystal devices should continue to grow, and consequently, quartz crystal production should remain strong, well into the future. Growth of the consumer electronics market (for products such as personal computers, electronic games, and cellular telephones) should continue to promote domestic production. This growing global electronics market may require additional production capacity worldwide (Dolley, 2002).

Price

Industrial Minerals, No. 419 in August 2002 reported:

- Foundry sand dry, bulk, ex-works, UK£15.50-16.50
- Glass sand, flint, container, ex-works, UK£15-17

Harben, 1995 reported the following prices:

- Silica sand US$8-25/ton
- Tripoli US$200-305/ton (micronized); US$115-155/ton (air-floated).
- Novaculite US$110-125/ton.
- As grown cultured quartz US30/kg.
- Lumbered quartz US$140/kg.

Economic Factors

Silica with desired specifications may be shipped to large markets where there is no local source. Virtually all the larger producers of high quality silica products are exporters (Harben,1995).

Yukon Occurrences

One reported silica occurrence is described as a dimension stone prospect in Yukon Minfile 2001 (See under Dimension Stone, this report).

No systematic evaluation of the Territory's is 629 quartz occurrences reported in Yukon Minfile 2001 has been conducted, and the silica resource potential in the Yukon Territory is not known.

Exploration Guidelines

In broad terms, the best potential for general purpose silica raw material in the Yukon is probably in quartzite units, reported in many terranes throughout the Yukon. There is the potential for large amounts of silica from these deposits. Specialty silicas have to be evaluated on individual bases.

SILLIMANITE MINERALS SI

Mullite ($3Al_2O_32SiO_2$) is a rare metamorphic mineral that was first discovered in Tertiary volcanics on the Isle of Mull, in Scotland. In nature it forms from the high-temperature alteration of sillimanite minerals. Mullite does not occur naturally in commercial quantities; however demand from the refractory industry because of its intense resistance to heat and corrosion, has created a market for synthetic mullite, manufactured from alumina minerals, like bauxite, and kaolinite. The most direct method of synthetic mullite production, is the calcination of the sillimanite group of minerals (andalusite, kyanite, sillimanite).

Chemical and Physical Characteristics

Sillimanite, kyanite and andalusite are anhydrous aluminosilicate minerals that have the same chemical formula (Al_2SiO_5), but have different crystal structures and physical properties. When calcined at high temperatures (around 1,350ºC for kyanite and slightly higher for andalusite and sillimanite), these minerals are converted to mullite, $3Al_2O_3 \cdot 2SiO_2$, and silica, SiO_2.

Sillimanite is a greyish, pale-green or white orthorhombic mineral, which occurs in long, slender needle-like crystals often found in wisp-like or fibrous aggregates in schist and gneiss. It is hard (7), heavy (SG 3.2) and often occurs as inclusions in other minerals, like quartz and feldspars.

Kyanite is a hard (6-7) to semi-hard (4-5), heavy (SG 3.67) fragile mineral with perfect prismatic cleavage. It is transparent or translucent, with a vitreous to pearly lustre, usually blue in colour but may be white, grey or green. The mineral is sometimes intergrown with staurolite.

Andalusite is a very hard (7.5) and heavy (SG 3.20) mineral, which displays perfect cleavage. It is translucent to opaque, rarely transparent and has a vitreous lustre. It may occur in a variety of colours including red, brown or dark olive green.

Deposit Examples

Yellow Creek, British Columbia; NARCO deposits, Quebec; Kyanite schist Temiskaming area, Ontario, (Canada); Willis Mountain kyanite, Virginia; Graves Mountain, Georgia, (United States), Pella District (South Africa); sillimanite-corundum deposits of Sonaphahar area (India).

Andalusite occurrences, Kootenay (082FSE099), Kwoiek Needle (092ISW052), Atna Peak (103H040), Sombrio River and Valentine Mountain on Vancouver Island, British Columbia; McGerrigle Pluton, Quebec, (Canada); Groot Marico-Zeerust, Thamazimbi, Lydenburg, (South Africa); Kerphales deposit (France);

General Geology

Kyanite and sillimanite deposits occur in metasedimentary belts, metasedimentary roof pendants and contact metamorphic zones. The age of mineralization coincides with the age of metamorphism.

The sillimanite minerals occur as porphyroblasts or crystalline masses in schist, gneiss, quartzite and paragneisses formed by metamorphism from aluminous sedimentary rocks. Host and associated rock types may include kyanite and/or sillimanite gneiss, schist and quartzite associated with marble, biotite and garnet. Host lithologies are derived from high-alumina protoliths such as high-alumina shale, paleo-regolith, paleo-placers or alteration zones.

Kyanite deposits are found in high-pressure metamorphic terrain. Sillimanite occurs mainly in schist and gneiss affected by high-temperature and pressure metamorphism. Deposits of high-grade lenses may be present within low-grade stratiform mineralization. Mineable portions are at least several metres thick and exposed over hundreds of metres along a strike. Larger deposits can be exposed over an area of several thousands of square metres.

Associated deposit types include garnet, crystalline flake graphite, staurolite, in metamorphic environments. In placer accumulations kyanite, sillimanite, andalusite, garnet or staurolite deposits. Corundum in aluminous metasediments, also may occur in similar geological environments (Simandl et al, 1999).

Andalusite occurs in metamorphosed rocks of originally clay-rich composition (usually pelitic) in thermal aureoles formed in the proximity of igneous intrusions. Andalusite is formed under conditions of high temperature and low pressure. Deposits occur mostly in orogenic belts, but also may occur in platformal environments.

Andalusite hornfels are a product of thermal recrystallization of rocks with high alumina and low calcium contents. The protolith is usually argillaceous sediment, but may also be hydrothermally altered volcanic or volcaniclastic rock. The host rocks are chiastolite metapelite. The associated rocks are spotted slates, analusite-cordierite hornfels, staurolite hornfels, spinel-corundum hornfels, silimanite hornfels, skarns and a variety of igneous intrusions. The whole spectrum of granitic to gabbroic igneous rocks can act as a source of heat. Andalusite deposits develop in pelitic rocks with high alumina and low calcium contents at temperatures of 550ºC to 600ºC and low pressures of about two kilobars. Such conditions usually develop within the contact aureole of an intrusive. At higher temperatures, sillimanite or corundum and spinel form at the expense of andalusite.

Metamorphic zonation of the contact aureole is characterized by distinct mineral assemblages and textural features, where andalusite may be a major or minor component, fine grained or as crystal porphyroblasts several millimetres or even centimetres in size (Hora, 1999). For example, aluminosilicate-rich pelitic schist of the Leech River Unit are exposed on southern Vancouver Island. This Cretaceous age unit is largely comprised of argillites and metagreywackes, with some metavolcanics. Metamorphic grades increase from north to south and exposed andalusite is present in porphyroblasts from 12 to 20 centimetres long (Pell, 1988).

Andalusite hornfel can be of any age from Precambrian to Tertiary. The largest producing deposits are related to intrusions of the Bushveld Igneous Complex (South Africa) which is estimated to be about 1.95 billion years old. The deposit in France, the second largest producer in the world, is related to granite of late Paleozoic (Hercynian age). Occurrences in British Columbia are Cretaceous and Eocene in age.

Large intrusions into pelitic sedimentary units may produce tabular deposits 20 to 60 metres wide and up to 6 kilometres long. However, the majority of occurrences are small and irregular in shape. Primary deposits may be associated with alluvial and eluvial accumulations. Andalusite development is a factor of the composition of the protolith and the high temperature/low pressure conditions adjacent to an igneous intrusion. The chemical nature and thickness of the original sedimentary layers and their respective distance from the intrusive contact are the main controls for the formation of andalusite hornfel orebodies. Although the metamorphic aureole may extend a great distance, typically only a few areas within the aureole satisfy the conditions necessary to produce economic accumulations of andalusite.

Associated deposits types may include wollastonite and garnet skarns. Andalusite hornfel deposits can be the source for placer andalusite. Microcrystalline graphite and gem corundum are also found in contact aureoles of igneous rocks (Hora, 1999).

World Occurrences

The estimated world mine production of sillimanite minerals during 2001 was 390,000 tonnes. Leading producers included South Africa (215,000 tonnes), the United States (90,000 tonnes), France (65,000 tonnes) and India (17,000 tonnes) (Potter, 2002). Canada currently has no producing sillimanite mineral mines.

End Use

The principal application for mullite is as a refractory material where it is incorporated into bricks, cements, mortars, plastics and ramming mixes. Its high price means mullite can rarely be the sole material in refractory products, but when combined with less expensive, less refractory minerals, is marketable. Markets utilizing mullite as a refractory mineral, are the metallurgical (primarily steel, but also bronze, brass, copper-nickel alloy, zinc (and gold where mullite forms the lining for electrical furnaces) and glass (as glass batch tank superstructure) industries and to a lesser extent the ceramics industry (as kiln furniture). Outside the refractories industry, mullite proves useful in abrasives, casting, welding rod fluxes, spark plugs, non-slip flooring and other areas where durability and resistance to corrosion are requirements.

Quality and Specifications

Andalusite, kyanite and sillimanite are the structural polymorphs of Al_2SiO_5 and form the sillimanite group of minerals. When all three are calcined they convert to mulite plus free silica:

$$\underset{\text{Andalusite}}{3(Al_2O_3 \cdot SiO_2) + \text{Heat}} \rightarrow \underset{\text{Mullite}}{3Al_2O_3 \cdot SiO_2} + \underset{\text{Free Silica}}{SiO_2}$$

Table 90 illustrates the chemical analysis of sillimanite, kyanite and andalusite, the three principal minerals:

Table 90

Analysis of Sillimanite, Kyanite, Andalusite (%)

	India Sillimanite (ore grade)	*China Sillimanite (Jaxi Mine)*	*USA Kyanite (Raw)*	*Sweden Kyanite*	*South Africa Andalusite (Purusite)*	*China Andalusite (Henan)*
Al_2O_3	60.1	26.48	54.00-60.06	59.8	59.1	19.02
SiO_2	36.9	59.74	37.64-43.70	35.8	38.6	61.7
Fe_2O_3	0.5	2.55	0.16-0.94	N/A	0.84	7.64
FeO		3.21				
Total Fe	N/A		N/A	1.3	N/A	
TiO_2	0.32	1.40	0.67	0.64	0.14	0.79
CaO	N/A	0.26	0.03	0.2	0.16	0.42
MgO	N/A	0.75	0.01	0.2	0.11	2.15
K_2O		3.50			0.3	2.80
Na_2O		0.33			0.09	1.06
Alkalis	N/A		0.42	0.028	0.32	
MnO_2		0.08				
P_2O_5		0.09				
C						1.11
LOI	N/A		0.21	0.43	0.82	2.48

Source: adapted after The Industrial Mineral HandyBook II

Market Trends

The steel industry is the largest user group of refractories in general, consuming an estimated 55-60 percent of total refractory output (Potter, 2002). Therefore, demand for mullite, as with all refractories is dependent on the economic health of the steel industry.

Potential alternatives to mullite are fused spinel, magnesia, mag-alumina spinel and fused Zr alumina, although at the present time none of these can compete with mullite's refractory property and price.

Price

During 2001, the USGS (Potter, 2002) reported estimated prices received for sillimanite mineral averaged (per tonne):

- U.S. Kyanite, raw US$165
- U.S. kyanite, calcined US$279
- Andalusite, Transvall, South Africa, 57% Al2O3 US$162
- Andalusite, Transvall, South Africa, 58% Al2O3 US$210

Economic Factors

The Graves Mountain deposit in Georgia (United States) has reported possible reserves of 30 million tonnes at 25 percent kyanite. The Willis Mountain kyanite deposit in Virginia (United States) has indicated reserves of 65 million tonnes, at 25 percent kyanite.

A limiting factor for the sillimanite group of minerals such as kyanite, is its relatively low price that is received for raw material, although processing to mullite or precalcination, does increase market price. As a rule, conversion to mullite requires one tonne of mineral concentrate, in order to yield about 0.88 tonnes of mullite.

The Kerphales deposit in France contains 15 percent andalusite crystals and is about 400 metres thick It has proven and possible reserves of 10 million tonnes and produces 65 Kt per year. The Adafrax deposit in South Africa is 60 metres thick with 5 to 20 percent andalusite crystals and with production of about 36 Kt per year.

Yukon Occurrences

There are no reported sillimanite group of mineral occurrences in Yukon Minfile, 2001. However, sillimanite group minerals do occur as common accessory minerals in metamorphic terrain and in contact zones around high-temperature intrusions.

Pell (Open File 1988-26) reported that strata within the Omineca Crystalline Belt and the Coast Mountain Belt of British Columbia locally contained concentrations of the kyanite group of minerals in excess of between 10-15 percent. Further suggested was the potential for secondary placer accumulations in the vicinity of reported hardrock showings. By extension, it is probable that similar enriched deposits of sillimanite group minerals occur in the Yukon is extension of the Omineca Crystalline Belt and the Coast Mountain Belt, particularly in strata, which is sufficiently pelitic, to contain major concentrations of these minerals.

Exploration Guidelines

Suggested exploration guidelines for sillimanite group minerals includes the evaluation of regional geophysical data, such as electromagnetic surveys (EM), to trace favourable metasedimentary units (if marker horizons or igneous intrusions have distinctive signatures).

Other useful tools include elimination of areas where metamorphic conditions are required to form anhydrous aluminum silicates. Favourable lithologies should be identified, with special attention paid to crest of folds and metasediment-intrusive rock contacts. Panning along stream beds for heavy minerals is an effective exploration tool, since the density of aluminum silicates will tend to concentrate them in stream sediments (Simandl et al, 1999).

There are no geochemical or geophysical signatures for andalusite. Most deposits are found within one kilometres of the related igneous intrusion and economic deposits are more likely found in prospective regions with well developed weathering profiles (Hora, 1999).

SODIUM CARBONATE Carb

'Soda Ash' is the trade name for sodium carbonate, a chemical refined from the mineral trona or sodium-carbonate-bearing brines (both referred to as "natural soda ash") or manufactured from one of several chemical processes (referred to as "synthetic soda ash").

Chemical and Physical Characteristics

Trona is the most important commercial ore of soda ash. It occurs in prismatic, tabular, colourless crystals, is soft to semi-hard (2.5-3), light (SG 2.17), and fragile with perfect cleavage. It is transparent to translucent with a dull, earthy lustre and when heated loses water and then carbon dioxide, fusing only at a high temperature. It does not alter when exposed to air. Table 91 illustrates trona and other less commercially significant sources of sodium carbonate.

Table 91

Minerals Containing Sodium Carbonate

Mineral	*Chemical Formula*	*% Na2CO3*	*% Na2O*
Trona*	Na2CO3·NaHCO3·2H2O	70.4	62.0
Nahcolite	Na2HCO3	63.1	-
Northupite	2Na2CO3·NaCl·MgCO3	40.6	-
Gaylussite	Na2CO3·CaCO3·5H2O	35.8	-
Shortite	Na2CO3·2CaCO3	34.6	-
Burkeite	Na2CO3·Na2SO4	27.2	-
Hanksite	2Na2CO3·9Na2SO4·KCl	13.6	-

** Commercially the most important sodium carbonate mineral*

Deposit Examples

Owens Lake, California; Big Soda Lake and Little Soda Lake, Nevada; Double Springs Marsh, Nevada; Union Pacific Lakes, Wyoming (United States); Lake Magadi, (Kenya).

General Geology

Trona is a product of some non-marine evaporite deposits in arid regions (salt lakes). As a curiosity, trona has also been found in minor amounts in lava cavities on Mount Vesuvius, Italy.

World Production

Estimates of world production of natural soda ash during 2001 were 10.7 million tonnes. Leading producers included the United States (10.3 million tonnes), Botswana (200,000 tonnes) and Kenya (230,000 tonnes). Other producers included China, Mexico, Turkey and Uganda, but production estimates for these countries were not available.

In addition, approximately 22.3 million tonnes of synthetic soda ash were produced during 2001 (Kostick, 2002).

Market Trends

Production of glass containers (the largest soda ash consumer) declined by about 6 percent in 2001. A major baby food manufacturing company began packaging its products in polyethylene terephthalate (PET) plastic jars, in lieu of glass. The beer sector also increased its use of PET. As this use increases (along with increase use of PET by other glass consumers), a corresponding decline in soda ash sales is expected.

China is rapidly expanding its soda ash manufacturing capability. It is anticipated that competition by the United States with China for markets in Asia, will be strong in the future. Notwithstanding the economic and energy problems in certain areas of the world, the overall world demand for soda ash is expected to grow from 1.5 to 2 percent annually in the early part of this century (Kostick, 2002).

End Use

Soda ash is consumed in glass (container, flat and coloured), chemicals (sodium bicarbonate, sodium chromates, sodium phosphates) in soap and detergents (emulsifying oil stains reducing the redeposition of dirt during washing), in distributors, flue gas desulphurization, and the pulp and paper industries and as well as in water treatment facilities.

Quality and Specifications

Table 92 illustrates the composition of some commercial soda ash.

Table 92

Composition of Commercial Soda Ash (%)

	USA brine lake Typical dense	***Kenya brine lake Typical dense***	***USA trona specification dense***
Na2CO3	97.1	97.33	99.2 (minimum)
Na2O	57.1	99.64	58
NaHCO3	-	0.25	
Na2SO4	0.7	0.48	0.2
NaCl	0.5	0.45	0.2
Na2B4O7	1.3		
NaF		0.9	
Fe2O3	-	0.02	20ppm (maximum)

Source: adapted after The Industrial Minerals HandyBook II, pg. 168

Price

Industrial Minerals, No. 419 listed soda ash during August, 2001 at:

- US natural, FOB Wyoming dense, s ton US$105-115
- Large contract US$80-90

Economic Factors

The world's largest known deposit of trona is in the Green River Basin, of Wyoming. About 47 billion tonnes of identified soda ash resources could be recovered from the 56 billion tonnes of bedded trona and from the 47 billion tonnes of interbedded or intermixed trona and halite, that are in beds more than 1.2 metres thick. Underground room-and-pillar mining, which uses a combination of conventional, continuous, and shortwall mining equipment is the primary method of mining Wyoming trona ore. This method averages 45 percent mining recovery, which is higher than the 30 percent average mining recovery that comes from solution mining.

Yukon Occurrences

There are no reported sodium carbonate occurrences listed in Yukon Minfile 2001.

SODIUM SULPHATE SSU

Sodium sulphate, also known as disodium sulphate (Na_2SO_4) or "salt cake", is an inorganic chemical that has several important industrial uses. It is produced from both naturally occurring sodium-sulphate-bearing brines and crystalline evaporate deposits. The most important natural mineral sources are mirablite and thenardite.

Chemical and Physical Characteristics

Minerals containing sodium sulphate are illustrated in Table 93.

Table 93

Mineral	*Chemical Formula*	*% Na_2SO_4*	*% Na_2O*
Thenardite	Na_2SO_4	100.0	43.6
Mirabilite (Glauber's salt)	$Na_2SO_4 \cdot 10H_2O$	44.1	34.8
Haksite	$2Na_2CO_3 \cdot 9Na_2SO_4 \cdot KCl$	81.7	-
Sulphohalite	$2Na_2SO_4 \cdot NaCl$	73.9	-
Glauberite	$Na_2SO_4 \cdot NaSO_4$	51.1	-
Bloedite	$Na_2SO_4 \cdot MgSO_4 \cdot H_2O$	42.5	-

Deposit Examples

Inglebright, Saskatchewan, (Canada); Okanogan County, Washington; Great Salt Lake, Utah; Searles Lake, California (United States); Antofagasta, (Chile).

General Geology

Sodium sulphate or 'salt cake' is produced from naturally occurring sodium-sulphate-bearing brines or crystalline evaporate deposits. It forms in continental basins and lakes with high evaporation rates and a low precipitation environment. Thenardite and mirabilite are temperature dependent, since sodium sulphate has a very unusual solubility curve in water. Below 1.2ºC, it is crystalline but above this temperature, increasing amounts of sodium sulphate become soluble. Above 32.4 ºC anhydrous thenardite, crystallizes out.

When a brine is artificially cooled to release mirabilite, the decahydrate form is known as 'Glauber's Salt'. Sodium sulphate minerals occur in brines and solid beds.

World Production

World production of mined sodium sulphate was estimated during 2001, at 3.3 million tonnes. Leading producers included the United States (860,000 tonnes), Spain (180,000 tonnes), Mexico (170,000 tonnes), Turkey (100,000 tonnes) and Canada (84,000 tonnes) (Kostick, 2002).

Market Trends

Sodium sulphate consumption by the soap and detergent industry, which has been the largest consumer of sodium sulphate, will continue to remain strong because of the demand for powdered home laundry products. South America continues to be a major region for increased sodium sulphate consumption. In areas with a depressed economy, powdered home laundry detergents are more in demand because they are less expensive than liquid concentrates or compact alternatives. This reverses an earlier trend in popularity for liquid detergents, that had been gaining popularity, prior to 2001.

End Use

The estimated distribution of sodium sulphate by end use was: soap and detergents (42 percent); textiles – dyeing processes (15 percent); pulp and paper (12 percent); glass (11 percent), and their uses such as sodium sulphate, for carpet freshners, starch manufacture, etc. (20 percent) (Kostick, 2002).

Quality and Specifications

There are no universally agreed grades of sodium sulphate. Even the term 'salt cake', which should be taken to mean low-grade material (with only 90-99 percent Na_2O_4), is freely used to describe purer grades of material. High-purity or technical grade refers to anhydrous sodium sulphate with a purity of 99 percent or more. There are also tight specifications for different end-uses. Table 94 illustrates detergent grades of sodium sulphate.

Table 94

Detergent Grade Sodium Sulphate (Na2SO4) Average Composition (%)

Na2SO4	99.7
Mg	Less than 0.02
NaCl	Less than 0.2
H2O	Less than 0.02
H2O insoluble	Less than 0.05
Fe	Less than 3 ppm
PH	Neutral to slightly alkaline
Solubility in water	4.5 grams in 100 grams of H2O @ 0ºC 28 grams in 100 grams of H2O @ 25ºC
Appearance	White crystalline powder
Melting point	888ºC
Bulk density	89-97 lb/ft^2
Specific gravity	2.671 @ 25ºC

Source: adapted after Industrial Minerals, No. 419, pg. 23

Price

Reported prices for sodium sulphate during 2001 were:

- Consumption, apparent (natural and synthetic)
- Sodium sulphate (100% Na_2O_4) bulk, f.o.b. works, East, dollars per short ton US$ 114

Economic Factors

The closing of byproduct sodium sulphate operations in Mobile, Alabama and Monument, New Mexico in the United States and the natural sodium sulphate operation in Inglebright, Saskatchewan, Canada, has reduced the oversupply. The outlook for 2002 is expected to be comparable to 2001, with detergents remaining the largest sodium sulphate consumer (Kostick, 2002).

Yukon Occurrences

There are no reported sodium sulphate occurrences described in Yukon Minfile 2001.

STRONTIUM STR

Chemical and Physical Characteristics

Strontium occurs commonly in nature averaging 0.04 percent of the Earth's crust. Only two minerals, celestite ($SrSO_4$) a strontium sulphate, and strontianite ($SrCO_3$) a strontium carbonate, contain strontium in sufficient quantities to make its recovery economic. Of these, celestite is the most important.

Celestite an ore of strontium, is colourless, milky white, pale blue or yellowish, has a pearly lustre, is semi-hard (3-3.5), heavy (SG 3.96), and is fragile with massive, granular and concretionary aggregates. The mineral is transparent to translucent and fluoresces when organic impurities are present.

Strontianite, is semi-hard (3.5-4), has crystals resembling hexagonal pyramids which can be scepter-shaped or globular with striations. The mineral is colourless, white or grey and becomes fluorescent in ultraviolet light.

Deposit Examples

Showings in the Stewart Camp - Stewart, British Columbia (Canada), Montevives and Escuzar deposits, (Spain).

General Geology

Strontium minerals are frequently associated with barite in vein deposits (together with calcite and galena), with gypsum in sedimentary beds, and as dissemination in limestone and in solution cavities in limestone (The general geology of these deposit types are covered under Barite and Gypsum in this report).

World Production

The estimated world production of mined strontium during 2001 was 520,000 tonnes. Leading producers included China (200,000 tonnes), Mexico (160,000 tonnes), Spain (130,000 tonnes) and Turkey (25,000 tonnes).

Canada does not currently produce primary strontium minerals but is the world's leading producer of strontium metals from an Ontario facility (Timminco Ltd.).

End Use

During 2001, almost 85 percent of all strontium was consumed in ceramics and glass manufacturing, primarily in television faceplate glass and secondarily in ceramic ferrite magnets and other ceramic and glass applications.

Since strontium burns with a brilliant red flame, strontium chemicals are used in pyrotechnics (such as tracer ammunition, flares, and fireworks). It is also used in metallurgy to remove lead during the electrolytic production of zinc, and in casting processes.

Quality and Specifications

Celestite (strontium sulphate), concentrate, the principal ore of strontium is converted to $SrCO_3$ (Strontium carbonate) via the black ash or calcining route, and forms chemical-grade strontium carbonate. If the direct or soda ash route is followed it forms technical-grade strontium carbonate as illustrated by:

$$SrSo_4 + Na_2CO_3 \rightarrow SrCO_3 + H_2S$$

The quality and specifications of strontium sulphate (celestite) and strontium carbonate is illustrated in Table 95.

Table 95

Celestite (strontium sulphate) and Strontium Carbonate: Quality and Specifications

Celestite (strontium sulphate) ore.	Minimum 90% $SrSO_4$
Strontium carbonate, chemical-grade (via black ash or calcining method.	Minimum 98% $SrSO_3$
Strontium carbonate, technical-grade (via the soda ash or direct method).	Minimum 97% $SrSO_3$
Strontium carbonate - glass grade.	99.6% $SrSO_3$
Strontium carbonate – ferrite-grade.	96-99% $SrSO_3$
Strontium carbonate – electrolytic zinc refining.	Minimum 97% $SrSO_3$
Strontium nitrate – pyrotechnics	Low moisture content to promote efficient combustion; low sulphur, manganese, ammonia
Strontium chromite	Low nitrate and chloride content to prevent corrosion.

Source: adapted after the Industrial Minerals HandyBook II, pg. 45

Market Trends

All colour televisions and other devices containing colour cathode-ray tubes (CRTs) sold in the United States, are required by law to contain strontium in the faceplate glass of the picture tube to block x-ray emissions.

With sales of CRTs expected to grow at about 6.3 percent per year through 2006, a corresponding demand for strontium carbonate, in that end-use, is expected. However, flat screen display systems for televisions and computer monitors have increasingly threatened to replace CRTs because they use either liquid crystal displays (LCD) or plasma technology which are smaller and use less energy than CRTs. Consequently there is less use for strontium. As the cost of large flat screen devices decreases and the technology matures, consumers are expected to favour them over smaller screened units. CRTs consequently, will become obsolete, and so will the major market for strontium carbonate (Ober, 2001).

Price

Based on data published by the United States Census Bureau, the average customs value for celestite imported from Mexico is about US$63 per tonne. The average unit customs value of imported strontium carbonate is US$0.55 per kilogram. The corresponding value for strontium nitrate is US$3.07 per kilogram (Ober, 2002)

Economic Factors

Strontium commonly occurs with barium and calcium, two elements with similar chemical properties thus making separation difficult. Because removing many impurities from celestite is difficult and energy-intensive, strontium chemical producers require ore that contains at least 90 percent strontium sulphate. Production facilities for strontium compounds and metal are located in Ontario (Canada), China, the CIS, Germany, Japan, the Republic of Korea, Mexico, Poland and the United States.

Yukon Occurrences

Three strontium occurrences are described in Yukon Minfile 2001. Of these one is listed as a major commodity (Table 96; Figure 4).

Table 96

Yukon Strontium Mineral Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Longitude/Latitude*
1	105F 038	105F/14	BARITE MTN.	CP	V	61º50’17”/133º00’37”
2	105O 007	105O/6	ART	SB	I	63º24’05”/131º20’45”
3†	116O 059	116O/16	DRIFTWOOD	MP	?	67º57’29”/138º13’21”

† Listed as a major commodity

CP (Cassiar Platform), SB (Selwyn Basin), MP (Mackenzie Platform); V (Vein), I (Intrusive),? (Deposit type unknown).

Exploration Guides

The strontium mineral celestite has a close association with barite and gypsum. Any investigation into the Yukon’s barite and gypsum deposits should include documentation of strontium values and occurrences (Exploration guides for each of these deposit types are described in this report under their own headings).

SULPHUR SUL

Chemical and Physical Characteristics

Sulphur (S), ranges in colour from yellow to white, is very soft (1.5-2.5), light (SG 2.0), fragile, and exhibits poor cleavage. In crystal form, the mineral is transparent to translucent with a resinous to greasy lustre, which is dependent on the amount of bitumen present.

Sulphur is produced from native sulfur deposits through traditional mining methods. Sulphur is also extracted from petroleum, heavy oil and natural gas, from coal burning powerplants and as a by-product of smelting sulphide ores such as chalcopyrite galena, sphalerite, etc. One special case is Frasch sulphur production where heated molten sulphur is pumped to the surface from underground deposits.

Deposit Examples

Oil sands, Alberta, (Canada); Main Pass Mine in the Gulf of Mexico, Louisiana (United States).

General Geology

Although sulphur is a widespread and abundant element, relatively few deposits are mined. These natural deposits occur through bacteria reduction of gypsum and anhydrite in salt dome cap rocks and bedded evaporites. Sulphur is also found in volcanic environments and may be associated with thermal springs. Sulphur is present as hydrogen sulphide in petroleum and natural gas, tar sands, oil shales and other organic compounds.

Sulphur occurrences are common in most volcanic regions, and are known to occur in the Canadian Arctic and the United States gulf region in salt dome gypsum cap rocks. Biochemical stratiform sedimentary sulphur deposits are associated with bedded gypsum and anhydrite, in oil-bearing evaporate basins. Table 97 illustrates potential sources of sulphur.

Table 97

Potential Sources of Sulphur

Source	*Formula*	*Sulphur Content*
Native Sulphur	S	Grade average 22-33% weight S
Pyrite	FeS2	53.4% S* with average 40-50% S
Chalcopyrite	CuFe2	34.9% S*
Galena	PbS	13.4% S*
Sphalerite	ZnS	32.9% S*
Pyrrhotite	NiFeS2	38% S*
Gypsum	CaSO4·2H2O	18.6% S*
Anhydrite	CaSO4	23.6% S*
Tar Sands		Averages 11% bitumen containing 5% S as organic sulphur compounds
Oil Shales		Average 0.3-6.2% S
Coal		Variable; averages 1.5% S

*Source: Industrial Minerals HandyBook II, pg. 176; * theoretical content*

World Production

There are three sources of sulphur namely, hydrogen sulphide from natural gas, petroleum, and tar sands; sulphur from smelter gases recovered as sulphuric acid; and, sulphur in base metal sulphide concentrates. By far the most important source is the hydrogen sulphide from natural gas production.

Approximately 13 percent of the world's elemental sulphur production comes from bedded deposits and salt dome cap rock, with over 70 percent recovered as a by-product of oil and natural gas. Total world production for the year 2000 was estimated at 57.4 million tonnes (Ober, 2000).

End-Use

Sulphur is used primarily in the production of sulphuric acid, which in turn is used in the production of phosphatic fertilizers. The sulphuric acid is also used in hydrometallurgical processes, in the production of synthetic rubber and plastic materials. Natural sulphur is used in the production of sulphur dyes, gunpowder and pyrotechnics.

Quality and Specifications

Crude sulphur (elemental sulphur), whether as a liquid or solid has a minimum sulphur content of 99.55 percent. Sulphuric acid, the primary use of elemental sulphur, is marketed on a 100 percent basis (32.69 percent sulphur content) but shipped at 66ºC Baumé (93 percent H_2SO_4), as 98 percent acid, or as a sulphur trioxide dissolved in sulphuric acid known as (20 to 22 percent) fuming oleum.

Market Trends

Current production of recovered sulphur is expected to increase from petroleum refineries due to an increase in refining capacity, and as refineries seek to remove even more sulphur from petroleum products.

It is expected that these increases in recovered sulphur production will further diminish direct native sulphur production. By-product sulfuric acid production will remain depressed in the United States as long as copper smelters are at reduced production. Worldwide, copper production costs are lower than in North America, so acid production has not decreased drastically. Increased sulphur production is more likely.

Frasch sulphur production and roasting pyrites production have little chance of significant long-term increases because of the continued growth of elemental sulphur recovery for environmental reasons rather than demand. Thus, discretionary sulphur has become increasingly less important. Pyrites with significant production costs are an even higher-cost raw material for sulphuric acid production.

Over the long term, sulphur and sulphuric acid will continue to be important in agricultural and industrial applications, although consumption is not expected to equal production. World sulphur demand for fertilizer is forecast to increase at 2.7 percent per year for the next eight years.

However, the most important changes in sulphur consumption will be in location. For example, phosphate fertilizer production, where most sulphur is consumed, is projected to increase by about 2.3 percent per year through 2010. With new and expanding phosphate fertilizer capacity in Australia, China and India, sulphur demand will grow in these areas.

Estimates show sulphur production exceeding consumption by 3 million tonnes for the next 20 years and worldwide inventories reaching 80 million tonnes by 2020. Unless new uses for elemental sulphur are found, the oversupply of sulphur will result in stockpiles accumulating worldwide (Ober, 2000).

Prices

Current prices for sulphur are:

- Canadian, liquid, bright, FOB Rotterdam, tonne C$60-70
- French, Polish, liquid, ex-terminal, Rotterdam, tonne C$66-71
- Canadian, solid state, FOB Vancouver, spot C$24-31
- Canadian, solid state, FOB Vancouver, contract C$22-27

Economic Factors

Sulphur is considered to be a pollutant, and legislation around the world is being designed to reduce the levels of sulphur dioxide emissions from industrial plants such as power plants, oil refineries and smelters. As this occurs, large volumes of sulphur are produced, with production now exceeding consumption. This trend is expected to continue.

Yukon Occurrences

There are no major sulphur occurrences reported in Yukon Minfile 2001.

Exploration Guidelines

Natural gas development in the Yukon will contribute to sulphur stockpiles.

TALC AND PYROPHYLLITE TAL

Chemical and Physical Characteristics

Talc ($Mg_3Si_4O_{10}$ $(OH)_2$ is a pale green, grey or creamy white hydrous magnesium silicate. It has a pearly luster, is soft (1), has a greasy feel and is usually very smooth. A massive talcose rock is called steatite and an impure massive variety is known as soapstone.

Phyrophyllite ($Al_2SiO_4O_{10}(OH)_2$ is a hydrous aluminum silicate with a structure similar to talc although it has a slightly greater hardness than talc (1-2 on Mohs scale of hardness). Its physical properties are similar to those of talc.

Deposit Examples

Carbonate-hosted talc deposits - Gold Dollar, Red Mountain, Saddle Occurrences, British Columbia; Henderson Talc Deposit, Ontario, (Canada); Treasure Mine, Montana; Gourverneur Talc, New York State (United States); Trimouns deposit (France).

Ultramafic-hosted talc-magnesite deposits - Rawhide, South Talc Lake Deposit, Gisby, British Columbia; Deloro magnesite-talc deposit, Ontario (Canada); Lahnaslampi mine (Finland); Three Springs talc operation, Western Australia (Australia); Haicheng, Liaoning Province, (China).

Pyrophyllite - Newfoundland deposits; Princeton (Tertiary volcanics), British Columbia, (Canada); North Carolina, (United States)

General Geology

Carbonate-hosted talc deposits - most economic carbonate-hosted talc deposits are lenticular or have sheet-like bodies and are concordant with surrounding marbles, siliceous dolomitic marbles, dolomites, schist and phyllites. The massive or schistose ore consists mainly of talc and may include dolomite, tremolite, calcite, magnesite, chlorite, serpentine, or phlogopite. In most cases, podiform or deformed, sheet-like bodies are oriented subparallel to the compositional layering within marbles and to geologic contacts. They are commonly folded, or pinch and swell. Typically dimensions are 2-20 metres thick and tens to hundreds of metres along strike and dip. Where fluids were the principal source of heat and/or silica, breccia zones and irregular deposits may occur near fault intersections. Ore varies from fine-grained, massive or layered talc to coarse talc schist. Mineralization is mainly Precambrian to Early Paleozoic but may be younger and in most cases syn-or post-metamorphic. The main ore controls are the presence of dolomite or magnesite protolith, and the availability of silica and favourable metamorphic/metasomatic conditions. Most carbonate-hosted talc deposits are believed to be formed by the following reaction:

$$3\ \text{Dolomite} + 4SiO_2 + H_2O = 1\ \text{Talc} + 3\ \text{Calcite} + 3CO_2$$

Associated deposit types are chlorite deposits, sedimentary-hosted magnesite deposits and deposits such as Balmat, which is probably a metamorphosed sedex deposit (Simandl and Paradis, 1999).

Ultramafic-hosted talc-magnesite deposits - ultramafic-hosted talc-carbonate deposits are located either along regional faults cutting ultramafic rocks, or at contact between ultramafic rocks and siliceous country rock. The ultramafic host rock is typically, but not necessarily of ophiolitic affiliation. Deposits related to regional fault systems cutting ultramafic host rock are commonly magnesite-rich. Deposits located within sheets of serpentinized peridotite, found along the periphery of ultramafic intrusions or near the borders of tectonically transported peridotite slices are typically talc-rich. Mineralization is Precambrian or younger. Post or syn-tectonic occurrences are found typically in obducted, accreted or otherwise tectonically transported seafloor and ophiolite slices or lenses, and in ancient greenstone belts. However, serpentinized ultramafic intrusions regardless of tectonic environment, should be considered a favourable host.

Ore is massive or schistose, and the talc has fine, to coarse flakes. Permeable fault zones or serpentinite-siliceous rock contacts control the sites of talc formation. Talc deposits are commonly magnesite-rich and are linked to CO_2 and H_2O metasomatism (carbonatization and hydration) of ultramafic rocks by fluids, following faults and contacts. The following reactions illustrate the concept:

$$18\ \text{Serpentine} + \text{Magnetite} + 30CO_2 \rightarrow 9\ \text{Talc} + 30\ \text{Breunerite} + 27\ H_2O + \tfrac{1}{2}O_2$$
$$2\ \text{Olivine} + 1CO_2 + 1H_2O \rightarrow 1\ \text{Serpentine} + 1\ \text{Magnesite}$$
$$2\ \text{Serpentine} + 3CO_2 \rightarrow 3\ \text{Magnesite} + 1\ \text{Talc} + 3\ H_2O$$
$$1\ \text{Serpentine} + 2\ \text{Quartz} \rightarrow 1\text{Talc} + H_2O$$

Talc was formed during metasomatism and/or regional metamorphism. Silica required for talc formation was derived from the country rock. Associated deposit types may include chrysotile deposits, magnesite veins and stockworks, podiform chromite deposits, dimension stone deposits and possibly nephrite and listwanite-related gold deposits (Simandl and Ogden, 1999).

Pyrophyllite - is a relatively uncommon mineral. It is found in association with acid volcanic rocks as a hydrothermal or metasomatic alteration of feldspars in rhyolites, dacites and andesites and their volcaniclastic equivalents. Associated minerals are kaolinite, alunite, quartz, sericite, montmorillonite, dispore, corundum and less commonly pyrite, chlorite, feldspar, hematite and magnetite. Pyrophyllite deposits can be located in shear zones near granitic contacts.

World Production

The estimated talc and pyrophyllite world mine production during 2001 was 9.49 million tonnes. Leading producers included China (3.5 million tonnes), the United States (915,000 tonnes), Republic of Korea (770,000 tonnes), and Japan (740,000 tonnes). Canada produced 86,000 tonnes (phyrophyllite, talc and soapstone) (Virta, 2002).

End-Use

Talc - ground (micronized) talc in the United States is consumed in ceramics (28 percent), paint (21 percent), paper (20 percent), roofing (8 percent), plastics (5 percent), rubber (4 percent), cosmetics (3 percent), and in other uses (11 percent). Micronized talc acts as a filler in paint, plastics, paper, rubber and adhesives. In paint, talc has a reinforcing effect, controls viscosity, and prevents sagging of paint films which controls gloss. In plastics, talc has a reinforcing effect, increases heat resistance, reduces mold shrinkage, improves melt rheology and reduces mold cycle time. In pharmaceuticals and cosmetics talc's greasy feel, fragrance retention and hiding power along with lubricity and ease of dispersion are important qualities to manufacturers. In roofing products, talc acts as a stabilizer for melted asphalt, increasing its resistance to fire and weathering. Talc also prevents shingles from sticking together.

Impure massive talc known as 'soapstone' is used as a carving stone.

Pyrophyllite - virtually chemically inert, has a low thermal expansion, low thermal conductivity, high dielectric strength, high melting point, good corrosion resistance and low electrical conductivity making it a suitable ceramic and refractory raw material. Refractory uses include alumina-silica monolithics, insulating firebricks, kiln car refractory and foundry mould coatings. In ceramics it is used in both whiteware (tiles, sanitaryware, tableware) and electrical porcelain. Because of its chemical inertness, neutral pH, absorbency and flowability, it is used in pesticides and specialty fertilizers. White grades of pyrophyllite are used in filler applications such as rubber, paint, mortars, and vinyl flooring.

Quality and Specifications

The physical properties used to determine the possible applications of talc concentrates include mineral composition, dry brightness, whiteness, specific gravity, oil absorption, pH, particle size distribution, tapped density, loose density, Hegman fineness, and chemical composition including loss on ignition (LOI). Slip is the general smoothness of greasiness of the mineral when tested in powder form. Grit may form due to contamination by quartz or aluminosilicate minerals. The "grittiness" is measured by the Valley Abrasion Test which indicates in milligrams, the wear on a piece of wire testing cloth.

Actinolite, tremolite and anthophyllite are the most common impurities in talc from some deposits, and because of environmental restrictions on these minerals, may limit the end-uses for such talc.

Tables 98 and 99 illustrate typical chemical composition of some commercial deposits and how the mineral composition of talc deposits influences potential end use (adapted after The Industrial Minerals Handybook II, pgs. 182-184).

Table 98

Chemical Composition of Commercial Talc (%)

	Canada (Cosmetics)	*USA Montana (Filler)*	*USA New York (Ceramics)*
SiO2	61.5	61.5-63.1	57.3
MgO	31.3	31.0-32.9	30.7
CaO	0.4	0.19-3.90	6.17
Al2O3	0.1	0.93-2.37	0.38
Fe2O3	1.3	1.0-1.3	0.16
TiO2		0.05-0.13	
K2O		0.01-0.41	
LOI	5	5.5-6.2	13.8
Brightness	88	70-84	

Table 99

Talc Composition Influences End-Use	
Ceramic Grade	Minimum 30% MgO and 60% SiO2, max. 1% CaO, 4% Al2O3, 1.5% Fe2O3, 0.4% alkali (talc containing tremolite is particularly well suited); 95% -325 mesh. Uniform chemical composition, PSD, with constant colour and shrinkage rate on firing.
Cosmetic Grade:	Max. 0.1% water-soluble substances, 6% acid-soluble substances, 6% LOI @ 1,000ºC, 0.1-1.0% quartz, 0.1% tremolite, 3ppm As, 20ppm Pb, 40 ppm heavy metals, neutral pH, no fibrous materials, grit or bacteria; odor, slip or lubricity, fragrance retention and whiteness according to customer preference; -200 mesh with APS 7µm.
Paint Grade:	Minimum 88% Mg and Ca silicates, max. CaO, 1% water-soluble matter, 1% moisture and other volatiles, 7% LOI, -325 mesh; good oil absorption (ASTM D281-84 which measures the number of parts of acid-refined linseed oil required to produce a coherent paste with 100 parts of talc pigment), brightness (>90%), and consistency.
Pitch Control:	12m^2/g min. surface area, >78 GE brightness; low abrasion; APS of 2-5 µm.
Paper Grade:	Less than 78GE brightness; controlled top size (50µm max.) APS of 8-12 µm.
Roofing Grade:	Low-grade with particle size of –80 mesh.
Rubber Grade:	Less than 2µm median with controlled top size.
Sculpturing Grade:	Soapstone requires attractive colouring, freedom from cracks, and homogenity.

Tables 100 and 101 illustrate the chemical composition of some commercial deposits and the composition of pyrophyllite (adapted after The Industrial Minerals Handybook II, pg. 143).

Table 100

Chemical Composition of Commercial Pyrophyllite (%)

	South Korea (White Cement)	*South Korea (clay filler)*	*USA (Ceramics)*	*Japan (Refractory)*
SiO2	83-87	65-71	57.8	75.76
Al2O3	9-12	21-27	33.31	17.68
Fe2O3	0.15-0.30	0.15-0.25	0.33	0.57
CaO		-	Trace	0.28
MgO		-	Trace	0.02
K2O		-	3.90	0.96
Na2O		-	0.06	0.15
TiO2		-	NA	0.31
LOI	2.9-3.4	4-5	5.56	4.38

Table 101

Composition of Pyrophyllite (%)

Minerals		***Chemistry***		***Screen Analysis Cumulative % retained (US Sieve)***	***Particle Size (% µm)***
Refractory Grade (low-sericite)					
Pyrophyllite	40-50	SiO_2	75.0	4	17.0
Quartz	30-45	Al_2O_3	19.3	8	40.0
Sericite	5-15	Fe_2O_3	0.8	16	57.8
Kaolin	1-3	Na_2O	0.1	30	72.5
		K_2O	0.1	50	80.8
		CaO	0.1	100	84.4
		LOI	3.9	200	88.6
				325	92.0
Ceramic Grade (high-sericite)					
Minerals		Chemistry		Screen Analysis Cumulative % retained (US Sieve)	Particle Size (% µm)
Pyrophyllite	20-30	SiO_2	80.9	40	90
Quartz	50-60	Al_2O_3	13.8	30	78
Sericite	20-25	Fe_2O_3	0.2	20	58
Kaolin	5-10	TiO_2	0.1	10	28
		Na_2O	0.4	5	10.6
		K_2O	2.3	2	1.6
		LOI	2.3	1	Nd

Market Trends

Growth in major markets for talc, such as ceramics, paint and paper, has leveled off during 2002. However, with the current construction boom in North America, the consumption of adhesives, ceramics, joint compounds, paint and roofing markets all of which consume talc, should maintain current levels of production and prices in the coming 2-3 years.

Recently, the talc industry has had to address questions concerning the potential health risk posed by exposure to some talc products. Of particular concern to the US National Department of Health and Human Services was the use of fibrous talc in wax crayons. This was resolved when crayon manufacturers agreed to eliminate fibrous talc from their products. However, the controversy has highlighted the continuing concerns over the risks posed by asbestos, tremolite, fibrous talc, and other fibrous minerals (Virta, 2001).

Price

Talc prices vary depending on the quality and the degree and method used for processing. Approximate prices for talc ranged from US$87 to $345 per ton with some sculpting grade talc and products such as body powders selling above US$1000 per ton. It is important to note that prices should be used only as a guideline, because actual prices depend on the terms of the contract between the seller and buyer.

Similar to talc, prices received for pyrophyllite depend on their end-use and will be influenced by the alumna content, levels of iron and other impurities, colour abrasiveness and absorbency. During 2002, Japanese pyrophyllite ore ranged from US$10 to $100 per tonne while processed pyrophyllite sold for between US$150 and 400 per tonne (Virta, 2001).

Economic Factors

Carbonate-hosted talc deposits - grades in talc deposits are variable. For example, New York State talc ores commonly contain over 50 percent associated minerals such as tremolite, actinolite and/or anthophyllite. Each talc deposit is unique and the degree to which it must be processed depends on the end use of the product. The physical and chemical properties are tested and the importance or applicability of each test depends on the specification of the consumer (Simandl and Paradis, 1999).

Ultramafic-hosted talc-magnesite deposits - grade and deposit sizes are variable. For example, the Deloro talc deposit in Ontario consists of 54 percent magnesite and 28 percent talc. It is about 1800 metres in length, 300 metres wide and has been drilled to a depth of 120 metres. The Lahnaslampi orebody in Finland contains over 30 million tonnes exceeding 50 percent talc and 0.1 to 0.2 percent nickel (Simandl and Ogden, 1999).

Yukon Occurrences

There are no reported talc occurrences reported in the Yukon although ten references describing talc as an alteration mineral were reported in Yukon Minfile 2001. However, the geology of the Yukon offers good potential for the discovery of talc deposits. A brief description of these settings is provided:

Altered Ultramafic Rocks - the association with serpentinite and ultramafics is the most common setting for talc deposits in the Cordillera. Talc forms as a result of low temperature alteration of magnesia-bearing minerals such as olivine, hypersthene, enstatite and augite. Talc can also form by direct metasomatism of ultramafic rocks or serpentinites and is usually found at the margins of ultramafic bodies or within shear zones. Talc deposits are usually associated with abundant carbonate.

The highest purity talc deposits are generally associated with magnesium carbonate rocks and talc of lesser purity comes from altered ultrabasic igneous rocks. There are many ultramafic belts in the Yukon. These are ideal settings for high-purity talc deposits.

Schist - is a common host for talc alteration. Good exploration targets are chloritic, quartz-sericite-graphite or low grade metamorphic mineral assemblages. The pre-metamorphosed sediments are the source of magnesia and silica.

Dolomite and Magnesite - talc may form through direct alteration of dolomitic sedimentary rocks. Approximately 15 percent of known talc occurrences in British Columbia for example, are hosted in this rock type and may provide a good exploration target for new occurrences of talc in the Yukon.

Mafic Volcanics - talc is formed, as a result of magnesia-bearing solutions circulating through mafic volcanics and is concentrated along faults. The Chu Chau talc deposit (Minfile 092P14O) in British Columbia is an example of this type of deposit where talc-magnetite bands of up to 7.5 metres occur in mineralized zones of siliceous, fine-grained, fractured, cherty, tuff. These zones also contain pyrite and magnetite, with dark grey talc in breccia zones.

In outcrop, talc-bearing zones may form ridges where chemical processes dominate, and topographic lows in areas where physical weathering and/or glaciation were prevalent.

Exploration Guides

Carbonate-hosted talc - electromagnetic surveys can identify either carbonate contacts within other lithologies, or talc-related fault zones, impregnated with water.

Talc occurs within belts of dolomitic rocks in metamorphosed terranes, or adjacent to intrusive rocks. Contacts with silica-bearing metasediments or intrusions are favourable hosts for talc deposits (Simandl and Paradis, 1999).

Ultramafic-hosted talc-magnesite deposits - ultramafic rocks are characterized by the Mg, Fe, Cr, Ni and Co suite of elements. Under normal conditions, this signature may be reflected in soils, streams or lake-sediments, and in overburden. Unserpentized portions of the host ultramafic rocks commonly correspond to strong airborne and ground magnetic anomalies, whereas talc-rich zones correspond commonly to airborne electromagnetic lows.

Talc-rich zones coincide commonly with topographic lows and can be covered by lakes and swamps. Some talc deposits exhibit zoning from siliceous country rock (quartz-sericite-chlorite schist) into chlorite schist, then into the talc-bearing rocks (talc-carbonate-serpentine-bearing schist, steatite) with a serpentinite core. Deposits are located within sheets of serpentinized periodotite, along the periphery of ultramafic intrusions or in thin, tectonically transported slivers, slices or lenses of peridotite. The ultramafic rocks and major faults may be detected by modern remote sensing technologies (Simandl and Ogden, 1999).

TITANIUM MINERALS TI

Chemical and Physical Characteristics

Titanium is not naturally found in its metallic form but occurs in many minerals forms such as oxides, titanates, and silicontitanates. As the ninth most abundant element in the Earth's crust, titanium is present in most rocks and soil. The titanium-bearing minerals that have significant economic importance include ilmenite ($FeO \cdot TiO_2$), leucoxene (TiO_2), rutile (TiO_2) and anatase (TiO_2).

Deposit Examples

Magmatic Ti-Fe±V Oxide Deposits - Lac-du-Pin-Rouge, Lac Tio, Magpie, Quebec, (Canada); Sanford Lake, New York, (United States); Tellnes, Egersund (Norway), Smaalands-Taberg, Ulvno (Sweden).

Heavy Mineral Placer Beach Sands - Murray Basin, (Australia), Kwale mineral sands, (Kenya).

General Geology

Rutile occurs in feldspathic pegmatites with ilmenite in Virginia, United States; as dissemination in an albite aplite, in southern Norway; and as placer beach sands, in Australia, South Africa, Madagascar and Sierra Leone.

Primary ilmenite deposits occur as ilmenite-magnetite and ilmenite-hematite bodies associated with gabbros and anorthosites from which they have become segregated during crystallization of the magma. Secondary placer accumulations occur as beach, bar, dune and stream sands. The requirements for the concentration of beach deposits include:

- A hinterland of crystalline rocks with constituent heavy minerals;
- Deep weathering of the source rocks;
- Uplift and rapid erosion of the weathered source and quick dumping of the erosion products into the sea;
- Emergence of a coastline with long-shore drift and high-energy waves, to concentrate the heavy mineral.

In Quebec (Lac Tio), ilmenite-hematite ore occurs in a sill-like ore body of anorthosite and anorthositic gabbro that is thought to be a late magmatic gravitational accumulation of oxides injected into the parent anorthosite.

Magmatic Ti-Fe±V oxide deposits - these deposits are associated with anorthosite-gabbro-norite-monzonite (mangerite) charnockite granite suites that are interpreted to be anorogenic and/or extensional. Some iron-titanium deposits occur at continental margins related to island arc magmatism, followed by an episode of orogenic compression.

The deposits occur in intrusive complexes that typically are emplaced at deeper levels in the crust. Progressive differentiation of liquid residual from anorthosite-norite magmas leads to late stage intrusions enriched in iron and titanium oxides and apatite. Typically, plagioclase crystallization results in concentrations of iron, and titanium in residual magmas which crystallize to form ferrodiorites and ferrogabbros. Layers form by crystal settling and accumulation on the floors of magma chambers. The disseminated deposits are believed to have formed in-situ. The origin of the discordant deposits, associated with Proterozoic anorthosites, is not well understood. Two genetic models have been suggested, remobilization of the crystal cumulates into cracks or fractures; or emplacement as a Fe-Ti-oxide-rich immiscible melt with little silica.

Deposit forms can be lensoid, dike-like or sill-like bodies of massive ore, or disseminated in mafic host rocks. Some ore is disseminated as layers in layered intrusions. Typically, the massive material has sharp, cross-cutting contacts with its anorthositic hosts forming large lenses, tens to hundred of metres wide and several hundred metres long. In layered deposits, individual layers range from a few centimeters to several metres thick, and can be traced over several thousand metres.

Associated deposit types include Ni-Cu-Co magmatic sulphide deposits, chromite deposits, (e.g. Bushveld Complex in South Africa), platinum group deposits (e.g. Bushveld Complex), and placer ilmenite, magmetite, rutile and zircon.

Titaniferous magnetite deposits associated with zoned ultramafic complexes in British Columbia (Tanglewood Hill - 092HSE035) and Alaska (Lodestone Mountain 092HSE034) are classified as Alaskan-type ultramafic deposits (Gross, Gower and Lefebure, 1999).

World Production

During 200l ilmenite supplied about 90 percent of the world's demand for titanium minerals. The estimated world ilmenite and rutile mine production during 2001 was 4.2 million tonnes and 380,000 tonnes respectively. Leading ilmenite producers included Australia (1.19 million tonnes), South Africa (1.0 million tonnes), and Canada (720,000 tonnnes). Leading rutile producers included the United States (220,000 tonnes), South Africa (90,000 tonnes), and the Ukraine (55,000 tonnes). Total world production of mineral concentrates (TiO_2) produced from ilmenite and rutile during 2000 is estimated at 417,000 tonnes (Gambogi, 2002).

End Use

Approximately 95 percent of titanium is consumed as TiO_2 pigment used in paints, paper, rubber, printing inks, cosmetics, soap, pharmaceuticals and plastics. The superiority of TiO_2 as a pigment is attributed to its high opacity (high refractive index of 2.55-2.7), reflectivity (brightness and whiteness), inertness (colour retention), tinting strength, non-toxicity and thermal stability over a wide range of temperatures.

Titanium metal alloys are used in aerospace and other industries for their high strength-to-weight ratio, and corrosion resistance.

Quality and Specifications

Mineral concentrates - commercial forms of titanium mineral concentrates include ilmenite, leucoxene, rutile, with titanium slag, and synthetic rutile produced from ilmenite. The concentrates are mainly used as a feedstock for titanium dioxide pigment (TiO_2) production. The need for higher titanium feedstocks has encouraged the upgrading of ilmenite to titaniferous slag, or synthetic rutile.

Metal - titanium sponge is the rudimentary form of titanium metal. The initial production step involves the chlorination of titanium-containing mineral feedstocks to produce titanium tetrachloride ($TiCl_4$). $TiCl_4$ is then reduced with magnesium, to form titanium sponge.

TiO_2 pigment - is produced from titanium mineral concentrates by either the chloride process or the sulphate process. In the sulphate process, ilmenite or titanium slag is reacted with sulphuric acid. Titanium hydroxide is precipitated by hydrolysis and is filtered and calcined. In the chloride process, rutile is converted to $TiCl_4$ by chlorination in the presence of petroleum coke. $TiCl_4$ is then oxidized with air or oxygen at about 1,000ºC. The resulting fine-size TiO_2 is calcined to remove residual chlorine, and any hydrochloric acid that may have formed during the reaction.

Tables 102 illustrates the composition of titanium minerals for some commercial deposits.

Table 102

The Composition of Titanium Minerals and Products

Ilmenite	E. Australia (ISK Minerals Pty Ltd.)	W. Australia (RGC Mineral Sands Ltd.)
TiO2	60	55.5
Fe2O3	30	28.9
FeO	6	20.7
Al2O3	0.8	1.3
Cr2O3	0.05	0.03
V2O5		
SiO2	0.4	0.85
P2O5	0.014	0.03
U+Th (ppm)	210	<70
Rutile	Australia, (Mineral Deposits Ltd.)	Australia, (Consolidated Rutile Ltd.)
TiO2	95.2	95.5
ZrO2	0.5-0.95	0.69
SiO2	0.7-1.0	0.72
Fe2O3	0.5-0.9	0.53
Cr2O3	0.18-0.28	0.16
V2O5	0.58-0.65	0.75

Source: adapted after The Industrial Minerals HandyBook II, pg. 189

Market Trends

Demand for TiO_2 pigment is expected to remain at current levels in the foreseeable future. Over the next three years, global economic growth is expected to increase TiO_2 pigment. The consumption of titanium minerals is expected to follow a similar trend. This of course is dependent on a healthy global economy. In the titanium metal industry, the resumption of some aerospace orders is expected to increase demand for titanium metal products. Long-term growth in passenger traffic and nonaerospace markets is expected to result in a five percent per year demand growth over the next decade (Gambogi, 2000).

Australia, Canada and South Africa dominate the titanium feedstock industry in terms of production and exports. Rutile is more restricted than ilmenite, and production is dominated by Australia, South Africa, and Sierra Leone. Titanium slag is produced in Canada, South Africa and Norway. Overall, titanium mineral production is geographically restricted and therefore, large quantities enter deep-sea trade. Titanium dioxide plants are generally located close to consuming markets rather than to raw material supply. Importers are usually the developed countries.

Syncrude Canada Ltd. continues to investigate the recovery of heavy minerals from tailings of the Athabasca oil sands operations in northern Alberta. According to Syncrude, 220,000 tonnes per year of TiO_2 could be recovered. In 2000, Syncrude's research was focused on finding an alternative to calcining, as a method for bitumen removal (Gambogi, 2000).

Price

Ilmenite and rutile prices reported by Industrial Minerals, No. 419 during August 2002 were:

Ilmenite - Bulk concentrates, Australian, minimum 54% TiO_2, FOB, US$85-100; Spot prices US$100-115.
Rutile - Australian concentrate, minimum 95% TiO_2 FOB; Bulk (large volume, for pigments) US$420-470; Bagged (small parcels, for welding rods, etc.) US$430-540.

Economic Factors

Ilmenite deposit size and grades are variable. They may range from reserves of several hundreds of millions of tonnes with grades from 10 to75 percent TiO_2, 32-45 percent iron and less than 0.2 percent vanadium. The Lac Tio deposit for example, contains more that 125 million tonnes of ore averaging 32 percent TiO_2 and 36 percent FeO.

Titaniferous magnetite deposits can range up to a billion tonnes with grades between 20 to 45 percent iron, 2 to 20 percent TiO_2 and less than seven percent apatite with vanadium averaging 0.25 percent.

Fewer environmental pollution problems are encountered when pigment is produced from rutile rather than ilmenite. The chloride process, using a rutile feed, generates about 0.2 tonnes of waste per tonne of TiO_2 product. The sulfate process on the other hand, which uses ilmenite, generates about 3.5 tonnes of waste per tonne of product. Producing synthetic rutile from ilmenite, results in about 0.7 tonnes of waste, mainly iron oxide, per tonne of product.

Yukon Occurrences

There are no major titanium occurrences documented in the Yukon. Two minor or trace occurrences are reported in Yukon Minfile 2001 (Table 103; Figure 4).

Table 103

Yukon Titanium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105D 169	105D/3	MATT	CPC	V	60º00’18”/135º22’25”
2	105L 045	105L/14	CLEAR LAKE	SB	Sedex	62º47’07”/135º07’56”

CPC (Coast Plutonic Complex); SB (Selwyn Basin); V (Vein).

Magmatic deposits are currently being investigated as a source of titanium minerals in British Columbia and Alaska and would be good exploration targets for titanium minerals in the Yukon.

Ilmenite and rutile and to a lesser extent anatase, are common constituents of Yukon placer concentrates. During 2002, eleven (11) raw gravel samples were collected by an independent geologist on behalf of claim owner Peter Risby, to assess the sites REE potential. The samples, taken from White Channel gravels on low benches from placer claims located approximately 30 kilometres south of Dawson City on the Indian River, were found to contain anomolous tin (Sn), titanium (Ti) and scandium (Sc) values (Table 104).

Table 104

Indian River Placer Claim Concentrate Sample Analysis

Sample	*Latitude/Longitude*	*Wet Wt. (lb)*	*Estimated dry Wt. (lb)*	*Dry Wt. Screened concentrate (lb)*	*Sn (ppm)*	*Sc (ppm)*	*Ti (ppm)*
Gov’t Site	N/a	60.16	54	0.24	18200	32	16,900
Top 40	N/a	63	57	0.32	261	10	630
Christy 1	N/a	55	50	1.06	5823	20	1110
Christy 2	N/a	45	40	0.52	1800	16	10300
Average					6521	19.5	7235
R1	63º46’13”/139º21’24”	73	66	0.92	33	30	3600
R2	63º46’08”/139º21’25”	85	76	1.16	257	15	7500
R3	N/a	73	66	1.00	600	30	4400
R4	N/a	65	58	0.76	53	30	7000
R5	63º45’10”/139º17’00”	73	66	4.32	100	54	3600
R6	N/a	78	70	6.32	75	40	2500
R7	N/a	71	64	7.20	100	31	2600
Average					174	32.86	4457

Source: Peter Risby

Following initial analytical results, a 150 pound bulk sample of raw field gravel was screened using a simple gravity separation process. Once screened, the sample was divided into five-pound samples and assayed according to screen size to establish which screened sample would obtain the highest values of Sn, Sc and/or Ti (Table 105). Results suggest, the –20+40 mesh and the –40 mesh screened samples will result in the highest Sn and Ti values.

Table 105

Analysis Five-Pound Samples Taken from a 150 Pound Bulk Sample (Indian River, Yukon)

Sample #	*Screen Size*	*Sc (ppm)*	*Ti (%)*	*Sn (%)*
1	Black-mags	5	0.64	0.08
2	+14 mesh	78	3.70	1.47
3	-14+20 mesh	91	0.95	12.69
4	-20+40 mesh	64	1.34	21.54
5	-40 mesh	72	5.91	1.77

Source: Peter Risby

Further investigation of the claims for tin, titanium and scandium as well reserve potential of these metals is planned (Peter Risby, personal communication).

Exploration Guidelines

Exploration methods used to locate magmatic Ti-Fe oxide deposits include:

- Identification of heavy mineral concentrations of ilmenite and titaniferous magnetite in placer deposits;
- Abundant apatite in placer deposits;
- Recognition of the association of deposits with anorthosite and gabbro intrusive complexes along deep fracture and fault zones;
- Ti, Fe, V, Cr, Ni, Cu, Co geochemical anomalies;
- Magnetic or electro-magnetic (EM) response. If the deposit is ilmenite-rich it may exhibit either a subdued or a strong negative anomaly. Sometimes the subdued response displays characteristic irregular patterns of negative and positive anomalies, that show broad smooth profiles, or patterns.

WOLLASTONITE WOL

Chemical and Physical Characteristics

Wollastonite ($CaSiO_3$) is a white to grey coarsely bladed non-metallic crystalline mass that breaks down into high-strength acicular cleavage fragments. Acicular crystals may be porphyroblastic, often forming rosettes that display fan-like textures.

Deposit Examples

Seeley Bay, Mineral Hill, Zippa Mountain, Rossland wollastonite, British Columbia (Canada); Fox Knoll and Lewis, New York (United States); Lappeenranta (Finland); Khila, Belkapahar (India); Liaoning Province, (China).

General Geology

Wollastonite skarn deposits form irregular masses or lenses in metamorphosed calcareous rocks that are usually adjacent or in close proximity to an igneous intrusion. The mineral occurs at the contacts of carbonate or siliceous calcareous rocks, with igneous intrusions, or within roof pendants of carbonate rocks in intrusive bodies. Some deposits are located in metasedimentary sequences lacking known intrusive bodies and are associated with mylonite zones that acted as channels for fluids. In these cases, it is difficult to determine if they are related to regional metamorphism, or very distant intrusives.

Host rocks are usually calcitic marble, limestone or calcite-rich siliceous metasediments. Associated igneous rocks are usually felsic intrusives, charnockites, pegmatites or gabbros. Gangue minerals are commonly garnets, clinopyroxene, calcite and rarely sulphides.

Deposits range in age from Precambrian to Tertiary and associated deposit types include Cu, Zn, Pb, Mo, and Au-bearing skarns.

World Production

World production of wollastonite was estimated to be between 580,000 and 630,000 tonnes during 2001. Leading producers (approximate tonnages) included China (300,000 tonnes), India (100,000 tonnes), Mexico (30,000 tonnes), and Finland (20,000 tonnes).

Canada's only wollastonite producer at Lac St.-Jean in Quebec, ceased production during 2001 (Virta, 2001).

End-Use

Wollastonite's main consuming markets are in ceramics, plastics and paint. With a high-aspect ratio (HAR) of up to 20:1, wollastonite is used as a substitute for asbestos, and to provide flattening, thermal and physical strength, and to prevent corrosion and abrasion when applied as a filler in coatings, plastics and rubber. Low-aspect ratio (LAR) wollastonite when powdered (10-75 µm) has an aspect ratio of up to 5:1, and is used as a source of calcium and silica in the manufacture of ceramics and glass and as a low temperature flux in metallurgy.

When used as a filler, the minerals acicularity, high brightness (90-93 percent), chemical inertness, a pH of 9.9, thermal stability, high melting point (1,540ºC), electrical insulation properties, and low moisture and oil absorption, facilitate its use in plastics, rubber, boards and panels.

In coatings, acicular particles (3-8µm) act as a good flattening agent and allow paint to settle out after application. The interlocking particles improve toughness and durability. With brightness between 84 to 93 percent and with its high whiteness, the mineral reduces pigment load. Its very low oil absorption value of 26 percent, further reduces the volume of binder required.

Quality and Specifications

There are three main grades of wollastonite: high aspect ratio (HAR), (15:1 to 20:1) low aspect ratio (LAR) (3:1 to 5:1) and synthetic wollastonite, all of which can be chemically treated to improve their industrial performance.

Important chemical and physical properties include a high aspect ratio (15 to 20:1), whiteness, high brightness (90 to 93 percent), chemical inertness pH (9.9), oil absorption, high melting point (1,540ºC), refractive index, good thermal insulation, and few impurities.

Tables 106 and 107 illustrate the chemical and physical properties of some commercial natural wollastonite (adapted after Harben, Industrial Minerals HandyBook II, pg. 197).

Table 106
Examples of Chemical Composition of Commercial Natural Wollastonite

	USA (NYCO)	*Russia*	*China (Anhul)*
CaO	47.5	40.64	46.1
SiO2	51.0	37.93	50.59
Fe2O3	0.4	1.56	0.38
MgO	0.1	1.7	1.03
Al2O3	0.2	3.66	0.33
TiO2	0.02	NA	NA
LOI	NA	13.82	1.3

Table 107

Physical Properties of Commercial Natural Wollastonite

	USA/NYCO (NYAD G)	*USA/NYCO (NYAD FP)*	*USA/NYCO (NYAD 400)*
G.E. Brightness	85	70	94
Bulk Density			
Loose	25	85	40
Tapped	50	90	60
Aspect ratio	15:1	5:1	
Particle size	-200	-10	-400

Market Trends

The growth in world production and sales of wollastonite has moderated since 1996, averaging about 2.1 percent per year. This contrasts sharply with the 24 percent growth between 1970 to 1995 and even the 18 percent growth between 1990 and 1995. Slow growth probably will be the trend for the future, because the wollastonite industry appears to be approaching mature industry status. However, the largest growth is likely to be in the plastics sector, notably in lightweight automobile parts. Growth in the ceramics and metallurgical sectors is likely to be slow, since they are mature markets (Virta, 2001).

Competition from alternative materials such as cellulose fiber, vermiculite and perlite is expected to be strong.

Price

Prices for wollastonite have remained stable since 1999 due to a strong demand for high-grade products. However, Industrial Minerals, No. 419, reports prices are falling due to increasing competition and a falling demand for high grades as well as overcapacity. Prices listed during August, 2002 were:

- US ex-works, short ton:Acicular
  minus 200 mesh US$190
  325 mesh US$234
  400 mesh US$258
- Acicular (15:1-20-1 aspect ratio) US$318
- Ground 10µ US$630
- US FOB bulk, per tonne 200 mesh US$209
- 325 mesh US$253

Economic Factors

Deposit grades vary widely from between 20 to 80 percent wollastonite, and reserves can range from 1 to 50 million tonnes. The average deposit size is 1.3 million tonnes at 49 percent wollastonite (Orris, 1992).

Wollastonite is generally mined using open pit methods but if ore grades are greater than 60 percent, underground mining techniques are potentially economical.

Yukon Occurrences

There are no major wollastonite deposits reported in Yukon Minfile 2001 although one report describes wollastonite occurring in a 170 metre wide skarn (Table 108; Figure 4). However, no reserve or grade estimates were documented.

Table 108

Yukon Wollastonite Occurrence

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	115F 050	115F/15	MONDAY	WT	S	61º57’48”/140º48’54”

WT (Wrangellia Terrane); S (Skarn)

Wollastonite is reported to be associated with 16 skarn occurrences, which were evaluated primarily for their precious metal content. However, in all instances there were no descriptions or reports of wollastonite grade or potential reserves in any of these occurrences.

Any systematic exploration program for wollastonite should focus on skarn occurrences, and in particular the contacts of carbonate or siliceous calcarious rocks with igneous intrusions or within roof pendants of carbonate rocks in intrusive bodies.

Exploration Guidelines

Wollastonite skarns are commonly found in calcareous sediments that are cut by igneous rocks. Boulder tracing is a successfully used exploration method. There are no direct chemical indicators for wollastonite, although associated metallic occurrences are detected by geochemical methods. Electromagnetic and magnetic methods may be used to locate intrusive contacts within calcareous rocks.

ZEOLITE ZEO

Chemical and Physical Characteristics

Zeolites are hydrated aluminosilicates of the alkaline and alkaline earth metals such as sodium, potassium, magnesium, lithium, barium and calcium. They have an empirical formula of: M+ M++) $Al_2O_3 \cdot gSiO_2 \cdot H_2O$ where M+ is usually Na or K and M++ is Mg, Ca or Fe. Rarely Li, Sr, or Ba may substitute for M+ or M++.

The groups of minerals are named after the Greek words “zein” and “lithos”, meaning “boiling stones” due to their visible loss of water upon heating. They are inert and white or near white, have pozzolanic properties (cement ingredient) and can be expanded when calcined from 1,200 to 1,400ºC. They have an internal honeycomb structure with pores ranging in size from 2 to 12Å. Cations are loosely bound and allow the zeolites to perform ion exchange. Water molecules can be reversibly expelled, by heating to 350ºC in a vacuum.

There are 48 minerals recognized as members of the zeolite group. Divided by their origin in two main groups, some of the more common zeolites include: clinoptilolite, mordenite, chabazite, phillipsite, heulandite (Open-system zeolites); and analcime, chabazite, clinoptilolite, erionite, mordenite, phillipsite (Closed-basin systems).

Synthetic zeolites, first synthesized in 1930, continue to be developed to higher levels of purity. In 1948, the first zeolite was manufactured, that has no natural equivalent.

Deposit Examples

Open-system zeolites - Clinoptilolite, Asp Creek, Bromley Vale Zeolite, Tailings Tephra, Sunday Creek; British Columbia, (Canada); John Day Formation, Oregon; Death Valley Junction, California, (United States); Yellow tuffs near Naples (Italy).

Closed-basin zeolites - Lake Tecopa, California; Bowie Deposit, Arizona,; Jersey Valley Deposit, Nevada, (United States); Lake Magadi (Kenya).

General Geology

There are two classifications of natural zeolite namely O*pen-System Zeolites* and C*losed-Basin Zeolites*. From an explorationists point of view they are impossible to distinguish.

Open-system zeolites - are hosted by thick, generally non-marine tephra sequences with ore zones up to hundreds of metres that occur as a vertical zonation of zeolites and associated silicate minerals within the host sequence. Zeolites crystallization (zeolitization) in the post-depositional environments ranging from thousands to millions of years, occur in active or unmetamorphosed continental arc-related or other insular volcanic complexes.

Deposits may range in age from Mesozoic to Holocene, but most are Cenozoic. Zeolite deposits in British Columbia for example (Asp Creek, BCMinfile: 092HSE164) are Cretaceous or Tertiary in age. Zeolite bearing rocks are part of volcanic ash and tuff beds with minor intercalated flows. Other rock types include fluviatile mudstone, sandstone, conglomerate and diatomite. Stratabound, stratiform or lens-shaped mineral zonation may crosscut the bedding. The thickness of zeolitic tuffs in major deposits range from hundreds to thousands of metres and may extend over thousands of square kilometres.

Vertical or near-vertical zonations of zeolite are a result of the flow of meteoric water downward in an open hydrologic system with zeolite formation linked to syn- and post-depositional reactions of volcanic glass within alkaline solutions. The zonation of the open-system type of zeolite deposits is similar to the upper zones of burial metamorphism that affected thick sequences of silicic, vitric tuff with temperatures less than 100ºC (although some deposits are thought to form at higher temperatures). Zeolitic tuffs commonly resist weathering and associated deposit types include pumice, bentonite, diatomaceous earth, volcanic-hosted precious opal, peat and coal.

Closed-basin zeolites - are found in varied tectonic settings in closed hydrographic basins in either block-faulted terrains (such as the Basin and Range province), trough valleys associated with rifting (eastern Rift Valley of Kenya) or as Tibet-type grabens formed in a compression environment (Emet and Kirka basins, Turkey). Deposits range in age from Late Paleozoic to Holocene but most are Cenozoic.

Stratabound deposits with thicknesses ranging from ten centimetres to ten metres with areal extent commonly tens to hundreds of square kilometres are found in rhyolitic to dacitic, vitric tuffs, especially those that are alkali-rich. Associated rocks include bedded evaporites (trona, halite, borates), mudstone, diatomite, bedded or nodular cherts, oil shale, conglomerates and sandstones.

Several zeolite types may coexist within the same deposits, with finely crystalline individual tuff beds showing lateral zonation from unaltered glass near the shore to potassium feldspar in the centre of the paleobasin. Zeolite deposits are not preserved in rocks where metamorphism exceeded zeolite facies conditions.

Microcrystalline zeolite formed during early diagenesis of silicic, vitric tuffs deposited in closed hydrographic basins. The zeolites crystallize in the post-depositional environment from thousands to hundreds of thousands of years by reaction of the vitric material with saline, alkaline pore water trapped during lacustrine sedimentation. Locally, zeolites form from detrital clays, feldspar, and feldspathoids and from chemically precipitated aluminosilicate gels in the same depositional environment. Associated deposit types include continental-basin bedded evaporites (trona, halite, borates), diatomite and finely crystalline, disseminated fluorite in lacustrine rocks (Sheppard and Simandl, 1999).

World Production

World production of natural zeolite during 2000 was estimated at between 3-4 million tonnes. Leading producers were China (2.5 million tonnes), Cuba (500-600 thousand tonnes), Japan (140-160 thousand tonnes), and the United States (36,000 tonnes).

Zeolite production in Canada was estimated at 4000 tonnes during 2000 (Virta, 2001).

End-Use

Natural zeolites are used in a variety of applications which in decreasing order by tonnage are: pet litter, animal feed, horticultural applications (soil conditioners and growth media), odor control, oil absorbent, desicant, water purifications, fungicide or pesticide carrier, wastewater cleanup, aquaculture, gas absorbent, and catalyst. Pet litter, animal feed and horticultural applications accounted for more than 65 percent of their usage during 2000 (Virta, 2001).

Quality and Specifications

Table 109 illustrates the chemical composition of some commercial zeolites.

Table 109

Chemical Composition of Commercial Zeolites (%)

	Ash Meadows, CA Clinoptilolite	***Mud Hills, CA PDZ-140***	***Zeolite Na-A Valfor® 100***
Clinoptilolite	90±5		
SiO2	69.1	66.03	69.54
Al2O3	11.9	10.47	9.86
CaO	0.7	1.55	0.88
MgO	0.4	0.58	0.17
TiO2		0.13	0.32
Na2O	3.5	3.25	1.16
K2O	3.8	1.81	4.65
Fe2O3	0.7	1.12	1.92
MnO	0.2	0.027	0.034
H2O			
Pore Size (Å)	4.0	4.0	4.0
Pore Volume (%)	15	15	15
Specific surface area (m^2/g)	40	40	40
PH stability	0-13	3-10	3-10
Cation exchange capacity (m equivalent/g)	1.85	1.65	1.55

Source: The Industrial Minerals HandyBook II, pg. 202.

Market Trends

Natural zeolites are increasingly facing competition from synthetically produced equivalents manufactured for specific end uses.

The market for natural zeolite is mature and growth is likely to be found in environmental, value-added and system-based applications. The spread of anti-phosphate legislation worldwide will expand the market for zeolites and continued research and development is finding new uses for zeolites. For example, the microporous nature of zeolites enables them to store gases, and to release them again when the temperature is raised. This property is being investigated with the intention of using zeolites to store hydrogen as fuel, reducing the risk of explosion.

Currently, the largest consumption of natural zeolites in the USA is in the production of pet litter, animal feed and for horticultural purposes. Zeolites are also in demand worldwide, for use in water purification processes. This market may grow.

The industry is waiting to see how two major environmental concerns play out. The first involves arsenic in drinking water. In experiments, modified zeolites have been shown to remove arsenic to levels below the EPA's new 10 ppb arsenic standard. While companies have three years to come into compliance, the EPA predicted that more than 6,000 water companies in the United States will not be able to comply with even a 20 ppb standard. If this proves true, then the potential for a large demand for modified zeolite, could occur.

Another issue concerns large animal stockyards. Animal waste runoff from these stockyards contributes to local stream pollution. With the advent of "supersized" dairy and hog farms, this has become a major environmental concern. Zeolites already have a proven record for controlling odors. Helping to solidify animal stockyards could prove a considerable market for natural zeolites (Virta, 2001).

Price

Prices received for zeolites vary depending on their use. For example, specialty zeolites having an increased cation exchange capacity receive a greater value, than low-value odour control zeolites. Prices received for ground, low-value industrial mineral use is US$30- 120 per ton. High-value zeolites used for radioactive waste clean up, can sell for more that US$1000 per ton (Sheppard and Simandl, 1999).

Economic Factors

The zeolite content of most economic deposits has a grade of above 60 percent however, deposits supplying the lower-value odour market (for pets) may have zeolite grades of less than 50 percent.

Nearly all zeolite mines are open-pit. The cost of transportation to market is the most important non-technical parameter. Other economic factors to consider include:

- Cation exchange capacity
- Crystal size (2-30 microns) which can affect absorption rates of gases and cation exchange.
- Hardness and attrition resistance.
- Iron staining and other impurities that limit end-use.
- Environmental regulations which may vary with jurisdiction.
- Excessive asbestiform compounds or free silica in the product, which limit marketability.
- Alternative mineral substitutes such as bentonite or attapulgite which are also known for their high absorbency rates and may be more cost effective alternatives, to natural zeolites.

Yukon Occurrences

No zeolite occurrences are listed under commodities in Yukon Minfile 2001. Three properties (Yukon Minfiles 105A 020; 105J 038 and 116B 006) mention zeolite as trace alteration products, but no other information is reported.

Exploration Guidelines

<u>Open-system zeolites</u> - there is no recognized geochemical signature for open-system zeolites. The mineral is identified using analytical techniques such as x-ray diffraction. Geophysical signatures may be recognized through the use of colour-composite imagery from an airborne multispectral scanner. The data is used to distinguish zeolitic tuffs. Other exploration guides include vertical zonation of zeolites and associated authigenic silicate minerals in thick (100 to 1000's of metres) tuffaceous sequences of very low grade or unmetamorphosed volcaniclastic sequences, typically containing large proportions of ash flows.

<u>Closed-basin zeolites</u> - the lacustrine environment of sodium carbonate-bicarbonate type that is favourable for closed- basin zeolites may include a geochemical signature that is enriched in boron and lithium. Geophysical signatures may be obtained through the use of colour-composite imagery from airborne multispectral scanner data, to distinguish zeolitic alteration. Other exploration tools include the recognition that *z*eolites are finely crystalline and may resemble bedded diatomite, or bentonite in outcrop. A combination of x-ray diffraction and cation exchange capacity (CEC) is essential in the early screening of zeolite prospects.

Exploration targets should focus on unmetamorphosed or very low metamorphic-grade environments and molds of evaporitic minerals, associated dolomitic mudstones and Magadi-type cherts. Other environments for zeolites include, recognition of concentric zonation and lateral gradation in a basinward direction of unaltered volcanic glass to alkali-rich, silicic zeolites to analcime and then to potassium feldspar in the central part of the depositional basin (Sheppard and Simandl, 1999).

ZIRCON ZIR

Chemical and Physical Characteristics

The two principal economic sources of the elements zirconium (Zr) and hafnium (Hf) are the zirconium silicate minerals zircon ($ZrSiO_4$) and to a lesser extent baddeleyite (ZrO_2).

Zircon is the primary source of hafnium with both zirconium and hafnium contained in zircon at a ratio of about 50:1. Zircon occurs in stubby, prismatic, sometime dipyramidal crystals that range in colour from colourless to yellow, red, brown, grey or green. Zircon is hard (7), heavy (SG 3.9-4.8) with indistinct cleavage, and conchoidal fracture. Zircon is sometimes perfectly transparent with adamantine lustre and strong birefringence, but may also be opaque, dull and almost isotropic when metamict (structures destroyed by radioactive thorium and uranium, which substitutes for up to four percent of the zirconium). As an accessory mineral in most intrusive rocks, and because it is weather resistant and hard, zircon is found in most clastic sediments and metamorphosed equivalents.

Baddeleyite, a zirconium oxide mineral is a colourless, yellow, brown or black monoclinic mineral found in carbonatites and corundum-syenites.

Deposit Examples

Heavy minerals sands (zircon concentrates) - Natashquan deposit, north shore St. Lawrence River, Quebec (Canada); Capel and Eneabba, Western Australia; North Stradbroke Island, Queensland, Culgoa and Dispersion deposits, Murray Basin, Victoria, (Australia); Hillendale and Fairbreeze deposits , Kwa Zulu Province (South Africa).

Baddeleyite -Kola Peninsula, (Russia)

General Geology

Zirconium may become concentrated in some alkaline rocks (carbonatites and syenites) and may comprise up to 2 percent. Zircon is an accessory mineral in most igneous rocks and in particular granites, pegmatites and nepheline syenites. Since zircon is resistant to weathering and heavier than most associated minerals, it tends to accumulate in placer deposits, particularly beach deposits with other heavy minerals such as cassiterite, monazite, rutile and ilmenite.

Residual phosphate with sand and gravel deposits have the potential to yield substantial amounts of zircon (as a future co-product).

World Production

Global mine production by the seven leading producers: Australia, (400,000 tonnes), South Africa (300,000 tonnes), United States (100,000 tonnes), Ukraine (75,000 tonnes), Brazil (30,000 tonnes), India (19,000 tonnes) and China (15,000 tonnes) produced over 95 percent of the world's zirconium during 2001. Total world production for that year was estimated at 1.07 million tonnes (Hedrick, 2002). World primary hafnium production statistics are not available.

End Use

Approximately 95 percent of all zirconium consumed is in the form of zircon, zirconium oxide or other zirconium chemicals. The remainder is consumed as zirconium metal and zirconium-containing alloys. The major end uses of the mineral zircon are refractories (paints for coating the surfaces of molds), foundry sands, (for increasing resistance to metal penetration and giving a uniform finish to castings), and ceramics (as an opacifier and pigment in glazes and colours for pottery). Zircon is also marketed as a natural gemstone. Its oxide is processed to produce cubic zirconia, a diamond and coloured gemstone, simulant.

Zirconium metal is used in nuclear fuel cladding, chemical processing equipment (pipes, valves, pumps), heat exchangers and as an alloy ingredient in various specialty alloys.

The principal uses of hafnium are in nuclear control rods, nick-based super alloys, in nozzles for plasma, arc metal cutting, and in high-temperature ceramics.

Quality and Specification

Zirconium and hafnium are always associated, and chemical analysis is often based on zirconia (ZrO_2) + hafnia (HfO_2). The typical composition of zircon concentrates, baddeleyite and zirconium oxides are illustrated in Tables 110, 111, and 112 (adapted after The Industrial Minerals HandyBook II, pgs.205-206).

Table 110

Specifications of Commercial Zircon Concentrates

	RGC USA Ceramic	RGC USA Standard	W. Australia Cable Premium	W. Australia Cable Standard
ZrO2	66.40	66.40	65.80	65.50
TiO2	0.13	0.12	0.13	0.20
Fe2O3	0.04	0.04	0.09	0.2
Al2O3	0.35	0.46	0.80	1
SiO2	32.60	32.40	32.14	32.8
U + Th (ppm)	350	350	450	450

Table 111

Typical Composition of Baddeleyite (%)

	96 Abrasive	99E3 Refractory	99E8 Pigment	99SEF Plasma spay
ZrO2 + HfO2	+96	+98	+98	+99
SiO2	1.5	0.6	1.0	0.5
TiO2	1.0	0.3	0.3	0.3
Fe2O3	1.0	0.3	0.3	0.1
P2O5	0.2	0.02	0.02	0.01
CuO	0.6	0.05	0.05	0.01
ThO2	0.03	0.03	0.03	0.03
U3O8	0.07	0.07	0.07	0.07

Table 112

Composition of Commercial Zirconium Oxides

Grade	Ceramic Pigments	Special Ceramics	Engineering Ceramics	Glass or Gemstones	Electronics	Mixed Metal Oxides
ZrO2+HfO2	99	99	92.3	99	98	91
SiO2	0.20	0.05	0.15	0.20	0.07	0.15
TiO2	0.15	0.15	0.15	0.15	0.12	0.15
Fe2O3	0.02	0.01	0.02	0.006	0.01	0.02
SO3	0.3	0.02	-	0.25	0.10	0.1
Y2O3	-	-	5.3	-	-	8
LOI (1400ºC)	0.30	0.10	2.0	0.30	1.20	0.3
Tamped BD	2.4	1.5	1.5	2.4	1.2	2.80
APS (µm)	14	3.5	<0.5	14	2.5	25
SSA, m^2/g	2-4	1-2	20	2-4	15-20	2.0

Market Trends

World demand for zirconium is expected to increase by two to three percent over the next few years. Long-term estimates suggest supply shortages may occur, unless new production sources of zirconium concentrates are developed.

The metal's market for nuclear-grade zirconium metal, the production of which necessitates hafnium's removal, produced more hafnium during 2001, than could be consumed by the demand. The excess hafnium was stored in the form of hafnium oxide (Hedrick, 2001).

Price

In 2002, according to Industrial Minerals, No. 419 the average value of zircon ore and concentrates (per tonne) were:

- Ceramic applications, bulk, FOB USA, US$375-400
- Refractory applications, bulk, FOB USA, US$350-390
- Foundry sand applications, bulk, FOB USA, US$350-390
- Hafnium sponge averaged US$165-209 per kilogram during 2001 (USGS Mineral Commodity Summaries, January 2002).

Economic Factors

Zircon is a co-product or byproduct of the mining and processing of heavy-mineral sands for the titanium minerals, ilmenite and rutile, or tin (cassiterite).

The Culgoa deposit, in the Murray Basin, Victoria State, Australia is reported to contain 11.8 million tonnes at 16.8 percent heavy minerals with a cut-off grade of 3 percent heavy minerals. Culgoa has 1.985 million tonnes of heavy mineral concentrate with a waste-to-ore ratio of 2:1. The high-grade mineralization is between 60 and 140 metres wide and averages four metres in thickness over a strike of 17.6 kilometres. Culgos's heavy minerals content average 79 percent of valuable heavy mineral, and consists of 68 percent ilmenite, 7 percent leucoxene, 2 percent rutile, 2 percent zircon and the remaining 21 percent gangue.

Reported grades of greater than 22 percent heavy minerals with mineral zones containing up to 27 percent rutile and 15 percent zircon, were reported at the Dispersion deposit in the Murray Basin, Victoria State, Australia.

The Natashquan deposit located on the north shore of the St. Lawrence River in Quebec, is reported to contain ilmenite, magnetite and zircon. Only a small portion of the deposit has been drilled. Resources are estimated to be 2.1 billion tonnes of ore grading 5.9 percent heavy minerals. The dredgeable resources at Natachquan have been calculated using geologic modeling to be about 770 million tonnes, grading at 9 percent heavy minerals, for the north zone and 890 million tonnes grading 7.19 percent heavy minerals, for the south zone.

Yukon Occurrences

There are no zircon occurrences listed under commodities in Yukon Minfile 2001, although zircons have been identified in heavy mineral concentrates coming from the Klondike.

A number of known alkaline rock complexes in British Columbia are enriched in zirconium (e.g. Trident Mountain nepheline syenite and the Lonnie Carbonatite) (Pell, 1987). The northern extension of this Cordilleran alkaline trend, in association with syenite and carbonatite, are good exploration targets for zirconium minerals in the Yukon.

Exploration Guidelines

Zircon is commonly found in siliceous and alkaline plutonic igneous rocks (granite, diorite, syenite, nepheline syenite) and pegmatites.

Fentinization increases the size of target in regional exploration for carbonatite-hosted deposits. U-Th associated with fluorite and barite within carbonatites are considered to be indirect REE and zircon indicators, and may be useful in locating new occurrences.

Annular topographic features may coincide with carbonatites. Geochemical surveys may indicate resistant niobium or phosphate minerals in soils and stream sediments and F, Th and U in water samples. Magnetic and radiometric expressions, and sometime anomalous radon gas concentrations furnish primary targets for carbonatites.

PART C

GEMS

GEM

General Description Gen

Throughout human history gems have intrigued people. Gems have been valued as treasured objects by all societies in every region of the world. The first stones known to have been used for making jewelry include amber, amethyst, coral, diamond, emerald, garnet, jade, jasper, lapis lazuli, pearl, rock crystal, ruby, serpentine and turquoise. Often, these stones served as status symbols for the wealthy or as collateral during hard or dangerous times. Today, gems are not worn to demonstrate wealth, as much as they are for pleasure or in appreciation of their beauty. However, gems may still be purchased as means to ensure wealth, particularly during times of world tension.

In this report, the terms “gemstone” and “gem” refer to any mineral used for personal adornment, display, or as objects of art owing to their beauty, rarity, and durability. Of the approximately 4,000 mineral species, only about 20 to 30 possess all these attributes. Of these, 13 are discussed in some detail, because of their known or possible occurrences in the Yukon.

The term gemstone is restricted to uncut stones while the term gem applies to cut stones. Gems are usually sold by the carat, a unit of weight equal to 200 milligrams.

Chemical and Physical Characteristics Che

Table 113 lists the chemical and physical properties of the 13 gems and gemstones reviewed in this report.

Table 113

Name	***Composition***	***Colour***	***May be confused with***	***Recognition Characters***
Agates	Silica	Any	Glass, plastic Mexican onyx	Cryptocrystalline, irregularly banded, dendritic inclusions
Diamond	Carbon	White, blue-white, yellow, brown, green pink, blue	Zircon, titania, cubic zirconia	High index, dispersion, hardness, luster.
Emerald	Beryllium Silicate	Green	Glass, tourmaline, peridot, green garnet	Emerald filter, dichroism
Garnet	Complex alumino-silicate	Brown, black, yellow, green, ruby red or orange	Synthetics, spinel, glass	Single refraction, anomalous strain
Jasper	Silica	Any, striped, spotted, uniform	-	Oqaque, vitreous
Jade	Hornblende and pyroxene	Green yellow, black, white or mauve	Onyx, bowenite, vesuvianite, grossularite	Lustre, spectrum, translucent to opaque
Lazulite	Hydrous phosphate	Bright-blue	-	Colour

Table 113 (cont'd)

Opal	Hydrous silica	Colours flash in white grey, black, red or yellow	Glass, synthetics, triplets	Play of colours
Rhodonite	Manganese Silicate	Deep pink	-	Colour, manganese staining
Ruby	Aluminum oxide	Rose to deep purplish red	Synthics, spinel	Inclusions, fluorescence
Sapphire	Aluminum oxide	Blue	-	Inclusions, double refraction, dichroism
Topaz	Hydrous alumina silicate	White, blue, green	Beryl, quartz	Refractive index
Zircon	Zirconium silicate	White, blue, brown, yellow or green	Diamond, synthetics, topaz, aquamarine	Double refraction, strongly dichroic, wear on facet edges

AGATE *AGA*

Agates are a translucent cryptocrystalline variety of quartz (chalcedony), frequently mixed with opal (See opal this report), and characterized by colours arranged in alternating stripes or bands, in irregular clouds, or in moss-like forms. Agate is found in virtually all colours, usually of low intensity. It is very hard (7) and light, and exhibits a smooth conchoidal fracture. It forms as a microcrystalline precipitate from aqueous solutions or as a dehydration product of opal, in low-temperature environments. It often occurs in rounded cavities in lava rocks (geodes), sometimes with beautiful cluster of rock crystal or amethyst (a violet coloured form of quartz) at the centre.

Yukon Agate Occurrences

Agates are found in the Carmacks Group Volcanics.

DIAMOND *DI*

Chemical and Physical Characteristics

Diamonds (C) usually occur in octahedral or rounded crystals that range in colour from colourless to yellow, brown, grey, green and black. As the hardest natural substance known (10), diamond is relatively heavy (SG 3.52), fragile and exhibits perfect cleavage. Crystals are transparent, have an adamantine lustre and strong dispersion of light.

Deposit Examples

Kimberlite-hosted diamonds - Diavik Mine, Ekati Mine, Northwest Territories (Canada); Kimberly, Premier and Venetia (South Aftrica); Orpap and Jwaneng (Botswana); River Ranch (Zimbabwe); Mir, International, Udachnaya, Aikhal and Yubilenaya, Sakha, (Russia).

Lamproite-hosted diamonds - Argyle, Ellendate (Western Australia); Prairie Creek Crater of Diamonds, Arkansas, (USA); Kapamba (Zambia); Majhgawan (India).

General Geology

In this report, two recognized deposit types are discussed.

Kimberlite-hosted diamonds - diamonds in kimberlites occur as sparce xenocrysts and within diamondiferous pyroclasitc rocks deposited in craters. The kimberlite host-rocks are small hypabyssal intrusions which grade upward into diatreme breccias near surface and pyroclastic rocks in the crater facies at surface. Kimberlites are volatile-rich, potassic ultrabasic rocks that commonly exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts set in a fine-grained matrix. The megacryst and macrocryst assemblage in kimberlites include anhedral crystals of olivine, magnesian ilmenite, pyrope garnet, phlogopite, Ti-poor chromite, diopside and enstatite. Matrix minerals include microphenocrysts of olivine and one or more of monticellite, perovskite, spinel, phlogopite, apatite, and primary carbonate and serpentine.

Kimberlites form from a small amount of partial melting in the asthenospheric mantle at depths usually in excess of 150km. The magma rises rapidly to the surface, capturing fragments of the mantle and crust, en-route. Kimberlites crosscut all types of rocks and commonly occur in steep-sided, downward tapering, cone-shaped diatremes that may have complex root zones with multiple dikes and “blows”. Diatreme contacts are sharp and surface exposures of diamond-bearing pipes range from less than 2 to 146 hectares. They are found predominately in regions underlain by stable Archean cratons with economic deposits occurring in kimberlites from Proterozoic to Tertiary, in age. The diamonds vary from early Archean, too as young as 990 million years (Ma).

If a kimberlite magma passes through diamondiferous portions of the mantel, it may sample and bring diamonds to the surface provided they are not reabsorbed during ascent. The rapid degassing of carbon dioxide from the magma near the surface, produces fluidized intrusive breccias and explosive volcanic eruptions. In some diatremes the associated crater and tuff ring may be preserved. Tuff cones may also form without associated diatremes.

Diamonds themselves occur as discrete grains and tend to be randomly distributed within kimberlite diatremes. In temperate climates, weathering is less pronounced than in tropical climates but clays are still the predominant weathering product. Diatreme and crater facies tend to form topographic depressions while hypabyssal dikes may be more resistant.

Macroscopic diamonds do not crystallize from the kimberlitic magma. They are derived from harzburgitic peridotites and eclogites within regions of the sub-cratonic lithospheric mantle where the pressure, temperature and oxygen fugacity allow them to form.

Kimberlites typically occur in fields comprising up to 100 individual intrusions that often group in clusters. Each field can exhibit considerable diversity with respect to petrology, mineralogy and diamond content. Diamondiferous and barren kimberlites can occur in close proximity and although not understood, may result from the different depths of origin of the kimberlite magmas.

Associated deposit types include residual concentrations (placer deposits) or lamproite-hosted diamond deposits (Pell, 1999).

Lamproite-hosted diamonds - lamproite-hosted diamonds can be of any age, except Archean, ranging from Proterozoic to Miocene in age. They form in a similar manner as kimberlite-hosted diamond deposits, but the magmas are of different origin. Lamproites form from a small amount of partial melting in metasomatized lithospheric mantel at depths in excess of 150km (within or beneath the diamond stability field). Lamproites are small-volume magmas that are confined to continental regions.

Only olivine lamproites are diamondiferous, as other varieties such as leucite lamproites probably did not originate deep enough in the mantle to contain diamonds. When magma rises rapidly to the surface, diamonds themselves do not crystallize from the lamproite magma. Instead, they are derived from harzburgitic peridotites and eclogites within regions of the sub-cratonic lithospheric mantel where the pressure, temperature and oxygen fugacity allow them to form in situ.

Lamproites are peralkaline and typically ultrapotasic (6 to 8 percent K_2O). They are characterized by the presence of phenocrysts and/or groundmass constituent forsteritic olivine, Ti-rich, Al-poor phlogopite and tetraferriphlogopite, Fe-rich leucite, Ti and K-richterite, diopside, and Fe-rich sanidine. Minor accessory minerals include priderite, apatite, wadeite, perovskite, spinel, ilmenite, armalcolite, shcherbakovite and jeppeite. Glass and mantle derived xenocrysts of olivine, pyrope garnet and chromite may also be present. They are generally emplaced in high-level, shallow "maar-type" craters crosscutting crustal rocks of all types. Most lamproites occur in craters that are irregular, asymmetrical, and generally shallow (often less than 300 metres in depth). Crater diameters range from a few hundred metres to 1500 metres. Diamonds occur as grains of xenocrystic origin that are sparsely and randomly distributed in the matrix of lamproites and some mantel xenoliths (Pell, 1999).

World Production

During 2000, an estimated 60 million carats of gem quality diamonds were produced from at least 15 countries. Canada's Ekati Mine completed its second full year in 2000, with diamond production of 2.63 million carats valued at US$454 million. In the sixteen-month period that ended May 31, 2001, Ekati produced 3.60 million carats of diamond, with an average sale price of US$168.30 per carat. Canada's Diavik project is expected to come on-stream in 2003 with production of 6-8 million carats per year. Canada's first underground diamond mine, the Snap Lake project is expected to come on-stream in 2005. When the Diavik and Snap Lake mines begin production, Canada will capture at least 15-20 percent of the world's total diamond market.

The USGS estimates that world consumption of industrial diamond during 2001 was approximately 1.15 billion carats. Although natural diamond resources have been discovered in more than 35 countries, natural diamond accounts for less than 10 percent of all industrial diamond consumed. The Argyle pipe in Australia produces more carats per annum (approximately 38,000 in 1995), far greater than any other single primary diamond source. The mine is presently the only major lamproite-hosted diamond mine. It contains at least 75 million tonnes, grading between 6 and 7 carats of diamonds per tonne (1.2 to 1.4 grams/tonne). The average value of the industrial diamonds at the Argyle mine is approximately $US7 per carat making a tonne of ore worth approximately US$45.50. The value of the total deposit is estimated to be in excess of US$3.4 billion, with approximately five percent of the diamonds from this source considered to be good quality gemstones (Olson, 2000 and 2002).

End-Use

Natural gem-quality diamonds are among the world's rarest mineral materials, and are highly valued for jewelry. Industrial diamonds are used in cutting tools for all kinds of industrial applications e.g., drilling-bits, stone cutting and polishing, etc. Stone cutting and highway building and repair, consume most of the industrial stones (for additional information see Industrial Diamonds, in this report).

Quality and Specifications

Diamonds are hand-sorted into gem, near-gem and industrial grades (Table 114).

Table 114

Grading Natural Diamond

Gem-quality diamond -	Are assessed by carat weight, colour, clarity and cut. Carat weight – diamonds are weighted within a tolerance of 1/200 by metric carat (0.2 grams) which is divided into 100 points (2,268 carats = 1 pound; 5,000 carats = 1 kg). Stones less than 2 carats are regarded as small gems. Colour - is measured by an instrument (e.g. DiamondLite) which compares the target stone with a master set of diamonds. Clarity - is the internal quality of diamond, and is a measure of its imperfections, inclusions, and flaws. A diamond is considered flawless if no bubbles, caron spots, feathers, crack clouds or blemishes of any kind can be seen using ten-power magnification in a binocular microscope with "dark field" illumination. Cut – There are several types of cuts with the most popular being the brilliant cut.
Near-gem diamond -	Are diamonds with substantial impurities and other defects that, depending on market conditions, can be either cut into "cheap gems," or used as industrial diamonds.
Industrial-grade diamond -	Are divided into several categories including: Industrial Stones (fine industrials); Large Stones: unsuited for gem use because of shape, mechanical imperfections, or colour; Bort: a low grade (small, irregular shape with flaws and imperfections) natural industrial diamond crushed into finer grades and used chiefly in drilling (drilling bort) or as grit, powder or dust; Carbonado (black diamond): a compact opaque dark grey to black diamond/graphite/amorphous carbon mixture, with no cleavage; Ballas (short bort): a dense, globular aggregate that is extremely hard and tough. Diamond grit ranges in size from very coarse (2.0-2.4 mm) to fine (38-44µm) with even finer material categorized as diamond powder.

Source: adapted after The Industrial Minerals HandyBook II, pg. 53-54.

Market Trends

The gem diamond trade is almost entirely controlled by De Beers though its Central Selling Organization (CSO) based in London, England. This company purchases diamonds from mines around the world and grades them. Prices received are dependent on gem quality, state of the world economy, availability of disposable income, fashion trends, the success of advertising programs, exchange rates and inflation.

Prices received for natural industrial diamonds are dependent on availability and the supply on the world market of synthetic diamonds at that point in time.

Price

Price received for gem-grade diamond is variable and dependent on crystal size, type, and quality. Industrial diamonds (the majority of which are synthetically produced) averaged an estimated US$4.47 per carat in 2001.(For information about prices of industrial diamonds see under abrasives for industrial diamonds in this report).

Economic Factors

Natural gem-grade diamonds are among the world's rarest minerals. Most diamond-bearing ore bodies have a diamond content that ranges from less than one carat per tonne, to approximately six carats per tonne. When assessing diamond deposits, grade, tonnage and the average value (price/carat) of the diamonds is considered. Diamonds, unlike commodities such as gold, do not have a set value and can be worth a few dollars per carat to thousands of dollars per carat, depending on their quality (size, colour, and clarity).

Most diamond deposits are mined initially as open pit operations. Economic concentrations of diamonds occur in approximately one percent of the kimberlite. Estimates for African producers are illustrated in Table 115.

Table 115

Pipe	*Tonnes*	*Grade (carats/100 tonne)**
Orapa	117.8	68
Jwaneng	44.3	140
Venétia	66.0	120
Premier	339	40

** One carat of diamond weighs 0.2 grams*

Recent Alaska Diamond Discovery

Shear Minerals Ltd., a Canadian based exploration company announced on July 8, 2002 from its operator and partner Golconda Resources Ltd., the discovery of 15 microdiamonds and one macrodiamond at its Shulin Lake Property in Alaska. The microdiamonds (defined as less than 0.5 millimetres in one direction with a minimum dimension of 0.10 millimetres) and the one macrodiamond measuring 0.71x0.57x0.47 millimetres, are reported to be characterized by Lakefield Research Laboratories of Ontario, as "generally being white, transparent, mostly fragments, some with crystal faces, frosted surfaces with graphite coatings". The 9.972 kilogram sample was taken from a drill hole at a depth of 574-609 feet (175-186 metres). The diamond-bearing interval is described as being a graded sequence of volcaniclastic rock but no other details were reported (Shear Minerals Ltd. news releases, September 6 and July 8, 2002).

Yukon Occurrences

There are no documented diamond occurrences in Yukon although undocumented alluvial diamonds and some indicator minerals have been reportedly recovered by placer operations in the Territory (Casselman and Harris, 2002).

In a recent 'powerpoint presentation' by M. Dufresen of APEX Geoscience Ltd., at the 2002 Yukon Geoscience Fourm - Northern Gemstone Seminar, evidence from Australia, California and a recent diamond discovery in Alaska, suggest certain Yukon terranes do have potential to yield diamonds based upon a shallow subduction diamond model (www.yukonmining.com).

Kimberlite occurs in the Mackenzie Mountains of the Northwest Territories in at least two pipes, the Mountain diatreme, which contains diamonds (Godwin and Price, 1986) and the Coates Lake diatreme (Gibbins and Atkinson, 1992). The Mountain diatreme is the largest of a small cluster of four kimberlites of Silurian age that were emplaced into Cambrian to Early Ordovician shelf carbonates of the Mackenzie Platform, near the shelf edge. This setting is similar to that of the more than 40 diatremes known in southeastern British Columbia (Erdwin and Downing, 1993). Two lamprophyre diatremes in the Golden-Columbia Icefields area of British Columbia, are reported to contain microdiamonds (Pell, 1987) in diatremes within the Cordilleran alkaline belt. This belt, which extends from British Columbia into the Yukon, occupies a broad zone parallel to and encompassing the Tintina Trench and would be a good exploration target for diamond occurrences in the Yukon.

Whether the Yukon could host diamond deposits is uncertain but Erdmer and Downing, 1993, point out the following:

- The buried Canadian Shield underlies more than fifty percent of Yukon and little is known of its age and nature west of the Cordilleran orogenic front;
- The existence of a cratonic basement which was sufficiently cool to have formed and stored diamond cannot be dismissed based on our present understanding;
- The occurrence of kimberlite along the Yukon/Northwest Territory border, well within the Cordillera, increases the potential for all the autochthonous platform cover to host kimberlite pipes. This would include all of the Yukon east of the Tintina fault, and that part of the ancient North American margin west of the fault in southern Yukon (in the Pelly Mountains). The potential of this region to host diamondiferous pipes is considered high, relative to the rest of the Yukon.

To the west of the Tintina fault, the nature of the deep crust in the accreted portion of the Cordillera, mainly in western Yukon between the Tintina and Denali faults, is less clear. Some evidence exists that at least part of this area may be underlain by old crystalline basement rocks of continental thickness. The Sr_{87}/Sr_{86} line crosses the Cordillera in this region (Armstrong, 1988). Other parts are likely thinner and have younger crust of oceanic origin beneath which no mantle root has had time to become established. The terrane west of the Denali fault is the youngest-accreted part of Yukon, and as such would appear to hold the lowest potential for economic diamondiferous pipe emplacement.

The structural control of deep faults and other lineaments that can be linked to at least some diatremes world-wide is potentially present in Yukon. The Tintina trench, a site of long-lived or repeated faulting, fits all the criteria noted in other lineaments associated with kimberlites world-wide. To a lesser extent, related parallel or splay faults, and faults intersecting the Tintina fault or splay faults at high angles may also have helped to let kimberlite magmas through.

Finally, relatively little is known of the nature and affinity of many ultramafic rocks in the Yukon, as in most of the northern Cordillera. The ‘Alpine’ type ultramafics are assumed to be the main or only group present. However, because of their relative abundance, and the variety of the petrology, it is possible that some unusual occurrences may be misidentified and may include kimberlitic or lamproitic phases (after Erdmer and Downing, 1993).

Exploration Guidelines

Exploring for kimberlite diamond deposits - kimberlites have typically high Ti, Cr, Ni, Mg, Ba and Nb values in overlying residual soils. Diamond-bearing kimberlites can contain high-Cr, low-Ca pyrope garnets (G10 garnets), sodium-enriched eclogitic garnets, high chrome chromites with moderate to high Mg contents and magnesian ilmenites.

Geophysical techniques used to locate kimberlites include ground and airborne magnetometer surveys (kimberlites can show magnetic highs or lows). Some kimberlites however, have no magnetic contrast with surrounding rocks. Some pipes have been detected using electrical methods (EM, VLF, resistively) in airborne or ground surveys. These techniques are particularly useful where the weathered, clay-rich upper portions of the pipes are developed and preserved since they are conductive and may contrast with the host rocks. Ground based gravity surveys may be useful in detecting kimberlites that have no other geophysical signature and in delineating pipes. Deeply weathered kimberlites or those with a thick sequence of crater sediments, generally give negative responses. Where fresh kimberlite is found at surface, a positive gravity anomaly can be obtained.

Indicator minerals are used extensively in the search for kimberlites and are an important exploration tool. Pyrope and eclogitic garnet, chrome diopside, picroilmenite, chromite and, to a lesser extent, olivine (in tills, stream sediments, loam etc.) may be indicative of a kimberlitic source. As well, weathered kimberlite produces a local variation in soil type that can be reflected in vegetation (Pell, 1999).

Exploring for lamproite diamond deposits - lamproites can have associated Ni, Co, Ba and Nb anomalies in overlying residual soils. However, it is important to note that other alkaline rocks can give similar geochemical signatures.

Geophysical surveys are used to locate lamproites but give no indication as to whether they host diamonds. Ground and airborne magnetometer surveys are commonly used, although some lamproites have no magnetic contrast with surrounding rocks. Various electrical methods (EM and VLF) in airborne or ground surveys are useful for detecting lamproites.

Heavy indicator minerals such as chromite, and to a lesser extent, pyrope and eclogitic garnet, chrome spinel, Ti-rich phlogopite, K-Ti richterite, low-Al diopside, forsterite and perovskite can be used as lamproite indicator minerals. Priderite, wadeite and shcherbakovite are also highly diagnostic of lamproites, although very rare (Pell, 1999).

EMERALD EME

Chemical and Physical Characteristics

Emerald is a green variety of the mineral beryl [$Be_3Al_2(SiO_3)_6$]. Beryl itself is colourless but when Cr or in some cases V (or both) substitute for Al in beryl structure, the colour green results. Other coloured varieties of beryl include aquamarine, morganite, and heliodor. The chemical and physical characteristics of beryl are illustrated in Table 116.

Table 116

Physical and Chemical Characteristics of Beryl

Chemical Formula	Be3Al2(SiO3)6
Crystal system	Hexagonal
Colour	Emerald (green); Aquamarine (pale blue-green); Morganite (pink-peach); Heliodor (green-yellow). Red beryl is very rare.
Hardness	7.5 to 8.0
Fracture cleavage parting	Indistinct basal cleavage
Specific gravity	2.67 to 2.84
Pleochroism	Strong (emerald); distinct (morganite); weak to distinct (aquamarine); weak (heliodor)
Fluorescence	Emerald: inert to weak (LW) orange-red; morganite: weak red (SW, LW)

Source: adapted after Walton, 1996, pg. 13

Deposit Examples

Schist-hosted emerald deposits - Regal Ridge Emerald Property, Finlayson Lake area, Southeast Yukon (Minfile105G/147), (Canada); Socoto and Carnaiba deposits (Brazil); Habachtal (Austria); Perwomaisky, Marinsky, Aulsky, Krupsky, Chitny and Tsheremshansky deposits (Russia); Franqueira (Spain); Gravelotte Mine (South Africa); Mingora Mines (Pakistan).

Colombia-type emerald deposits - Civor, La Mina Glorieta, Las Cruces, La Vega de San Juan, Coscuez and Muzo (Colombia)

General Geology

Schist-hosted emeralds - schist-hosted emerald deposits (the world's most common source of emeralds) are found in cratonic areas, as well as in mobile belts. In many cases they appear to be related to major Phanerozoic or Proterozoic suture zones that may involve island arc-continent or continent-continent collision zones.

Archean or younger schist-hosted emeralds are found mainly in greenstone belts, but also in other areas where Cr-bearing rocks may be adjacent to pegmatite, aplites, granites and other felsic rocks rich in beryllium. Metamorphic grade is variable although it typically reaches green schist to amphibolite facies. The age of mineralization is often linked to either a period of tectonic activity, or a time of pegmatoid emplacement.

The most common host rock is biotite schist, although deposits also occur in metamorphosed mafic volcanic rocks such as epidote-chlorite-actinolite-bearing rock, chlorite and chlorite-talc schist, talc and talc-carbonate schist, white mica schist, mafic schist and gneiss and amphibolite. Less common emeralds occur in unmetamorphosed mafic or ultramafic rocks and possible listwaenites. Pegmatite's or quartz veins in the contact zone between granitic rocks and mafic rocks, may in some cases host emeralds. Associated rock types can include granite, syenite, tonalite, granodiorite, marbles, black phyllites and other metamorphic rocks.

Most mineralization is hosted by tabular or lenticular mafic schist or "blackwall zones". Favourable zones can be a few metres, to tens of metres wide and follow contacts between felsic and mafic/ultramafic lithologies for up to hundreds of metres. The principle control is the relationship of beryllium and chromium-bearing lithologies along deep suture zones. Emerald crystals are present mainly within the mafic schist. Another setting is their occurrence along fracture-controlled glimmerite zones or they may be concentrated along the planes of regional metamorphic foliation, especially in cores of the folds. Serpentinite roof pendants in granites, are also prospective targets for emerald crystallization.

The origin of schist-hosted emerald deposits is not clear but all emerald deposits require special geological conditions where chromium (vanadium) and beryllium coexist. Where pegmatoids or plagioclase-rich lenses occur within ultramafic rocks, the crystallization of emeralds is commonly explained by interaction of pegmatite's or pneumatolytic-hydrothermal, Be-bearing fluids with Cr-bearing mafic/ultramafic rocks. In other cases, emeralds in schist form by syn-or post-tectonic regional metamorphic chemical exchange (metasomatism) between felsic rocks, such as felsic gneiss, garnet mica schist or pre-metamorphic pegmatoids, with adjacent Cr-bearing rocks such as schist, gneiss or serpentinites.

Importantly, industrial grade beryl (a source of Be oxide) is commonly recovered as a by-product in this type of deposit (Simandl, Paradis and Birkett, 1999).

Colombia-type emeralds - Cretaceous-age Colombia-type emerald deposits (which contain the largest and most valuable emeralds) occur in basins (shale deposited in epicontinental marine anoxic environments spatially related to evaporites) that were subjected to a compressional tectonic environment.

The most recent hypothesis for the formation of these deposits suggests compressional tectonics resulted in the formation of decollements that are infiltrated by alkaline fluids, resulting in albitization and carbonatization of shale and mobilization of Be, Al, Si, Cr, V, and REE. The alkaline fluids are thought to be derived from the evaporitic layers of salt diapirs. As the regional compression continues, disharmonic folding results in the formation of fluid traps and hydrofracturing. A subsequent decrease in fluid alkalinity or pressure could be the main factor responsible for emerald precipitation.

The deposits are controlled by deep, regional decollements, reverse or thrust faults, hydraulic fracture zones, intersections of faults and by permeable arenite beds interbedded with impermeable black shale consisting of mainly black pyritiferous shale, black carbonaceous shale, and slate host emerald-bearing veins and breccia. Claystone, siltstone, sandstone, limestone, dolomite, conglomerate and evaporites are also associated. Emeralds are found disseminated in veins as clusters, single crystals or crystal fragments, however the best gemstones are found in cavities. In some circumstances, emerald may be found in black shale adjacent to the veinlets.

The metasomatically altered tectonic blocks may be up to 300 kilometres in width and extend 50 kilometres in length. Individual productive zones are usually 1 to 30 metres in thickness (Simandl, Paradis and Birkett, 1999).

World Production

There are no published world reserves (or reserve base) for emeralds (or other coloured gemstones) however, an estimated 30 percent of the world's emeralds are produced from mines in Colombia. Other producing countries include Brazil, Zambia, Zimbabwe, Madagascar, Afghanistan, Pakistan and Russia. Emeralds have also been found in Australia, Bulgaria, India, Madagascar, Mozambique, Nigeria, Norway, Pakistan, South Africa, Tanzania, United Arab Republic, and the United States (Walton, 1996).

End Use

Emeralds are an important and valuable gemstone. Industrial grade beryls recovered as a by-product, are used to produce Be metal alloys used in the aerospace and defense industries. Be oxides are also used as high performance specialty ceramics, fusion reactors, and in electronic and electrical components.

Quality and Specifications

Emeralds are graded according to the size, intensity of the green colouration and flaws, if present.

Market Trends

The production of emerald is largely dependent on the overall health of the world economy. It is anticipated that as more synthetics, simulants and treated gemstones enter the marketplace, more transparent trade industry standards to maintain customer confidence will be required. As well, it is expected that more gemstones and jewelry will be sold through online marketplaces and other forms of e-commerce that may emerge to serve the gemstone industry. This will take place as industry and its customers become more comfortable with, and learn the best applications of new e-commerce tools for the gemstone industry (Olsen, 2000).

Price

Unlike diamonds, coloured gemstones such as emerald, are primarily produced at relatively small, low-cost operations by a few dominant producers. Prices are influenced by consumer demand, in addition to supply availability. The USGS (Olson, 2000) reported that emeralds during 2000, were valued at between US$1000-2400 per carat (dependent on grade, size and quality). However, there are no set prices for emeralds. Consumers may pay between C$3-7 thousand dollars at a jewelry store, for a fine quality one carat emerald (Walton, 1996).

Economic Factors

The distribution of emeralds within mineralized zones is usually erratic, making reserve estimation difficult. Emerald grades reported from Colombian deposits are approximately one carat per cubic metre, although tonnages are unknown. Similar to Colombia-type emerald deposits, schist-hosted emerald grades and reserve forecasts are difficult to estimate since they are not reported. This is a result of erratic emerald contents, and labour intensive mining methods that tend to high-grade deposits (Walton, 1996).

Yukon Occurrences

In August 1998, while exploring a base metal geochemical soil anomaly in the Finlayson Lake area of southeast Yukon, Expatriate Resources Ltd. geologist Bill Wengzynowski, discovered an occurrence of emeralds on the company's Goal Net Property (Minfile105G 123**).** About one kilogram of emerald was collected from float and outcrop at the discovery site (30 by 100 metre area), during a two-hour examination. Company reports issued following field investigation in 1999, confirmed numerous emerald bearing float trains over an 400 by 800 metre area. Hand trenching at the site also exposed recessive weathering emerald bearing bedrock consisting of altered chlorite-tourmaline schist horizons and subparallel quartz-tourmaline veins. Both the host schist and veins were found to project subhorizontally at a shallow depth making the emerald prospect potentially suitable for open pit mining. Washing and hand sorting of about one-half kilogram of green beryl, including small gem quality emeralds up to approximately one-quarter carat in size and having excellent colour and clarity, were reported (Expatriate News Releases, 1999-2002).

In June 2001, True North Gems Inc. ("True North") entered in to an option agreement with Expatriate Resources Ltd. for a 50 percent interest in the Regal Ridge emerald property (Table 117, Figure 5).

Table 117

Yukon Emerald Occurrence

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1*	105G 147	105G/7	REGAL RIDGE	YT	IR	61º16'33"/130º35'04"

** Listed as a major commodity in Minfile 2001. YT (Yukon Tanana); IR (Intrusive Related)*

Property Geology

The emerald occurrence lies within the Yukon-Tanana Terrane in the Finlayson Lake area. Recent geological mapping completed by Murphy et al., (2001) found the emerald occurrence area is predominantly underlain by Devonian to Early Mississippian, metavolcanic and metasedimentary rocks assigned to the Grass Lake's succession. The oldest exposed rock in the area is the mafic meta-volcanic Fire Lake (unit DF), composed mainly of chloritic phyllite, but also including carbonaceous phyllite and rare muscovite-quartz phyllite of probable felsic meta-volcanic protolith.

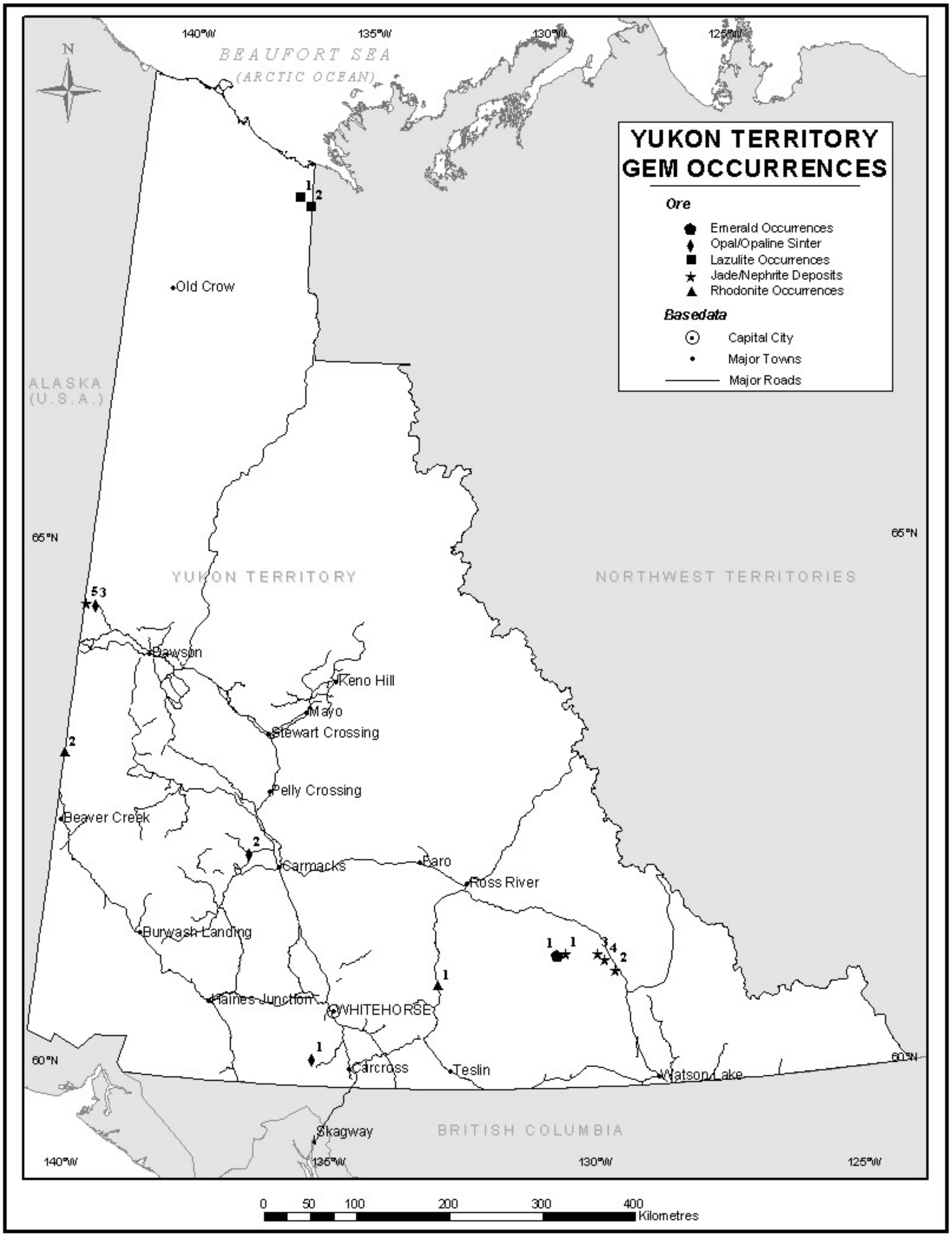


Figure 5. Yukon Gemstone Occurrences Fig5

Groat (2000) reported that emeralds occur where quartz veins cut mafic-rich layers in a shallow dipping mica-chlorite schist of the Upper Devonian Fire Lake mafic meta-volcanic unit (unit DF). In the discovery area, the Fire Lake unit consists of meta-basalt of boninitic composition (a glassy olivine-bronzite andesite that contains little or no feldspar) and overlies a thick, laterally tapering slab of variably serpentinized mafic and ultramafic meta-plutonic rocks. Murphy et al (2001) interpreted this slab as a comagmatic sill that intruded laterally from feeder dykes localized along a nearby synvolcanic fault.

In the discovery area, the schist is foliated and dips gently to the north. The strata are isoclinally folded; vergence is to the south and the fold axis plunges to the west approximately 10 degrees. The quartz veins associated with the emerald mineralization are slightly discordant to the bedding planes. At least eight such veins have been located and in most cases the quartz veins are surrounded by a zone of yellow sulphate mineralization and a much more extensive, overlapping mass of fine tourmaline crystals, which locally contain minor amounts of scheelite. Where the quartz veins cut mica-poor chlorite schist there are no sulphate or tourmaline zones and no emeralds (although there may be tourmaline in the quartz veins), implying that mica-poor strata are unreactive with respect to the hydrothermal system. All quartz veins seem contemporaneous and the presence or absence of emeralds in influenced strongly by the geochemicsty of the host rock.

The quartz veins seem to be genetically linked to one of the largest bodies of mid-Cretaceous granite in the area, which is exposed east of, and within 600 metres of, the emerald mineralization. This pluton is zoned; the outcrop closest to the emerald showing is apparently marginal muscovite granite that grades (over a relatively small distance) to a reddish-weathering, biotite-muscovite granite. A preliminary geochemical analysis of the granite shows that it is rich in Tungsten (W) and Zirconium (Zr) and impoverished in the elements Europium (Eu) and Lutetium (Lu) which is typical of an evolved S-type granitoid system. The granite is discordant with respect to planar fabrics of the host metamorphic rocks, yet locally weakly foliated, indicating late- to post-kinematic emplacement. The western contact of the granite is observed to be gently west-dipping, underlying the occurrence at a relatively shallow depth. The orientation of the western granite contact and the contact between the Fire Lake unit and the co-magmatic mafic and ultramfic sill are such that the granite likely intrudes through the ultramafic sill at depth.

During 2002, trenching at the discovery site revealed that vertical joints and shears, which intersected the mineralized schist horizons, have also provided conduits for the mineralizing fluids. Emerald mineralization was identified in association with these cross-structures, where it forms as dissemination's within the tourmaline pods measuring up to one metes in diametre and 0.2 metres in thickness. Detection of emerald mineralization in the vertical cross structures suggests increased potential yield of emeralds from this occurrence.

Exploration Guidelines

In any exploration program for emeralds, all bright green crystals should be examined and identified. If the mineral is not emerald it may be another valuable gem such as tourmaline, chrome diopside or tsavorite garnet. As a rule, emeralds will show up in stream sediment samples because of the mineral's resistant nature but it is important to remember that because of a relatively low specific gravity (between 2.67-2.68), emerald will not concentrate in the heavy mineral fraction of the sample (Walton, 1996).

Schist-hosted emerald deposits

Exploration for schist-hosted emerald deposits should consider the presence of beryl in eluvial and alluvial deposits, as they are good geochemical pathfinders. As well, a good understanding of basin drainage patterns is required to fully assess the distribution of beryllium in stream sediments and the location of potential sources.

The berylometer is a useful instrument for detecting beryllium minerals in outcrop. As well, radiometric surveys are useful for detecting radioactive minerals in pegmatite host rock. Magmatic and electromagnetic surveys can trace suture zones where ultramafic rocks and felsic rocks are faulted against each other.

If chromium or vanadium-bearing rocks are exploration targets, then ultramafic rocks, black shales or their metamorphic equivalents are favourable host rocks, to prospect. Any beryllium mineral occurrence in a favourable geological setting should be considered a good indicator. If exploration is focused on a variety of gem-quality beryls (not restricted to emeralds), or if the targeted areas is not mapped in detail, then Be occurrences without known spatial association with Cr or V-bearing lithologies should be carefully considered.

Geophysical surveys are also useful in locating zones of Be enrichment coincident with magnetic highs on aeromagnetic maps to locate meta-ultramafic rocks covered by overburden (Simandl et al, 1999).

Colombian-type emerald deposits

Exploration programs develop to located Colombian-type emerald deposits should concentrate on locating black shales within tectonic blocks that are depleted in REE, Li, Mo, Ba, Zn,V and Cr. It is important to remember that albitized zones contain total REE values of 40 ppm, while unaltered shales have total REE values of about 190 ppm. Stream sediments associated with these altered shales generally have low K/Na ratios. Soils overlying deposits may also have a low K/Na ratio.

In the field, recognition of white metasomatic layers within black shale described as albitites, and stratiform polygenetic breccias consisting of black shale fragments cemented by pyrite, albite and shale, should be carefully explored, as they are often closely associated with mineralization.

Regional consideration of exploration programs should include the presence and location of indicators such as beryl showings and structural controls (fault intersections, decollement, reverse faults). Available sources of Cr and Be should also be closely examined when possible. In favourable areas, bleached zones, albitization and pyritization may be indicative of mineralized zones.

Geophysical exploration methods (magnatometer surveys, and electromagnetic surveys) are useful in locating major faults zones where outcrop is lacking. The berylometer may prove useful while conducting ground exploration programs (Simandl et al, 1999).

TSAVORITE GARNET AND TANZANITE TSA

Tsavorite garnet is the name given to the gem variety of the mineral species “grossular garnet [$Ca_3Al_2(SiO_4)_3$”]. Pure grossular garnet is colourless, but when both vanadium and chromium are present, then a pure, vivid green colour results. This gemstone is currently mined at the Jeffrey Mine in Quebec, and in Sri Lanka (For additional information about garnet, see “Garnet” in this report).

Tanzanite is the name given to the gem-quality blue transparent variety of the mineral zoisite ($Ca_2Al_3Si_3O_{12}OH$). Zoisite, is a species of the epidote group which tends to form bladed, edge-shaped crystals. The element vanadium (V), which substitutes for aluminum in the zoisite crystal structure, is responsible for the violet-blue colour of tanzanite.

Tanzanite crystals can grow very large (up to 2,500 carats), but the average mineral is much smaller. Consumers can pay between C$500-1000 for a one carat stone of tanzanite, with five carat gems ranging from C$1000-2000 per carat.

The bulk of the world’s tanzanite is mined from deposits near the town of Merelani in the Lelatema Mountains in Tanzania. Tsavorite is also produced at this mine.

In Tanzania, tsavorite garnet and tanzanite are found within an orogenic belt in a succession of thick marbles and major graphitic units, which represent late Proterozoic (800 million years before present) altered marine continental shelf deposits. The host rocks are early Proterozic (1.0 to 1.8 billion years before present) and consist of interbedded kyanite-sillimanite-biotite graphitic gneiss and marbles. Subsequent collision-related deformation has resulted in folding and thrusting accompanied by high-grade metamorphism. Tsavorite garnet deposits are confined to where graphitic schist or gneiss is interbedded with, or adjacent to, marble. Tanzanite deposits occur in the same sequence of rocks as does tsavorite garnet, but are found in the crest of anticlinal folds (Walton, 1996).

Exploration Guidelines

Based on the world's only known deposits of tsavorite garnet and tanzanite, exploration criteria should consider:

- That the only known deposit is located in a marble host rock which is interbedded with graphitic schist or gneiss, and where graphite is derived from bituminous black shales. Tsavorite garnets grow under granulite facies metamorphic conditions at temperatures of about 750ºC and five kilobars pressure. Tanzanite crystals precipitate from hot, vanadium-rich hydrothermal fluids, indicating the metamorphic grade of the host rock is not critical.
- Basing exploration criteria on the model in Tanzania, geochemical targets should focus on graphitic gneiss enriched in vanadium and possibly chromium. (obtained from soil/stream sediment samples). Exploration programs concentrated on locating these minerals should also recognize that mineralization will be concentrated in intensely folded and faulted sequences of interbedded marbles and graphitic gneiss (Walton, 1996).

JASPER JAS

Jasper varies in colour from white, grey, red, brown or black. It has a compact texture with a splintery or conchoidal fracture. Often it occurs with variously coloured zones in folds and constricted areas. It consists mainly of chalcedony and quartz with hematite pyrolusite, clay and sometimes calcite. Jasper forms in oceanic terranes by silica precipitating from hydrothermal vents in a volcanic environment.

Yukon Jasper Occurrences

In the Yukon, Jasper is found throughout the territory in deposits of gravel. It is sometimes used as a decorative stone.

JADE JAD

Jade is a generic term that refers to two minerals jadeite a pyroxene ($NaAlSi_2O_6$) and a calcium magnesium amphibole called nephrite [$(Mg, Fe)_5(Si_4O_{11})_2(OH)_2$]. Of the two minerals, jadeite is the rarest and most expensive. Jade minerals are found in albite-jadeite dykes that intrude serpentinized ultrabasic rock. These dykes may be a result of magmatic segregation, or occur from the metamorphism of an albite-nepheline rock. To date, jadeite has not been documented in Canada.

Nephrite is formed by metasomatic alteration of serpentine with the addition of calcium, silica, and possibly iron, by gabbro and dioritic rocks; or by reaction of ultramafic rocks with cherty sediment. Nephrite jade deposits are usually associated with small satellite bodies outside the main ultramafic mass.

Alluvial, large, (up to several tonnes) nephrite jade boulders have been recovered near Dease Lake and Cassiar in northern British Columbia. British Columbia has been a steady jade producer for over the past thirty years, with production from both loose and in-situ deposits.

The Alaska Department of Natural Resources reported an estimated 1.8 tonnes of nephrite was produced in 2000, although no mine location was given.

Yukon Jade Occurrences

In the Yukon, five occurrences of nephrite jade are described in Yukon Minfile 2001 (Table 118, Figure 5). One producer, the LIND property (Minfile 105H 014) first staked in 1964, has produced jade from talus block with sizes of up to 90 tonnes and from lenses of up to 15 metres long and 5 metres thick. Reported production on the property is over 110 tonnes of jade. The GEN property, originally staked in the late 1950's, produced several tonnes of jade between 1977-1979 from jade boulders which were derived from alteration zones at the margins of rodingite dykes.

Table 118

Yukon Jade/Nephrite Deposits/Occurrences

Map #	Minfile Number	NTS	Name	Tectonic Element	Deposit Type	Latitude/ Longitude
1	105G 114	105G/8	LADY LEE	YT	UM	61º17’42”/130º25’13”
2	105H 014	105H/3	LIND+	SMT	UM	61º07’14”/129º25’43”
3	105H 016	105H/5	GEN+	SMT	UM	61º16’53”/129º47’10”
4	105H 085	105H/4	BEANS	YT	?	61º13’15”/129º38’16”
5	116C 114	116C/7	LAST CHANCE	YT	?	64º27’06”/140º56’01”

+ Past Producer. YT (Yukon Tanana); SMT (Slide Mountain Terrane); UM (Ultra Mafic); ? (Unknown)

Exploration Guidelines

Evaluation of ultramafic rocks, particularly serpentinized zones.

LAZULITE LAZ

Lazulite $[MgAl_2(PO_4)_2(OH)_2]$, Yukon's official gemstone, occurs in bright-blue crystals up to five centimetres in size. It is a translucent, relatively hard (5-6), heavy (S.G. 3.0), fragile mineral with indistinct prismatic cleavage. It occurs in hypersilicic rocks, such as pegmatites and quartz veins where it may be associated with andalusite, and in metamorphic rocks (quartzites), where it can occur with corundum, kyanite, sillimanite, garnet and/or sapphirine.

Yukon Lazulite Occurrences

Lazulite occurs in the Blow River Formation in northern Yukon's Richardson Mountains. The Blow River Formation is best known for the secondary minerals, chiefly phosphates, which have been found as veins and breccia fillings in the Rapid Creek area. Thirty-two phosphate minerals have been identified to date, including ten new species, the best known of which is lazulite (Robertson, 1980).

The mineral although relatively hard, is considered too soft for use as a gemstone, but is highly valued by collectors. Reported lazulite occurrences are listed in Table 119, Figure 5.

Table 119

Yukon Lazulite Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	117A 027	117A/9W	DAWN	Blow Trough	?	68º33’35”/136º46’57”
2	117A 038	117A/8	DELTA	Blow trough	?	68º28’47”/136º28’21”

? (Unknown Deposit Type)

OPAL OPA

Chemical and Physical Characteristics

Opal ($SiO_2 \cdot nH_2O$), an amorphous form of hydrated silica occurs as small veins, globules and crusts. It can be colourless, milky white, often hazy blue or black with splendid iridescence. Opal is hard (5.5-6.5), light, fragile and does not exhibit cleavage. Opal may be transparent or translucent with greasy lustre. It is flourescent yellow or green in ultraviolet light. Precious opal may display various colours, with a characteristic play of colour caused by the dispersion of light that varies according to the angle of incidence and the size of the ordered spherical particles of which the mineral is composed. Fire opal is a variety of precious opal, reddish in hue not necessarily iridescent. Hydrophane is a whitish opal that becomes transparent and sometime iridescent when soaked in water. Hyalite opal is white or colourless and occurs mainly in globular and dendritic masses. Wood opal replaces the fibres in fossilized wood without destroying the texture of detail.

Precious opal is characterized by its play of colour. The term common opal, refers to any opal that does not show this play of colour. Some common opal may be used as gemstone, but in general they have lower economic value than precious opal. The term “fire opal” describes a common opal having a transparent orange to red-orange base colour. Such opal is commonly faceted.

Gem opal contains up to 10 percent water, which contributes to the translucency of the mineral.

Deposit Examples

Volcanic-hosted precious opal - Carmacks Volcanics, Yukon (Minfile 115I 061), Klinker property near Vernon (Minfile 082LSW125), Northern Lights claim, Falkland, Eagle Creek (093K 095), Savona Mountain (092INE158), British Columbia (Canada); Queretaro Mines (Mexico) Tepe Blue Fire Opal Mine, Idaho, (USA)

Sediment-hosted precious opal - Lightning Ridge and White Cliffs, New South Wales; Minatabie, Coober Pedy, Lambina and Andamooka, South Australia; Yowah, New Angledool, Queensland (Australia).

General Geology

Volcanic-hosted precious opal deposits - Tectonic settings for opal are volcanic arcs, rifts, collapsed calderas, and hot spots related to volcanism. Host rocks include rhyolite, basalt, andesite, trachyte lavas and lahars that may be intercalated with lacustrine sedimentary rocks. Associated rocks can include perlite, bentonite, scoria, volcanic ash and diatomite. The volcanic sequences were deposited in subaerial or shallow marine environments where porous, pyroclastic or lacustrine rocks have been interbedded with lava flows.

Opal bearing horizons are usually stratabound and occurrences of precious opal within these horizons are erratic (they were controlled by permeability at the time of opal formation). Mineralization is Tertiary or younger, commonly Miocene. Opal occurs in seams of volcanic ash or lahars between successive lava flows usually as open-space fillings and impregnations. While common opal, opalized wood and fire opal are common in Triassic or younger volcanic sequences, precious opal is rare. When opal occurs in massive volcanic rocks, it occurs as open space fillings. Precious and common opal coexist within the same deposits. Common opal and opaline silica are also often associated with the spectacular hydrothermal systems characterized by hot spring pools and geysers, mud pots, and fumaroles where it may be deposited as common opal, opaline silica or silica sinter. Examples of such well-known systems, are the Yellowstone Hot Springs and the Geyser Valley in Kamchatka.

One popular hypothesis on how opals and opalized wood form suggests that during long periods of volcanic inactivity, driftwood accumulated in newly formed, shallow lakes. After the volcanic activity resumed, eruptions covered everything with pyroclastic rocks that in turn became lava flows. This results in aquifers, perched water tables, and anomalous geothermal gradients. This process in conjunction with subsequent brittle tectonic deformation is ideal for the formation of hydrothermal systems. Such systems decompose silicate minerals and volcanic glass and become silica-saturated solutions. Consequently, varieties of silica form including silica sinter, opaline silica, chalcedony and common opal as a result of the deposition of these silica-bearing fluids. At least a portion of the opal in volcanic rocks is believed to precipitate directly from these supersaturated solutions.

Associated deposits can include beds of diatomaceous earth, zeolite deposits, perlite and a variety of semi-precious or ornamental silica gemstones such as jasper, agate and chalcedony. Other deposit types may include hydrothermal Au-Ag-Cu deposits (Paradis, Simandl and Sabina, 1999).

Sediment-hosted precious opal deposits - Australian opal is found in strongly weathered sandstones that are underlain by relatively impermeable barriers of claystone, siltstone and ironstone. The clastic sediments were deposited in shallow inland basins and were subsequently affected by climate changes (from the transformation into a desert environment) that resulted in rapid fluctuations in water table levels and entrapment of silica-rich waters. Periods of intense weathering are evidenced by indurated crust horizons. Silica-transporting solutions derived from this intense weathering of feldspar within sandstone, percolated downward to the contact between the porous sandstone and the underlying impermeable layers. During a subsequent dehydration (dry) period, silica was progressively concentrated by evaporation. The last, most concentrated solutions were retained within bedding irregularities at the permeable/impermeable rock interfaces, in joints and other traps. Gem-quality opal was formed by ordered settling and hardening of silica microspheres of uniform dimensions. Disordered arrangements of silica microspheres or variability in microsphere size, resulted in the formation of common opal.

Opal occurrences are stratabound and ore can exceed ten metres in thickness and extend over 100 kilometres. However, the distribution of individual precious opal occurrences within favourable areas is erratic since veins of up to 10 centimetres thick pinch and swell, and branch or terminate abruptly.

In Queensland, clastic host rocks are Cretaceous or Paleozoic, affected by deep weathering during the Early Ecocene and late Oligocene (thought to be the time of opal precipitation). Similar conditions favourable for opal deposition could have prevailed in different time periods, in other parts of the world (Paradis, Townsend and Simandl, 1999).

World Production

Australian sedimentary-hosted opal deposits account for most of the world's opal production cost, with estimates averaging about A$100 million annually.

Market Trends

Prices for quality opal have risen steadily since the early 1990's. There is a good market for precious opal, however strong marketing and value added processing (jewelry) are considered essential considerations for successful opal mining strategies.

End Use

Precious opal is a valued gemstone. Fire opal may be faceted for jewelry. Opalized wood may be an ornamental specialty. Ornamental stone is often used for decorative items such as plaques or bookends.

Quality and Specifications

Precious opal from some deposits may not be suitable for gems because they crack easily, however many volcanic hosted occurrences are as stable as the Australian varieties of opal.

Price

Fire opal ranges in value from C$5-300 per gram. Commercial precious opal sells for an average of about C$40 per gram, while high quality stones sell for up to C$1400 per gram.

Economic Factors

Grade and reserves for volcanic-hosted opal deposits are not well documented, since most deposits are mined or worked by sole proprietors or family businesses. While volcanic rock-hosted opal deposits are more common, most of the high quality opal production comes from Australian sedimentary-hosted deposits.

Yukon Occurrences

Three opal or opaline sinter occurrences were reported in Yukon Minfile 2001 (Table 120, Figure 5).

Table 120

Yukon Opal/Opaline Sinter

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Environment*	*Deposit Type*	*Latitude/Longitude*
1	105D 166	105D/6	SAID	CPC	V	60º15’20”/135º24’14”
2	115I 061	115I/2	OPAL	CV	?	62º12’13”/136º53’46”
3	116C 025	116C/7	CLINTON CK.	SMT	UM	64º26’21”/140º42’58”

CPC (Cassiar Plutonic Complex); CV (Carmacks Volcanics); SMT (Slide Mountain Terrane); V (Vein); UM (Ultra mafic)

Exploration Guidelines

Volcanic hosted opal deposits - a common exploration technique for opal exploration is boulder tracing in unmetamorphosed or weakly metamorphosed (zeolite facies) terrains (gem opal deteriorates and becomes brittle if subject to moderate temperatures) in tertiary or younger rocks. Opal occurrences are hosted by volcaniclastic rocks and are commonly confined to the same lithologic unit over a large areas. The presence of warm springs in an appropriate setting may also be a good indirect exploration indicator. In some opal deposits mineralogical zoning within vesicule fillings may be used to delimit the most favourable areas, as common opal occurs only within broad areas of agate mineralization and precious opal only in small areas within the common opal mineralization. In some instances, the indicator elements used in exploration for epithermal metalliferous deposits such as Hg, Sb, and As may be indirectly applied to precious opal exploration.

There are no geophysical signatures for opal deposits but VLF and/or resistivity surveys may be useful in locating perched water tables and/or faults (Paradis, Simandl and Sabina, 1999).

Sedimentary-hosted opal deposits - Exploration of unmetamorphosed or weakly metamorphosed areas known for:

- Prolonged periods of deep chemical paleoweathering characterized by rock saturation and dehydration cycles;
- Board sedimentary structures permitting shallow underground solution pooling;
- Local traps where opal could precipitate from nearly static, silic-bearing ground waters;
- Presence of common opal.

Most opal fluoresces brightly if exposed to ultraviolet light and this is an effective exploration tool, particularly when examining old tailings for opal (Paradis, Townsend and Simandl, 1999).

RHODONITE RHO

Rhodonite (Mn,Fe,Mg) SiO_3 is deep pink in colour often covered with black staining due to surface oxidation. It occurs in compact or granular masses with characteristic veins and black marks caused by manganese oxides. It is hard (5.5-6.5), heavy (SG 3.4-3.7), fragile, transparent to translucent, with a vitreous lustre. It is sometimes a typical product of metamorphism of manganese and silica rich limestone.

Sometimes it also occurs as a result of contact metasomatic processes (skarn).

Faceted crystals of rhodonite are highly prized as collector's pieces. Transparent or translucent varieties are cut as cabochons or as beads for necklaces and other types of jewelry or artwork. In British Columbia rhodonite occurs in sedimentary layers and lenticular bodies in association with oceanic radiolarian cherts in accreted oceanic terranes and occurs in the Insular, Coast, Intermontane and Omineca belts (Hora, 2002). By extension, similar lithologies in the Yukon within these three belts are potential explorations targets for new discoveries of rhodonite.

Yukon Occurrences

Eight occurrences of manganese oxides (rhodonite) are described in Yukon Minfile, 2001, of these, two are listed as major commodities (Table 121, Figure 5).

Table 121

Yukon Rhodonite Occurrences*

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105C 017	105C/11	EVE	YT	S	60º42'26"/133º20'07"
2	115K 086	115K/10	OLGA	CPC	V	62º31'36"/140º57'11"

* *Listed as major commodity, Yukon Minfile, 2001. YT (Yukon Tanana), CPC (Coast Plutonic Complex); S (Skarn), V (Vein)*

RUBY AND SAPPHIRE RUB

Chemical and Physical Characteristics

Ruby and sapphire are varieties of the mineral species corundum (Al_2O_3). Corundum occurs in nature as hexagonal (six sided), barrel-shaped crystals with either tapered or stubby terminations which are very hard (9) and heavy (SG 3.9-4.1).

Pure corundum is colourless and it is only when chemical impurities such as the elements Cr, Ti, and Fe are present that a variety of colours result - usually grey or brown, but sometimes red (ruby variety), or blue, yellow, green, violet (sapphire variety). Approximately one percent chromium is needed to produce a deep red colour in ruby but less than 0.01 percent iron and titanium are needed to colour blue sapphire. The other colours of sapphire (yellow, orange, green, violet) are caused by varying amounts of Fe and Ti.

Deposit Examples

Alkali basalt and lamprophyre-hosted sapphire and ruby (gem corundum deposits) - Mark Diatreme (Minfile 082N089), British Columbia, (Canada); Yogo Gulch, Montana, (United States); Stratmore and Kings Plains Creek, New South Wales, (Australia); Changle (China).

Ultramafic-Related Corundum (contact metamorphic/metasomatic) - Corundum Hill, North Carolina; Emery Hill, New York State, (United States); Natal and Birdcage camp (South Africa); Umba (Tanzania); Kinyiki Hill and Penny Lane ruby mine (Kenya).

General Geology

Alkali basalt and lamprophyre-hosted sapphire and ruby deposits - sapphires and rubies are found as xenocrysts in some hypabyssal or eruptive rocks of alkali basalt, lamprophyre, nephelinite, basanite, or phonolite composition. Deposits occur in continental and pericontinental settings, which appear related to rifts, deep faults and/or hot spots. They are typically hosted in Cenozoic or younger rocks (Oligocence and Miocene in New South Wales, Australia).

Several hypotheses have been proposed to explain the origin of the sapphire-bearing lithologies. Most involve alkali volcanic or hypabyssal rocks incorporating previously formed sapphires and/or rubies as xenocrysts then transporting them to the surface (in a manner similar to diamonds in kimberlite). Corundum gems may have formed by metamorphism of aluminous sediments; crystallization in deep-seated syenitic melts or from undersaturated fractionated felsic melts. The primary controls appear to be sapphire and ruby-bearing alkali basalt, lamprophyre, nephelinite, basanite or phonolite dikes, flows, pyroclastics or possible diatremes. Unconformities, paleoregoliths or current erosional surface intersecting sapphire/ruby-bearing lithologies provide a vehicle for identifying secondary deposits.

In extrusive rocks, sapphire and ruby occur as megacrysts that are bi-pyramidal or barrel shaped. The corundum crystals can be corroded and etched with some crystals zoned, and containing a variety of solid inclusions, which can be intergrown with other minerals. Sapphires range up to 5.5 centimetres (typical size in alluvial sediments is 3-6 millimetres) in size while ruby have been reported up to 1.5 centimetres. In lamprophyre dikes, most of the sapphire occurs as subhedral to anhedral grains with the most common shape a wafer with etched surfaces and a thin spinel crust.

Weathering can greatly enhance the corundum grade and transform a low-grade occurrence into an economic deposit through concentration of the minerals. Associated deposit types include placer corundum ± zircon ± diamond and corundum-bearing regolith (Simandl and Paradis, 1999).

Ultramafic-Related Corundum (Contact Metamorphic/Metasomatic) - Archean or younger, ultramafic-related corundum deposits that may contain sapphire and/or ruby, occur in orogenic belts where felsic rocks are thrust against silica-undersaturated rocks in stable cratons. Deposits are located within, or adjacent to aplite, pegmatite, albite, plumasite or marundite dikes, sills and occasionally plugs which cut mafic/ultramafic rocks and their metamorphosed equivalents.

Abrasive-grade corundum deposits are commonly contemporaneous with contact metamorphism and occur commonly along contacts of mafic/ultramafic intrusions with metapelites or other felsic country rocks. Gem-quality corundum may post-date metamorphism and the peak of the tectonic activity and sometimes occurs near the contacts of mafic/ultramafic intrusions with country rocks. Emery may form veins, layers and irregular or lens-shaped masses. Sapphire and ruby in these types of deposits can form as rhombohedral or hexagonal prisms or they may occur as clear portions of large, poikilitic corundum crystals that may, exceptionally, reach over a metre in length.

Common hosts are vermiculite ± chlorite, plumasite, syenite, pegmatite, aplite or hornfels. Associated rocks can include ultramafic and mafic rocks such as gabbro, amphibolite and serpentinite. Ore mineralogy in plumasite and marundite can consist of sapphires, rubies and specimen-quality or industrial-grade corundum. Ore mineralogy within contact metamorphic zones of mafic or ultramafic intrusions consists mostly of emery or silimanite-corundum rock or coarse industrial-grade corundum. Along tectonic contacts ore mineralogy can consist of rubies, sapphires, specimen and industrial-grade corundum.

Most dike associated or fracture-controlled deposits that crosscut ultramafic/mafic rocks are planar or lens-shaped, zoned and less than 10 metres thick while extending up to 10 metres laterally. There are three major spatial ore controls namely:

i) fracture zones controlling metasomatic and plumasite mineralization within the mafic/ultramafic rocks;
ii) tectonic contacts controlling mineralized pockets between gneisses and serpentinites;
iii) contact metamorphic zones around mafic/ultramafic intrusions.

Several theories have been developed to explain the origin of mafic/ultramafic-related corundum deposits. They include:

i) The desilicifiation of granitic pegmatites or pegmatitic fluids by the interaction with silica-undersaturated country rocks.
ii) In contact metamorphic/metasomatic settings, the high ratio of Al_2O_3 $(CaO+Na_2P+K_2O)$ and low silica content that favour corundum formation may be achieved by magmatic interaction of mafic or ultramafic rocks with metapelites or by partial melting of the pelitic country rocks.
iii) Where the felsic rocks were thrust against ultramafic rocks, reaction zones may have formed under open system conditions during regional metamorphism.

Some uneconomical primary gemstone and industrial grade deposits may form viable residual or placer deposits through redistribution and concentration of weathered materials. Associated deposit types include placer corundum deposits, vermiculite, nepheline syenite, and pegmatite (Simandl and Paradis, 1999).

World Production

Table 122 illustrates major world occurrences of corundum (ruby/sapphire).

Table 122

Major World Occurrence of Corundum (Ruby and Sapphire)

Location	***Occurrence***	***Varieties of Corundum***
Mogok, Burma	Ruby: found in alluvial gravel derived from metamorphosed crystalline limestone Sapphire: found in alluvial gravel derived from granitic pegmatite, or rarely from corundum syenite.	Ruby (most common), blue sapphire, also yellow, violet, green, sapphire, stars, colour-change sapphires.
Thailand and Cambodia	Ruby and sapphire found in eluvial and alluvial gravel derived from nepheline normative and highly alkaline basalt, especially basanitoid basalt.	Ruby, blue, yellow, green and black star sapphires.
Sri Lanka	Ruby and sapphire: found in alluvial stream gravel derived from granulites, pegmatite’s, garnetiferous gneiss, skarns, and cordierite gneiss and associated rocks.	All colours, except green (rare); also stars.
Kashmir, India	Blue sapphire: found in feldspar pegmatite surrounded by modified actinolite-tremolite bodies and in alluvial gravel derived from these rocks.	Blue sapphire, rarely pink sapphire, also star sapphires.
Queensland and New South Wales, Australia	Sapphires: found in eluvial and alluvial gravel derived from alkali basalt. Recent work suggests that ‘basaltic’ tuffs may in fact be the source of the sapphire in NSW.	Blue, green, yellow, and black star sapphires.
Jagdalek, Afghanistan	Ruby: occurs in situ within a metamorphosed dolomitic limestone cut by granitic intrusions of Oligocene age.	Ruby
Umba Valley, Tanzania	Ruby and sapphire: found in eluvial and alluvial gravel derived from limestone or pegmatite veins within or bordering a serpentinite pipe.	All varieties.
Mangari district, Kenya	Ruby: found in situ or in eluvial gravel derived from desilicified veins cutting through altered and serpentinized ultramafic rocks, or in or near the contact zone of a serpentinized pipe associated with desilicified pegmatoidal segregations.	Ruby
Yogo Gulch, Montana, USA	Blue sapphire: commonly found in eluvial or alluvial gravel derived from lamprophyric igneous dyke intruded into a fault within the limestone country rock. The dyke is also mined.	Blue and lilac-coloured sapphire.
Kaduna, Nigeria	Secondary deposits associated with alkali basalts.	Mainly blue sapphires, also greens, yellows and bi-colours (green/yellow or blue/yellow)

Source: adapted after Walton, pg. 10

End Use

Ruby and sapphire are both highly sought after gemstones used for jewelry.

Quality and Specifications

Ruby and sapphire are governed by many factors and qualitative characteristics, including beauty, clarity, defects, demand and rarity.

Market Trends

Ruby and sapphire and most coloured gemstones are generally influenced by market supply and demand consideration that is largely governed by the state of the world economy.

The increased misuse of terms like "synthetic" and "laboratory-created" in deceptive advertising and owing to the proliferation of treatment process to enhance gemstone quality artificially without disclosure, prompted the United States government in April 2001 to modify its "Guides for the Jewelry, Precious Metals, and Pewter Industries". These modifications were made as a preventive measure to reduce consumer confusion and fraud (Olson, 2001).

Price

The USGS reports the price paid per carat of US cut ruby and sapphire in December 2000 was between US$1800-2800 and US$450-1450 respectively (Olson, 2000).

Economic Factors

Primarily, alkali basalt and lamprophyre hosted sapphire and ruby deposits are very rare. Most of the corundum gems are recovered from associated residual soil or placer deposits.

In New South Wales, Australia, corundum volcanoclastic sediments may contain as much as 12 kilograms of corundum per cubic metre of material. The Yogo dike yielded about 10 carats/ton between 1897 and 1929 with grades probably varying between 0 and 70 carats/tonne. However, no reliable grades in terms of carats per metric tonne are available so it is difficult to establish parametres for economic deposits (Simandl and Paradis, 1999).

Yukon Occurrences

There are no reported ruby or sapphire occurrences in the Yukon. However, in placer deposits ruby can sometimes be confused with red spinel (also a gemstone) and miners should consider all red minerals as potential rubies.

Exploration Guidelines

Ruby and sapphire associated with alkali basalts - good exploration targets for ruby and sapphire in the Yukon are pipes, dikes (lamprophyre), plugs and diatremes of alkali composition, especially alkali basalt rocks which are undersaturated; for example nephelinite and nepheline hawaiite.

The presence of corundum gemstones and/or indirect indicator minerals such as kaersutite and chrome diopside in heavy mineral concentrates from stream and lake sediments or from tills, are good geochemical signatures. So are heavy mineral suites of zircon, spinel, ilmenite, olivine, clinopyroxene, garnet, magnetite (Simandl and Paradis, 1999).

Rubies and sapphires associated with marbles or aluminum-rich metasedimentary rocks - the presence of marble, either as beds, lenses or intercalations within schist and gneiss packages is important for gem corundum formation. In the Urals, gem corundum preferentially precipitated with magnesian calcite marble and dolomitic calcite marble, as opposed to calcite marble. The host rocks for the Ural Mountain ruby deposits were regionally metamorphosed under conditions of between 620-660ºC and 2.5 kbars. In general, the regional metamorphic conditions are medium to high-grade.

In the Urals, pegmatites are found associated with ruby deposits, for example, the Mogok Stone Tract, but the geochemical relationship between pegmatite intrusion and ruby formation is not known (Walton, 1996).

Gem Corundum Associated with Ultramafic Rocks - chromite-bearing ultramafic bodies are the most suitable host rock for ruby and sapphire formation. Ruby crystal may grow adjacent to ultramafic/pegmatite or ultramafic/paragneiss contacts during an upper amphibolite to granulite facies metamorphic event. Although the lithology of the host rocks next to the ultramafic bodies is not important, the absence of fluids after the peak of regional metamorphism prevents retrograde mineral reactions during cooling and allows the for the preservation of gem corundum (Walton. 1996).

Geophysical surveys using electromagnetic or magnetic surveys may be effective in delimiting sapphire/ruby host rocks, assuming a good contrast with surrounding lithologies is possible.

TOPAZ TOP

Chemical and Physical Characteristics

Topaz ($Al_2SiO_4(F,OH)_2$, also known as brown, smoky topaz, imperial or golden topaz, is a very hard (8), heavy (S.G. 3.49), fragile transparent or translucent mineral with a vitreous lustre. Its colour is variable ranging from colourless, yellow, blue, green, violet or reddish-yellow.

Clear or coloured varieties of topaz have always been used as gems. The deep-golden-yellow variety is the most highly regarded, though blue or green stones are also very popular with collectors. Unfortunately, in the jewelry trade many faceted yellow stones are known as topaz (i.e. citrine quartz) and the purchaser should be aware of this marketing deception when purchasing topaz jewelry.

It is estimated that approximately 80 percent of topaz deposits are pegmatite-related, 10 percent rhyolite-hosted and the rest in greisen and rarely veins and skarns. Topaz is derived from highly evolved granites and rhyolites that are rich in both fluorine and silica. Most topaz is primary, although it can replace feldspars. Topaz deposits occur more frequently in closed systems such as pegmatites or rhyolites where the fluorine-rich fluid is enclosed rather than open systems like a greisen or skarn where the hot fluid or magma seeps unhindered into the host rock.

The largest and finest topaz crystals come from pegmatites in Minas Gerais (Brazil) and from Alabaschka (Russia). Other producers include Burma and Sri Lanka (Walton, 1996).

Exploration Guidelines

An exploration guideline for topaz is to recognize when simple quartz-feldspar-mica pegmatite's become increasingly complex and are marked by changes in mineralogy - perhaps the presence of black tourmaline crystals in addition to the basic mineral assemblage or texture or internal zoning patterns. Walton (Open File 1996-2) provides a detailed description of guidelines useful in the exploration for topaz in pegmatites and deposits associated with rhyolites and greisens.

Yukon Occurrences

Fluorine-rich magmas are generated in long-lived, tectonically active zones such as the coast ranges in the Yukon.

Topaz is a minor constituent of placer heavy mineral concentrates in the Hunker Creek area of the Klondike, and an in situ occurrence is reported nearby on Germain Creek (Minfile 116B 04) where topaz is associated with fluorite and cassiterite. Topaz is also reported to occur in a pegmatite on the GEM claims in the Wolf Lake map area (Minfile 105B 32) and in the Selwyn Basin in skarn at the TEE claim (Minfile 115P 008).

ZIRCON ZN

The mineral zircon ($ZrSiO_4$) forms in stubby, prismatic, sometime dipyramidal crystals that range in colour from yellow, red, brown, grey to green. Zircon can also occur as colourless. Zircon is hard (7), heavy (SG 3.9-4.8) with indistinct cleavage, and conchoidal fracture. The mineral is sometimes perfectly transparent with adamantine lustre and strong birefringence, but may also be opaque, dull and almost isotropic when metamict (structure destroyed by radioactive thorium and uranium, which substitutes for up to 4 percent of the zirconium). Zircon may also contain up to 20 percent hafnium (See under the mineral hafnon).

Zircon is a typical accessory mineral of acidic igneous rocks and their metamorphic derivatives. It is often concentrated as small grains in alluvial deposits.

Well known zircon deposits occur in beach sands in Australia, Brazil and Florida in the United States. Large crystals are mined from alluvial deposits in Sri Lanka and the Urals of Russia. In Canada, zircon is extracted from deposits near Renfrew in Ontario.

Besides its use as a gemstone, zircon is an important source of zirconium, hafnium and thorium.

Yukon Zircon Occurrence

Zircon is found in placer mines in the Klondike but no economic or significant occurrences have been documented. There are no reported zircon occurrences reported in Yukon Minfile 2001.

PART D

MINOR METALS

MMET

The Economics of Minor Metals Eco

Although not considered industrial minerals, minor metals play an important role in today's society. Marketing in general, is one of the most important factors in the development of "high-tech" metal resources. As is the case with many industrial mineral commodities, the problem of finding a promising prospect is often surpassed by the difficulty of finding a market. When considering exploration for "high-tech" metals, a number of factors should be considered:

a) These commodities have very specialized applications and therefore limited markets, that is, markets controlled by a small number of companies on an international level, frequently with its own mineral resource.
b) Almost all applications require very small volumes of material (in most cases international consumption of these commodities is in the order of a few tens of thousands of tonnes annually).
c) Most of the 'elements' discussed in this report are present in trace amounts and commonly require expensive processing to recover. High unit costs commonly reflect high processing costs, not the value of the commodity in the ground.
d) In many cases, known producing sources are limited.
e) Most forecasts are for increasing demand in known applications.
f) The possibility exists for new uses to result from research and development efforts.

Although it may appear the negative factors outweigh the positive ones, many experts believe that there is room in the international marketplace for a small number of new producers (Pell and Hora, 1990).
The potential exists for commercial deposits of the "high-tech" metals to be discovered and developed in the Yukon. A brief general review of these metals is included, to raise awareness of their importance and potential, as exploration targets.

The Minor Metals Met

To follow is a brief summary about individual minor metals, their properties, occurrences, end use. The metals are listed alphabetically.

ANTIMONY ANT

Chemical and Physical Characteristics

Antimony (Sb) is a hexagonal mineral, silver-white in colour with a low melting point. Antimony's main ore is stibnite (Sb_2S_3) which occurs in encrusted granular masses or radiated nodules. This natural sulphide is soft (3-3.5), exhibits perfect cleavage, and is opaque with a bright metallic lustre. It fuses at low temperatures (630°C) and burns in air, giving off white fumes and colouring the flame blue-green. In its elemental form, antimony exhibits poor electrical and heat conductivity properties. Commercial forms of antimony are generally ingots, broken pieces, granules and cast cake. Other forms are powder, shot, and single crystals.

Estimates of the abundance of antimony in the earth's crust range from 0.2-0.5 ppm. Antimony is chalcophile, occurring with sulphur and the heavy metals, lead, copper, and silver. Over a hundred minerals of antimony are found in nature. Stibnite (Sb_2S_3) is the predominant ore mineral of antimony.

Deposit Examples

By-product of complex silver-copper-antimony sulphide ore - Coeur d'Alene District Idaho (United States); Guangxi Province, (China).

General Geology

Antimony occurs in hydrothermal lodes containing sulpho-arsenides and sulpho-antimonides, especially of silver, as a reduction product of these minerals. Canada's only antimony mine in New Brunswick, was sold to Amspec Chemical Group in 1990, but was shut down in 1991. Remaining reserves are reported to be 10,000 tonnes of 4.15 percent antimony. Small stibnite veins are scattered in many mineral districts worldwide.

World Production

World primary production during 2001 is estimated at 115,000 tonnes with leading producing countries including China (95,000 tonnes), South Africa (5,000 tonnes), Russia (3,000 tonnes), and Bolivia (3,000 tonnes), and the United States (300 tonnes). During 2000 Canada produced 364 tonnes of antimony (Carlin, 2000).

End Use

During 2000, about one-half of the primary antimony used in the United States went into flame-retardants; most of the remaining supply was used by transportation, chemical, ceramics, and the glass industries.

Market Trends

North American consumption of antimony, especially for important uses such as flame-retardants, is likely to remain strong in the near future. Industry observers attributed the price decline during the first half of 2001 to a continued world oversupply situation, aggravated by growing exports from China. However, government officials in China believe that smuggling of antimony, which in previous years accounted for a significant tonnage of antimony shipped abroad, has been virtually eliminated due to greater efforts against illegal shipments.

Environmental and ecological problems associated with the treatment of antimony raw materials were minimal, because all American processors of raw materials now avoid sulphide-containing materials (Carlin, 2002).

Quality and Specifications

At the present time, Canada's antimony production is mostly a byproduct of lead refining. The quality and specifications of antimony are illustrated in Table 123.

Table 123

Antimony: Quality and Specifications

Chemical-grade ore	Ore sufficient to produce the oxide, chloride, or other compounds required <0.25% As & Pb, with no single metallic impurity >0.1%.
Crude antimony oxide	<98% Sb2O3
Commercial antimony oxide	99.2% to 99.5% Sb2O3 with impurities such as As, Fe, and Ti
Antimony metal	Grade A 99.8% antimony, max. 0.05% As, 0.10% S, 0.15% Pb and 0.05% others; Grade B min 99.5% antimony, max 0.1% As, 0.1% S, 0.2% Pb and 0.1% each other element.

Source: adapted after The Industrial Minerals HandyBook II, pg. 1

Price

Antimony prices reported by Industrial Minerals, No. 419 during August, 2002 were:

- Lump sulphide ore, min 60% SB CIF US$7-8.
- Antimony oxide type 99.5% Sb_2O_3 FOB Antwerp, (5t lots duty unpaid)
- Chinese US$1,900-2,000; European US$2,000.

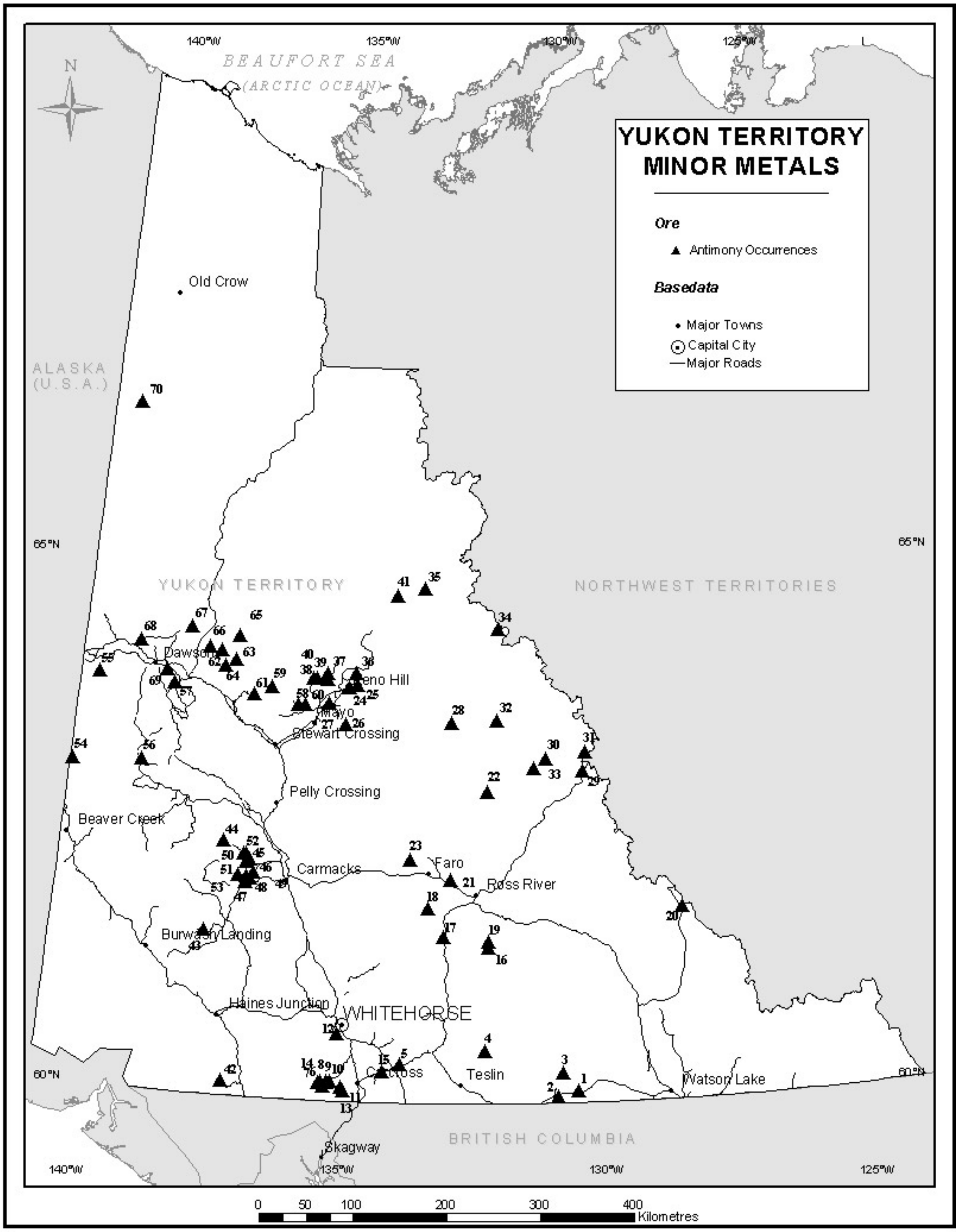


Figure 6. Yukon Antimony Occurrences Fig6

Yukon Occurrences

Seventy antimony occurrences are described under commodities in Yukon Minfile 2001.Of these, eleven are listed as major commodities (Table 124; Figure 6).

Table 124

Yukon Antimony Occurrences

Map #	Minfile Number	NTS	Name	Tectonic Element	Deposit Type	Latitude/Longitude
1	105B 003	105B/1	JAX	CP	R	60º06’57”/130º27’06”
2	105B 011	105B/2	CARLICK	CP	V	60º03’34”/130º50’09”
3	105B 007	105B/7	BUC	CB	V	60º17’26”/130º44’02”
4	105C 003	105C/9	BAR	YT	SEDEX	60º30’16”/132º14’26”
5	105C 055	105C/5	EAGLENEST	CCT	V	60º22’02”/133º53’22”
6	105D 021	105D/3	BERNEY	CPC	V	60º10’04”/135º26’36”
7	105D 022	105D/3	COMBINATION	CPC	V	60º10’45”/135º24’42”
8	105D 025	105D/3	GODDELL	CPC	V	60º11’32”/135º16’55”
9*	105D 026	105D/3	EMPIRE	CPC	V	60º10’34”/135º16’56”
10*	105D 027	105D/3	PAYMASTER	CPC	V	60º11’05”/135º12’54”
11	105D 035	105D/2	MILLHAVEN	NST	V	60º05’51”/134º58’17”
12	105D 057	105D/11	POLAR	NST	S	60º38’36”/135º06’40”
13	105D 092	105D/3	OPULENCE	NST	V	60º08’28”/135º00’45”
14	105D 195	105D/3	MIK	CPC	V	60º08’33’/135º21’22”
15	105E 053	105E/8	DEET	YT	V	60º18’01”/134º13’22”
16	105F 015	105F/8	KAY	CP	V	61º29’14”/132º09’03”
17	105F 032	105F/11	PONY	CP	MV	61º35’11’/133º03’53”
18	105F 034	105F/14	RISBY	CP	S	61º51’35”/133º23’04”
19	105F 057	105F/9	KETZAKEY	CP	V	61º33’03”/132º09’25”
20	105H 082	105H/16	TUNA	SPC	P	61º49’34”/128º14’31”
21	105K 023	105K/2	GREEN VALLEY	SMT	?	62º08’07”/132º55’46”
22*	105K 090	105K/16	SOLO	SB	V	62º58’41”/132º10’26”
23	105K 091	105K/5	EL PINO	TV	?	62º19’25”/133º45’39”
24	105M 004	105M/14	GOLDEN QUEEN	SB	V	63º56’40”/135º09’23”
25	105M 034	105M/15	COBALT	SB	V	63º58’42”/134º58’16”
26*	105M 037	105M/11	GORDON	SB	V	63º35’32”/135º12’07”
27	105M 054	105M/13	CHANCE	SB	V	63º47’32”/135º34’19”
28	105N 024	105N/10	BERDAHL	SB	?	63º37’48”/132º55’07”
29	105O 001	105O/1	TOM	SB	SEDEX	63º09’53”/130º08’40”
30	105O 032	105O/7	BRICK	SB	V	63º17’24”/130º54’56”
31	105O 033	105O/8	BORD	SB	V	63º20’47”/130º04’21”
32	105O 041	105O/12	FANGO	SPC	I	63º39’29”/131º56’45”
33	105O 056	105O/3	GOLD	SB	V	63º11’59”/131º11’22”
34	106B 015	106B/12	NECO	MP	V	64º31’27”/131º53’38”
35	106C 009	106C/13	DOLORES	MP	V	64º54’23”/133º31’45”
36	106D 012	106D/3	CAMERON	MP	V	64º05’27”/135º00’39”
37	106D 020	106D/4	SKATE	SB	V	64º00’58”/135º37’48”
38	106D 021	106D/4	PESO	SB	V	64º01’28”/135º56’42”
39*	106D 022	106D/4	BARKER	SB	V	64º01’53”/135º51’41”
40*	106D 029	106D/4	CJ	SB	V	64º04’37”/135º37’55”
41	106D 095	106D/16	WALLACE	SB	V	64º49’59”/134º08’08”
42	115A 005	115A/3	PHOTO	WT	V	60º08’32”/137º18’21”
43	115H 045	115H/12	AL	MNV	V	61º33’49”/137º52’58”
44	115I 037	115I/5	CASH	NST	P	62º25’45”/137º37’12”
45	115I 051	115I/6	CASTLE	YT	V	62º19’00”/137º08’13”
46*	115I 055	115I/6	EMMONS HILL	NST	V	62º16’13”/137º03’14”
47	115I 064	115I/3	BROWN-MCDADE	YT	V	62º03’00’/137º07’19”
48	115I 085	115I/3	CAR	NST	P	62º05’20”/137º01’36”
49*	115I 086	115I/2	LEE	NST	V	62º08’27”/136º57’19”
50	115I 088	115I/3	BATH	NST	?	62º14’38”/137º07’38”
51	115I 117	115I/3	DIC	MNV	V	62º06’19”/137º16’25”
52	115I 121	115I/6	STODDART	YT	V	62º19’15”/137º10’36”
53	115I 122	115I/3	GRIZZLY	YT	V	62º06’35”/137º05’09”
54	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36”/140º55’14”
55	115N 042	115N/15	BUTLER	YT	S	63º54’56”/140º34’33”
56	115O 013	115O/3	DONAHUE	YT	?	63º07’41”/139º29’08”
57	115O 068	115O/15	MITCHELL	YT	V	63º53’18”/138º56’54”
58*	115P 003	115P/16	HAWTHORNE	TSZ	I	63º46’11”/136º14’31”
59	115P 007	115P/15	MAHTIN	SB	S	63º55’11”/136º49’37”
60	115P 033	115P/16	HIGHET	TSZ	I	63º46’04”/136º04’55”
61	115P 055	115P/14	BARNEY	SB	?	63º50’32”/137º12’25”
62	116A 013	116A/4	RIMROCK	SB	V	64º14’05”/137º58’30”
63	116A 027	116A/4	IDA	SB	V	64º09’00’/137º38’06”
64	116A 031	116A/4	AUSSIE	SB	V	64º05’27”/137º52’31”
65	116A 037	116A/5	HEIDI	SB	I	64º23’17”/137º36’55”
66*	116B 001	116B/8	AM	TSZ	I	64º15’50”/138º13’53”
67	116B 056	116B/7	MOONDANCE	SB	S	64º26’08”/138º40’11”
68*	116B 076	116B/5	CUPCOWLODE	YT	?	64º15’13”/139º46’37”
69	116B 159	116B/3	ALPHA	YT	?	64º00’23”/139º08’13”
70	116K 003	116K/9	RUSTY SPRINGS	MP	S	66º30’25”/140º23’31”

CPC (Coast Plutonic Complex), SB (Selwyn Basin), SPC (Selwyn Plutonic Complex), NST (Northern Stikine Terrane), TSZ (Tombstone Strain Zone), YT (Yukon Tanana), WT (Wrangellia Terrane), TSZ (Tombstone Strain Zone), MNV (Mt. Nansen Volcanics), TV (Tertiary Volcanics),CB (Cassiar Batholith), MV (Mississipi Valley); V (Vein), I (Intrusive), P (Porphyry), S (Stratabound), ? (Deposit type unknown).

Grades announced by Yukon Antimony Corporation on samples collected from one of three adits on the PAYMASTER property (Minfile 105D 027) during the mid-1960’s reported 4.8 percent Sb, 0.6 percent Pb and 30.9 grams per tonne silver over an average width of 1.5 metres along a strike of 107 metres. The company estimated probable reserves at 20,866 tonnes grading 3.6 percent Sb across an average width of

1.95 metres. In 1974, another company (reported probable and possible reserves) at 127,000 tonnes grading four percent Sb.

In 1984, a 331 kilogram bulk sample from a surface pit tested by the Mineral Processing Division, Department of Mines and Technical Surveys assayed 11.21 percent Sb. Single stage flotation produced a concentrate, grading 60.7 percent Sb with a recovery of 92.8 percent.

Mineralization is reported to occur in lenses of quartz and barite within a 2.4 metres shear zone that cuts a rhyolite dyke (early Eocene Mount Skukum volcanic complex) and older andesite which may be upper Jurassic rusty weathering, blue-grey andesite porphyry flows and breccia (Hart and Radloff, 1990).

BERYLLIUM BER

Chemical and Physical Characteristics

Beryllium (Be) is silver in colour, one of the lightest of all metals, and has one of the highest melting points (1,280°C) of any light metal. Only two beryllium minerals, beryl ($Be_3Al_2Si_6O_{18}$) and bertrandite ($Be_4Si_2O_7$ $(OH)_2$ are of commercial importance with beryl containing about 4 percent Be and bertrandite, less than one percent Be. Bertrandite is the principal beryllium mineral produced in the United States, and beryl is the principal mineral produced in the rest of the world.

Individual crystals of beryl are sometimes enormous, up to 9 metres long and weighting more than 25 tonnes. Colour can very from grey-white, yellowish-white or pale blue-green but some varieties are transparent yellow (heliodor), pink (morganite), blue (aquamarine) and green (Emeralds - see in this report). The mineral is very hard (7.5-8), light, (SG 2.65-2.90) with imperfect basal cleavage.

Beryl is characteristic of granitic rocks and pegmatites, where it can sometimes occur in enormous crystals. It is also present in very high-temperature hydrothermal deposits (greisen) associated with quartz, spodumene, cassiterite, columbite, tantalite and other rare minerals. It is less common in nepheline syenites, in calcite veins caused by metamorphic segregation and in biotitic schist in medium-to-high facies. Because of its hardness and great chemical resistance, it remains unaltered in alluvial deposits derived from the rocks where it originally crystallized.

Bertrandite occurs in thin tabular or prismatic crystals usually pseudomorphous after beryl. Twinning is common and it ranges in colour from colourless to pale yellow. It has a hardness of 6-7, is light (SG 2.6), and is transparent to translucent with vitreous lustre. It is found in environments similar to beryl and forms through the breakdown of beryl, frequently crystallizing in cavities corroded out of beryl crystals by hydrothermal solutions.

The commercial bertrandite deposit at Spor Mountain in Utah (United States), is in association with fluorspar as impregnations in waterlain volcanic ash. The deposit is related to a topaz rhyolite intrusion.

Deposit Examples

Thor Lake, Northwest Territories, Strange Lake and Seal Lake, Labrador (Canada); Seward Peninsula, Alaska; Spor Mountain and Gold Hill, Utah (United States).

General Geology

The two main geological environments in which beryllium occurs are, volatile-enriched granite systems and peralkaline granite-syenite complexes.

Beryllium, commonly in the form of beryl, occurs in zones, filled fractures and replacement bodies associated with heterogeneous granite pegmatites. These pegmatites which may also contain lithium minerals, commonly are late-stage differentiates of volatile-enriched or ‘specialty’ granites. Beryllium is also concentrated in quartz-greissen veins and skarns related to volatile-enriched granites that often also carry other elements such as tin, tungsten, fluorine, and occasionally molybdenum. Topaz rhyolites, which are the extrusive equivalent of volatile-enriched granites, may also contain or be associated with beryllium mineralization, in some cases containing the mineral bertrandite.

Peralkaline granite-syenite complexes sometimes contain significant accumulations of beryllium. They generally consist of multiphase intrusions, with beryllium minerals such as phenacite and bertrandite, concentrated in late-stage intrusions and pegmatites. Commonly, other 'high-tech' elements such as niobium, rare earths, yttrium and zirconium are associated with beryllium in these deposit types (Pell and Hora, 1990).

World Production

World beryllium ore productions in 2001 totaled about 5,650 tonnes with producing countries including the United States (4,510 tonnes), Russia (1,000 tonnes), Kazakhstan (100 tonnes), Madagascar (30 tonnes), Brazil (10 tonnes) and Portugal (4 tonnes) (Cunningham, 2001).

Canada has no domestic production of primary beryllium although Highwood Resources at Thor Lake in the North West Territories has delineated deposits of beryllium mineral phenacite ($BeSiO_4$), which occurs with niobium, tantalum, zirconium, gallium and rare earth elements.

End Use

Beryllium metal is used principally in aerospace and defense applications because of its stiffness, lightweight, and dimensional stability over a wide temperature range. Beryllium-copper alloys are used in a wide variety of applications because of their electrical and thermal conductivity, high strength and hardness, good corrosion and fatigue resistance and nonmagnetic properties. Beryllium oxide is an excellent heat conductor, with high strength and hardness, and acts as an electrical insulator in some applications, particularly high-tech ceramics. It is considered extremely toxic.

Quality and Specifications

Beryl ore averages 10-12 percent BeO, with the average bertrandite ore grade being 0.69 percent BeO. Specifications for beryllium are illustrated in Table 125.

Table 125

Specifications for Beryllium (Weight %)

	Commercial beryllium powder SP-2-F	Hot pressed powder billet Grade A	Hot pressed powder billet Grade B	Hot pressed powder billet Grade C
Min. Be	98.50	98.00	98.00	94.00
Max. BeO	1.50	1.50	2.20	9.00
Max. Al	0.10	0.07	0.10	0.16
Max. C	0.15	0.10	0.15	0.25
Max. Fe	0.13	0.12	0.15	0.25
Max. Mg	0.08	0.80	0.08	0.08
Max. Si	0.06	0.80	0.08	0.08
Max. each other	0.04	0.04	0.04	0.10

Source: The Industrial Minerals HandyBook II, pg. 27, after Brush Wellman Inc.

Market Trends

Beryllium alloys, primarily beryllium-copper, is expected to remain the dominant form of consumption for beryllium. Beryllium demand should rise owing to increased usage of beryllium-copper in automotive electronics, computers, and portable telephones. Also, the newer beryllium-aluminum alloys are expected to gain in importance in terms of beryllium demand, with usage in applications such as aerospace and computers. The beryllium-aluminum alloys contain up to about 60 percent beryllium compared to about beryllium-copper alloys which contain about 2 percent beryllium.

Price

Beryllium prices during 2001 are illustrated in Table 126.

Table 126

Year-End Beryllium Prices (US dollars per pound)

Beryl ore (per short ton unit of contained BeO)	(1/)
Beryllium vacuum-cast ingots, 98.5% pure, in lots up to 1,000 pounds	$325-350
Beryllium metal powder, in 1,000 to 4,999 pounds lots and 99% pure	$350-400
Beryllium-copper master alloy (per pound of contained Be)	$160
Beryllium-copper casting alloy	$5.52-6.30
Beryllium-copper in rod, bar, wire	$9.85
Beryllium-copper in strip	$8.90
Beryllium-aluminum alloy, in lots up to 100 pounds; 62% Be, 38% Al	$260
Beryllium oxide powder, in 10,000 pound lots	$100

*Source: Cunningham, USGS after the American Metal Market, Brush Wellman Inc., Metal Bulletin, and Platts Metals Week. * The published price for beryl ore was discontinued in October at a range of $75-80.*

Economic Factors

Two zones at the Thor Lake beryllium deposit in the Northwest Territories contain about 497,000 tonnes of ore (phenacite, a beryllium silicate) grading 1.4 percent BeO and the other about 1.3 million tonnes of 0.66 percent BeO. Spor Mountain in Utah (United States) in 1980 had reported ore reserves of 4.85 million tonnes grading 0.56 to 0.60 percent BeO with a cut-off grade of 0.30 percent.

Although the cost of beryllium is high compared with other materials, it is used in applications in which its properties are crucial. Graphite, steel, and titanium may be substituted for beryllium metal in some applications but these substitutions can result in substantial loss in performance Because of the toxic nature of beryllium, the industry must maintain careful control over the quantity of beryllium dust and fumes in the workplace (Cunningham, 2002).

Processing beryl is a much more expensive process than processing bertrandite ore, which is easy to leach and dissolve.

Yukon Occurrences

Two beryllium occurrences are reported as minor or trace commodities in Yukon Minfile 2001 Table 127; Figure 7).

Table 127

Yukon Beryllium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105G 071	105G/7	MYDA	YT	S	61º24’39”/130º30’26”
2	105M 066	105M/7	KALZAS	SB	V	63º15’58”/134º42’07”

YT (Yukon Tanana), SB (Selwyn Basin); S (Skarn), V (Vein)

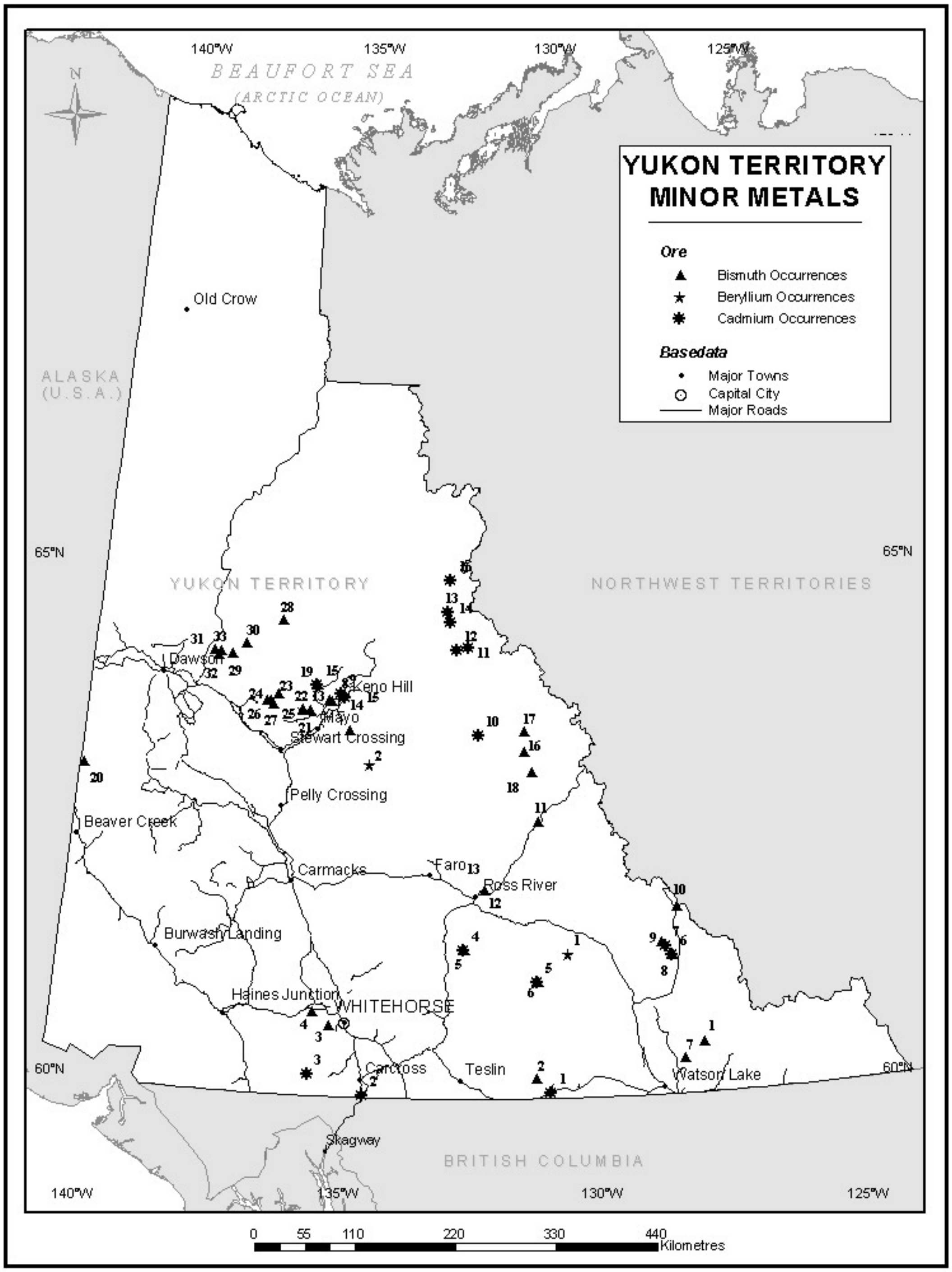


Figure 7. Yukon Bismuth, Beryllium and Cadmium Occurrences Fig7

BISMUTH BIS

Chemical and Physical Characteristics

Bismuth (Bi) crystals are rare and imperfect. They almost always occur in lamellar masses and dendritic and skeletal aggregates of a rose pink colour tarnished with an iridescent film. Crystals are soft (2-2.5), very heavy (SG 9.7-9.8), display perfect cleavage and are opaque with a bright metallic lustre and have a relatively low melting point (271ºC).

Deposit Examples

Usually, bismuth is recovered as a byproduct of lead or tungsten production except in China, North Korea and Vietnam, where it is found with copper-gold ores. The world's only significant primary source of bismuth was the Tasna Mine in Bolivia, which closed in 1985.

World Occurrences

During 2001 Canada produced an estimated 225 tonnes of bismuth from an estimated total world mine production of 5,810 tonnes. China, the world's leading mine producer, produced approximately 2,500 tonnes of bismuth (Brown, 2002).

General Geology

Bismuth occurs in hydrothermal veins, and is associated with lead, zinc, nickel, cobalt, silver, gold, tin, and uranium minerals.

End Use

Bismuth is mainly a byproduct of lead ore processing. Among the heavy metals, it is the heaviest and the only non-toxic. Bismuth is used in several applications designed to provide nontoxic substitutes for lead (fixtures and pipes for potable water, water metres, short for waterfowl hunting, fishing sinkers, lubricating greases). Bismuth is also used in the production of bismuth alloys, pharmaceuticals , chemicals, and as a metallurgical additive.

Market Trends

World lead mine production and world primary lead refinery production has not increased significantly in recent years limiting the amount of bismuth that can be produced as a lead byproduct. World mine production of bismuth was steady and world refinery production increased in 2001. Bismuth is potentially recoverable as a byproduct of the processing of molybdenum and some tungsten ores, although extraction of bismuth from these ores usually is not economic (Brown, 2002).

Price

Bismuth averaged an estimated US$3.80 per pound during 2001 (Brown, 2002).

Economic Factors

The long-range outlook for bismuth suggests demand will grow, especially in new applications as lead replacement (electronic ceramics, thermal fuses, soldering, galvanizing–alloy). A partial ban on lead has been announced in Denmark. However, in Japan and elsewhere, the increase in substitution for lead has been slow to materialize as applicable environmental regulations have been less stringent. It appears that the low prices for bismuth due to the constant availability of Chinese bismuth or the general deflationary trend for metals during the past decade, are the limiting factors to bismuth supply. Usually, more bismuth appears in the market, whenever prices increase.

Yukon Occurrences

Thirty-three bismuth occurrences are described in Yukon Minfile 2001. One is listed under major commodity (Table 128; Figure 7).

Table 128

Yukon Bismuth Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	95D 033	95D/5	CUZ	SB	V	60º29’35”/127º51’46”
2	105B 026	105B/3	ATOM	YT	S	60º11’33”/131º12’42”
3	105D 076	105D/11	GROUSE	WT	S	60º41’24”/135º21’52”
4	105D 082	105D/13	FARM	NST	S	60º49’12”/135º42’45”
5	105F 012	105F/7	ARNOLD	CP	V	61º27’29”/132º38’32”
6	105G 006	105G/3	EAGLE	CP	R	61º08’30”/131º09’02”
7	105H 027	105H/8	CORRIE	SB	?	61º20’44”/128º16’09”
8	105H 028	105H/8	BLACK JACK	SB	S	61º21’44”/128º22’55”
9	105H 032	105H/7	HELEN	SB	S	61º29’27”/128º36’08”
10	105H 082	105H/16	TUNA	SPS	P	61º49’34”/128º14’31”
11	105J 008	105J/11	MT. SHELDON	SPS	V	62º43’06”/131º05’29”
12	105K 103	105K/1	TENAS	YT	SEDEX	62º02’54”/132º13’54”
13	105M 029	105M/13	WAYNE	SB	V	63º53’00”/135º40’44”
14	105M 037	105M/11	GORDON	SB	V	63º35’32”/135º12’07”
15	105M 060	105M/13	AUREX	SB	S	63º52’22”/135º37’40”
16	105O 007	105O/6	ART	SB	I	63º24’05”/131º20’45”
17	105O 009	105O/11	EMERALD	SB	I	63º35’58”/131º20’02”
18	105O 056	105O/3	GOLD	SB	V	63º11’59”/131º11’22”
19	106D 021	106D/4	PESO	SB	V	64º01’28”/135º56’42”
20	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36”/140º55’14’`
21	115P 003	115P/16	HAWTHORNE	TSZ	I	63º46’11”/136º14’31”
22	115P 004	115P/16	SCHEELITE DOME	TSZ	I	63º47’05”/136º16’01”
23	115P 007	115P/15	MAHTIN	SB	S	63º55’11”/136º49’37”
24	115P 012	115P/14	RHOSGOBEL	MPS	P	63º50’23”/137º03’22”
25	115P 033	115P/16	HIGHET	TSZ	I	63º46’04”/136º04’55”
26	115P 061	115P/15	BIG	?	?	63º50’29”/136º58’07”
27	115P 063	115P/15	VAN	?	?	63º48’31”/136º54’48”
28	116A 009	116A/10	HART RIVER	MP	V	64º38’05”/136º49’30”
29	116A 012	116A/5	HAMILTON	TPS	V	64º16’45”/137º53’54”
30	116A 037	116A/5	HEIDI	SB	I	64º23’17”/137º36’55”
31	116B 001	116B/8	ANTIMONY MTN.	TPS	I	64º15’50”/138º13’53”
32	116B 094	116B/8	AJ	TPS	I	64º17’18”/138º10’19”
33	116B 095	116B/8	SANDOW	TPS	I	64º17’45”/138º18’18”

SB (Selwyn Basin), YT (Yukon Tanana), WT (Whitehorse Trough), NST (North Stikine Terrane),
CP (Cassiar Platform), SPS (Selwyn Plutonic Suite), TSZ (Tombstone Shear Zone), MPS (McQuestion Plutonic Suite);
V (Vein), R (Replacement), S (Skarn), I (Intrusive), ? (Deposit type unknown).

United Keno Hill Mine ore contains minor amounts of bismuth. The company is reported to have received $7000 for 1000 kilograms of bismuth in 1986 (Downing, 1993). The most promising bismuth occurrences may occur in hydrothermal veins associated with nickel, silver, tin, uranium and cobalt sulphide deposits. Bismuth values in these deposit types should be carefully appraised.

CADMIUM CAD

Chemical and Physical Characteristics

Cadmium (Cd) is a soft, malleable, ductile, bluish-white metal. The only cadmium mineral of commercial importance is greenockite (CdS), a cadmium sulfide, which is nearly always associated with sphalerite (ZnS). Greenockite is a yellow or orange hexagonal mineral, which usually occurs as an earth incrustation or coating on sphalerite and other zinc ores. It is semi-hard (3-3.5), fragile, displays perfect cleavage, and is translucent with adamantine or resinous lustre. It is a alteration product of cadmium-rich sphalerites, which forms only on the surface, or in parts of deposits affected by water. The average ratio between contained zinc and cadmium in sphalerite is about 400:1 or 0.25 percent.

Deposit Examples

Primary cadmium metals are produced as a byproduct of smelting and refining zinc metal from sulphide ore concentrates.

General Geology

Greenockite occurs as an alteration product of cadmium-rich spalerites. It forms only on the surface or in parts of deposits affected by ground water.

World Production

Estimated world refinery production of cadmium during 2001 was 18,700 tonnes with leading producers being Japan (2,500 tonnes), China (2,200 tonnes), United States (1,400 tonnes), Belgium (1,400 tonnes) and Canada (1,150 tonnes).

End Use

Cadmium is produced mainly as a byproduct from mining, smelting and refining sulphide ore of zinc and to a lesser degree, lead and copper. Approximately three-fourths of cadmium is used in batteries, with the remaining used in pigments, coatings and plating and as stabilizers for plastics.

Market Trends

Low prices, limited growth in many mature cadmium markets, and due to its high toxicity, pending environmental restrictions are negative factors for future cadmium production. In fact, some zinc mining companies that produce cadmium as a byproduct, have begun to regard the metal as a liability rather than an asset. The future of the cadmium market will be determined by the extent to which industry is able to fully implement the collection and recycling of cadmium products (e.g. Ni-Cd batteries).

Price

Average 2001 New York dealer price for 99.9 percent purity in 5-short-ton lots as reported in “Platts Metals Week” was US$0.15 (Plachy, 2002).

Economic Factors

Estimated world resources of cadmium are about six million tonnes based on zinc resources that contain about 0.3 percent cadmium.

Zinc-bearing coals in different regions of the world also contain large subeconomic resources of cadmium (Plachy, 2002).

Yukon Occurrences

Sixteen cadmium occurrences are described in Yukon Minfile 2001 (Table 129; Figure 7). However, none are listed as major commodities and no reserve estimates or grades are reported.

Table 129

Yukon Cadmium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105B 129	105D/2	LOWEY	YT	V	60º03’11”/130º55’26”
2	105D 005	105D/2	VENUS	CCT	V	60º01’30”/134º38’05”
3	105D 128	105D/4	KREFT	NT	S	60º12’21”/135º44’23”
4	105F 012	105F/7	ARNOLD	CP	VOLC.	61º27’29”/132º38’32”
5	105G 006	105G/3	EAGLE	CP	R	61º08’30”131º09’02”
6	105H 028	105H/8	BLACK JACK	SB	S	61º21’44”/128º22’55”
7	105H 031	105H/7	RON	SB	S	61º27’19”/128º30’41”
8	105M 001	105M/14	UNITED KENO HILL	SB	V	63º54’35”/135º18’01”
9	105M 020	105M/14	CAROL	SB	V	63º56’59”/135º23’13”
10	105N 004	105N/9	ROGUE	SB	?	63º34’08”/132º20’35”
11	106C 020	106C/7	BARRIER REEF	MP	MVT	64º25’43”/132º32’47”
12	106C 021	106C/7	HARRISON	MP	MVT	64º23’57”/132º49’22”
13	106C 023	106C/14	COB	MP	V	64º46’15”/133º01’53”
14	106C 037	106C/10	FRIGSTAD	MP	MVT	64º40’54”/132º57’30”
15	106D 021	106D/4	PESO	SB	V	64º01’28”/135º56’42”
16	106F 007	106F/2	COLLEY	MP	MVT	65º05’28”/132º57’34”

YT (Yukon Tanana), CCT (Cache Creek Terrane), NT (Nisling Terrane), CP (Cassiar Platform), SB (Selwyn Basin), MP (Mackenzie Platform); V (vein), S (Skarn), Volc.(Volcanogenic), MVT (Mississippi Valley), R (Replacement, ? (Deposit type unknown).

CESIUM AND RUBIDIUM CES

Chemical and Physical Occurrences

The element, Cesium (Cs) is the most electropositive and least abundant of the five naturally occurring alkali metals. Pollucite, the cesium aluninosilicate mineral, may contain up to 1.35 percent rubidium.

Rubidium (Rb) forms no known minerals in which it is the predominant metallic element. Rather, it substitutes for potassium in a number of minerals, especially those that crystallize late in the formation of pegmatites. Lepidolite, a potassium lithium mica, that may contain up to 3.15 percent rubidium, in the principal ore of rubidium.

Deposit Examples

There are three significant deposits of cesium in the western world: Bernic Lake, Manitoba, (Canada) Bikita Mine, (Zimbabwe), and the Karibib area in (Namibia). The Bernic Lake deposit is valued for its tantalum and lithium contents, but has estimated reserves of pollucite grading at 24 percent Cs_2O.

General Geology

The principal ore of cesium, the aluminosilicate mineral pollucite, is found in association with lithium minerals lepidolite (principal ore of rubidium) and petalite in zoned pegmatite.

World Production

Data on mine production of cesium is not available and data on resources is sketchy. The estimates of reserves are based on occurrences of the cesium aluminosilicate mineral pollucite, found in zoned pegmatites in association with lithium minerals lepidolite and petalite. Pollucite is mined as a byproduct with other pegmatite minerals. Commercial concentrates of pollucite contain about 20 percent cesium by weight.

Total world estimates of cesium reserves are 100 million kilograms, of which Canada has 70 million kilograms followed by Zimbabwe (23 million kilograms). Total world resources of rubidium are unknown (Reese, 2002).

End Use

Cesium, usually in the form of chemical compounds, is used in research and development and commercially in electronic, photoelectric, medical applications and nuclear industries.

The properties of rubidium and its compounds are similar to those of cesium and its compounds thus, rubidium and cesium are used interchangeably in many applications.

Market Trends

Rubidium (Rb) and its compounds are largely the subject of laboratory studies and are of little commercial significance. No major breakthroughs or developments are anticipated that would change the production or consumption patterns.

Price

The cesium market is very small, with annual consumption probably amounting to only a few thousand kilograms. As a result, there is no active trading of the metal, and therefore no official market price. However, several companies publish prices for cesium and cesium compounds. The per-unit price for the metal or compounds varies inversely with the quantity of material purchased. For example in 2001, one company offered 1-gram ampoules of 99.98 percent grade cesium metal at US$50. The price for 100 grams of the same materials from the same company was US$1,370 or US$13.70 per gram.

The market for rubidium is small with annual consumption in the United States for example estimated at only a few thousand kilograms. There is no active trading of the metal, however published prices for rubidium, and rubidium compounds, per-unit price vary inversely with the quantity of material purchased. For example in 2001, 1-gram ampoules of 99.8 percent grade rubidium metal sold at US$52; the price for 100 grams of the same material sold at US$998 or US$9.98 per gram ((Reese, 2002).

Economic Factors

The high cost and extreme reactivity of cesium limit its applications at present. Because of the small scale production of cesium products, no significant environmental problems have been encountered.
Rubidium-bearing minerals are mined as byproducts or co-products with other pegmatite minerals.

Yukon Occurrences

There are no major cesium/rubidium commodity occurrences described in Yukon Minfile 2001. A systematic evaluation of pegmatites in the Yukon for these two elements is required to determine their potential.

CHROMIUM CH

See under chromite in this report.

COBALT COB

Chemical and Physical Characteristics

Cobalt (Co) is a malleable metal closely resembling nickel in appearance. It has a high melting point, approaching 1,500ºC. It can be produced by the reduction of its oxides by carbon. The chief cobalt minerals are Cobaltite (CoAsS), Smaltite [$(Co,Ni)As_{3-n}$], and linnaeite (Co_3S_4). These cobalt minerals, when exposed to the atmosphere, weather on their exterior to a characteristic and distinctive pinkish hydrated cobalt bloom called Erythrite $Co_3 (AsO_4)_2 \cdot 8H_2O$. The principle ore of cobalt is cobaltite.

Deposit Examples

Frye Lake copper-cobalt-gold deposit (Minfile 105G 034); Wellgreen nickel-copper-cobalt deposit

(Minfile115G 024), Yukon; Windy Craggy Copper-cobalt deposit, British Columbia; Sudbury Basin, Ontario; Cobalt, Ontario (Canada); garnierite deposits of nickel, (New Caledonia). Cobalt is mostly a co-product of processing nickel ores – both sulphides and laterites.

General Geology

Cobalt deposits of economic value occur in three main ways: as cobalt veins carrying smaltite and cobaltite (Saxony, Cobalt Ontario); as cobaltiferous pyrrhotite (Sudbury, Ontario); and as asbolite which results from the weathering of cobaltiferous basic and ultrabasic rocks – this last origin being analogous to the garnierite deposits of nickel (New Caledonia).

World Production

The estimated world mine production during 2001 of mined cobalt was 36,900 tonnes. The principal producing countries included the Democratic Republic of the Congo (7,000 tonnes), Zambia (7,000 tonnes). Australia (6,500 tonnes), Canada (5,000 tonnes), Russia (4,000 tonnes), Cuba (2,600 tonnes) and New Caledonia (1,100 tonnes). World production of refined cobalt during 2000 was 35,200 tonnes (Shedd, 2000 and 2002).

End Use

Cobalt is a strategic and critical metal used in many diverse commercial and industrial applications. The largest market for cobalt is in super alloys that are used to make parts for gas turbine aircraft engines. Cobalt is also used to make magnets, corrosion-and wear-resistant alloys, high-speed steels, cemented carbides (also called hard metals) and diamond tools, catalysts for petroleum and chemical industries, drying agents for paints, varnishes, inks, ground coats for porcelain enamels, pigments, battery electrodes, steel-belted radial tires and magnetic recording media.

Market Trends

World demand for cobalt is influenced by general economic conditions and by demand from industries that consume large quantities of cobalt, such as superalloy, magnetic alloy, and cemented carbide producers. In 2001, several factors reduced demand for cobalt, including weak economic conditions in major consuming countries such as the United States and Japan, and a decrease in the production of rechargeable batteries. In September, 2001 terrorist attacks in the United States caused economic uncertainty and as well, financial problems in the world airline industry, which resulted in decreased demand for cobalt. Since 1995, the general trend in cobalt prices has been downward. This trend is likely to continue if cobalt supply continues to increase at a faster rate, than demand for the metal (Shedd, 2002).

Price

Reported spot prices for cathode (minimum 99.8 percent cobalt), as reported by Platt's Metals Week, fluctuated between US$13-18 per pound (approximately 0.4536 kilograms) during 2001.

Economic Factors

Most cobalt is produced as a byproduct of copper or nickel ores often providing an economic stimulus when principal ore metal prices are low.

In the Yukon, the Frye Lake copper-cobalt-gold deposit contains and estimated 15.4 million tonnes grading 2.1 percent copper, 0.11 percent cobalt and 0.73 grams/tonne gold (Yukon Mineral Property update, 1998). The Wellgreen nickel-copper-cobalt mine operated from 1972-1973, has outlined reserves of 669,150 tonnes grading 2.04 percent nickel, 1.42 percent copper, 0.07 percent cobalt, 1.3 grams/tonne platinum, 0.93 grams/tonne palladium and 0.17 grams/tonne gold (Yukon Exploration and Geology, 2001).

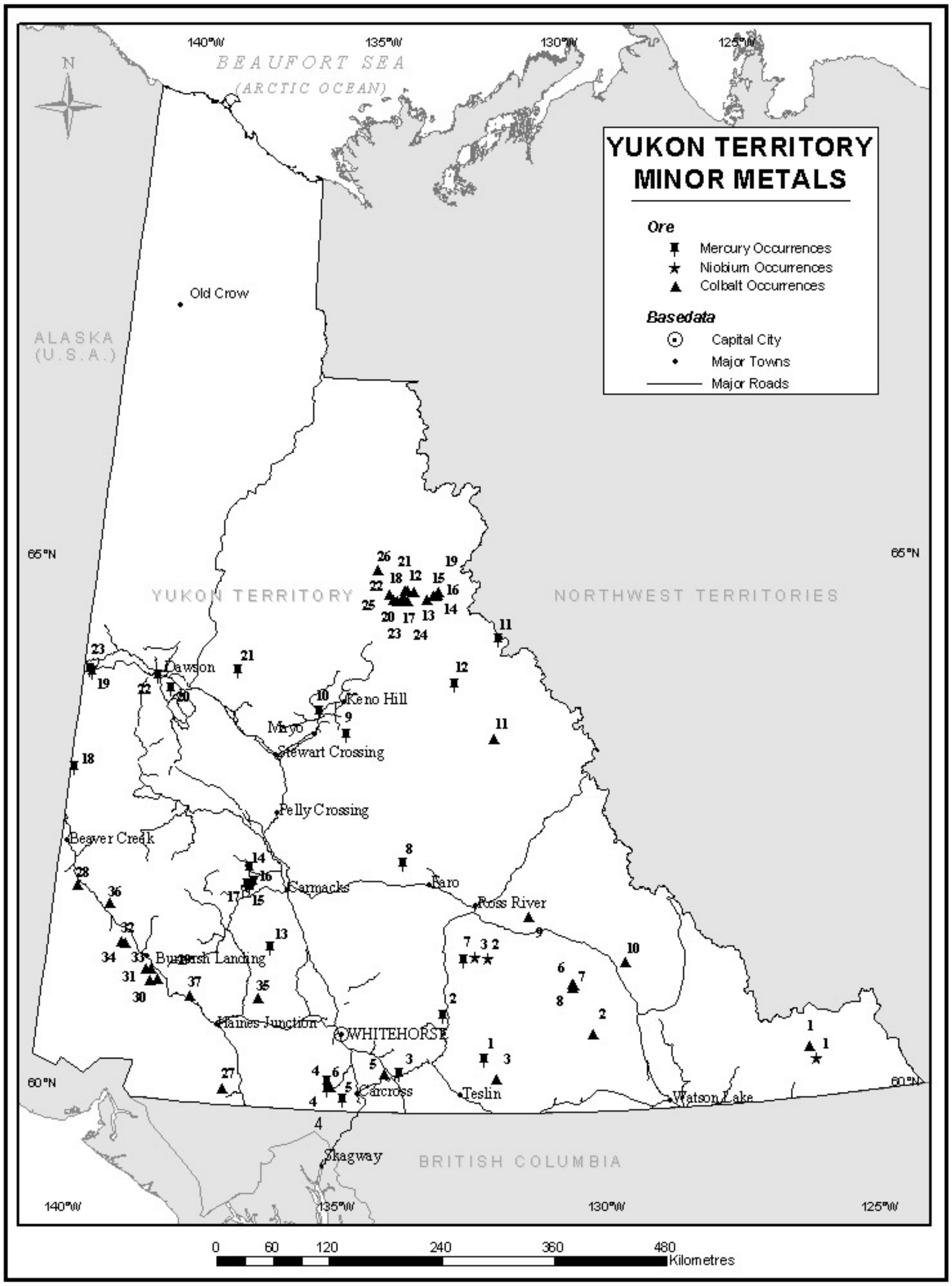


Figure 8. Yukon Cobalt, Mercury and Niobium Occurrences Fig8

Yukon Occurrences

Thirty-seven cobalt occurrences are described in Yukon Minfile 2001. Of these, six are listed as major commodities (Table 130; Figure 8). All other occurrences are listed as minor elements. Cobalt in the Wellgreen ultramafic deposit is listed as a minor commodity but is included in Table 130 because of reported reserves (See Economic factors).

Table 130

Yukon Cobalt Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	95C 069	95C/5	TRANZ	SB	?	60º28’50”/125º56’02”
2	105B 048	105B/9	BLACK	CP	V	60º44’26”/130º08’22”
3	105C 029	105C/8	MCLEERY	YT	S	60º19’05”/132º02’01”
4	105D 028	105D/3	FLEMING	CPC	S	60º13’11”/135º13’54”
5	105D 069	105D/8	MARSH	CCT	M	60º21’43”/134º11’22”
6*	105G 034	105G/2	FYRE	YT	VOLC.	61º13’34”/130º30’55”
7*	105G 035	105G/1	TOP	YT	VOLC.	61º12’18”/130º29’28”
8*	105G 036	105G/2	DUB	YT	VOLC.	61º11’16”/130º30’28”
9	105G 118	105G/14	ICE	YT	VOLC.	61º52’29”/131º21’37”
10	105H 019	105H/6	AL	CP	S	61º24’52”/129º25’26”
11	105N 003	105N/9	GREY	SB	V	63º35’09”/132º01’55”
12	106C 006	106C/13	PLUME	MP	WB	64º59’13”/133º56’48”
13	106C 009	106C/13	DOLORES	MP	V	64º54’23”/133º31’45”
14*	106C 012	106C/14	CIRQUE	MP	VV	64º56’40”/133º18’21”
15	106C 043	106C/14	DOWSER	MP	?	64º56’29”/133º22’23”
16	106C 069	106C/14	PTERD	MP	WB	64º57’35”/133º18’02”
17	106C 070	106C/13	NORANDA	MP	WB	64º53’28”/133º57’41”
18*	106C 076	106C/13	OTTER	MP	V	64º59’10”/138º48’02”
19	106C 086	106C/14	ANOKI	MP	WB	64º58’53”/133º15’56”
20	106D 052	106D/16	FORD	MP	WB	64º54’24”/134º16’02”
21	106D 070	106D/16	SLAB	MP	WB	64º59’43”/134º01’46”
22	106D 078	106D/16	ARCTOS	MP	WB	64º56’56”/134º21’26”
23	106D 079	106D/16	CHIEFTAIN	MP	WB	64º53’30”/134º10’43”
24	106D 087	106D/16	SNOWSTAR	MP	WB	64º54’15”/134º00’36”
25	106D 089	106D/16	ZELON	MP	V	64º54’57”/134º03’54”
26	106E 005	106E/2	GREMLIN	MP	WB	65º11’07”/134º38’05”
27	115A 005	115A/3	PHOTO	WT	V	60º08’32”/137º18’21”
28*	115F 045	115F/15	MICRO	WT	UM	61º57’11”/140º32’16”
29	115G 003	115G/2	CONGDON	WT	UM	61º08’08”/138º44’51”
30	115G 005	115G/2	DICKSON	WT	UM	61º07’02”/138º53’05”
31	115G 006	115G/2	DESTRUCTION	WT	UM	61º13’45”/138º59’19”
32*	115G 024	115G/5	WELLGREEN	WT	UM	61º27’55”/139º31’39”
33	115G 084	115G/2	BOCK	WT	UM	61º13’46”/138º53’30”
34	116G 094	115G/6	LINDA	WT	UM	61º27’17”/139º26’41”
35	115H 015	115H/2	AH	NT	S	61º02’19”/136º43’18”
36	116B 103	116B/13	DAS	MP	?	61º49’04”/139º51’16”
37	116G 034	116G/1	DYKE	MP	UM	61º00’41”/138º04’39”

** Listed as a major commodity in Minfile 2001.*
Yt (Yukon Tanana), MP (Mackenzie Platform), WT (Wrangellia Terrane), CCT (Cache Creek Terrane),
CPC (Coast Plutonic Complex); Volc. (Volcanogenic), V (Vein), UM (Ultra Mafic), S (Skarn), WB (Wrenecke Breccia),
M (Magmatic), ? (Deposit type unknown)

GALLIUM AND GERMANIUM GAL

Chemical and Physical Characteristics

The element Gallium (Ga) is more abundant in the earth’s crust than antimony, silver, bismuth, molybdenum or tungsten and is only slightly less abundant than lead, however, it is rarely concentrated into rich deposits like these elements. Gallium (Ga) has chemical similarities to aluminum and to a lesser extent, ferric iron. In different environments it can be lithophile, or to a lesser extent, chalcophile, siderophile and organophile (Pell and Hora, 1990).

The element Germanium (Ge) is a hard, grayish-white element, which is mainly produced as a byproduct of zinc ore processing. It is brittle, has a metallic luster and the same crystal structure as diamond. It is a good semiconductor, with electrical characteristics between those of a metal and an insulator.

Deposit Examples

World lead-zinc deposits.

General Geology

Most highly aluminous rocks and minerals, and some zinc minerals, contain detectable amounts of gallium. The main deposit types in which gallium are concentrated in:

a) Bauxite deposits (not known in the Yukon);
b) Low to moderate temperature, sphalerite-rich-sulphide deposits in sedimentary rocks (e.g. 'Mississippi-Valley' type deposits);
c) Zinc-rich volcanogenic massive sulphide deposits;
d) Copper-rich sulphide deposits, particularly sedimentary breccia pipes (solution-collapse breccia) and the oxidized zones of these deposits;
e) Rare metal deposits associated with metasomatism and late-stage, highly alkaline or peralkaline granite-syenite intrusions (Pell and Hora, 1990).

Like gallium, germanium can be lithophile, chacophile, siderophile or an organophile element in different environments. It concentrates in sphalerite-rich sulphide deposits, particularly low-temperature sediment-hosted deposits and copper-rich sulphide deposits. More specifically, germanium appears in sedimentary host rocks and is commonly associated with high arsenic, antimony and tin levels (copper-rich breccia pipes), and the oxidized portions of these deposits. Germanium may also be concentrated in coal and lignite, and in iron oxide deposits. In zinc-rich sulphide deposits, it is concentrated in sphalerite, or rarely, may occur as germanite inclusions within the sphalerite (in copper-rich minerals or in sulfosalts, it substitutes for arsenic, antimony or tin). In iron-oxide deposits and the oxidized zones of copper deposits, germanium is concentrated in hematite and goethite (e.g. Apex mine in Utah). In coal, it is bound to organic compounds (Pell and Hora, 1990).

World Production

Data on world production of primary (mined) gallium is unavailable because data on the output of the few producers is considered to be proprietary. However, world 2001 primary production was estimated to be about 100 tonnes with Germany, Japan, Kazakhstan, and Russia being the largest producers (Kramer, 2002).

In 2001, world refinery production of primary germanium was estimated to be approximately 68,000 kilograms. During 2001, more than half of the germanium metal used during the manufacture of most electronic and optical devices is routinely recycled as new scrap (Brown, 2002).

End Use

Analog integrated circuits are the largest application for gallium, with optoelectronic devices (mostly laser diodes and light-emitting diodes) as the second largest end use (Kramer, 2002).

Eighty-five per cent of the world's germanium is used in fibre optics communication networks, infrared night vision systems, and polymerization catalysts applications (Brown, 2000).

Market Trends

An overall economic decline in the United States has resulted in lower demand for gallium from the record-high levels of 2000. The largest factor influencing gallium demand was the decline in the purchase of new cellular telephone products, which is a significant consumer of gallium arsenide (Kramer, 2001).

World germanium consumption has been greater than primary production in recent years. The release of

American government stockpiles and increased recycling have met these shortfalls. Expected demand increases for fibre optics and new uses could fuel a drive for the development of new germanium resources. The industry appears poised for expansion in spite of recent lackluster price performance. Greater volatility in the germanium market, however, could occur during the next few years if stockpiles and recycling do not adequately balance supply and rising demand.

New uses as catalysts, increases in demand for infrared applications in security, and the potential replacement of gallium arsenide devices by silicon-germanium in wireless telecommunications all suggest a bright, long-range future for germanium (Brown, 2002).

Price

Prices reported for gallium metal and oxide during 2001 are illustrated in Table 131.

Table 131

2001 Year End Gallium Prices (US$ per kilogram)

Gallium metal, 99.99999% pure, 100 kilogram lots	$640
Gallium metal, 99.9999% pure, 100 kilogram lots	$595
Gallium metal, 99.9999 pure, imported to USA	$380-425
Gallium oxide, 99.99% pure, imported to USA	$275-350

Source: Kramer, 2001 after American Metal Market.

Zone refined germanium averaged an estimated US$1,100 per kilogram for 2001 while dioxide (electronic grade) averaged US$700 per kilogram for the same year (Brown, 2002).

Economic Factors

Gallium is received during the refining of bauxite to aluminum and during the smelting and refining of sphalerite (zinc) concentrates containing 50-200 ppm gallium.

Germanium is principally recovered during the smelting of zinc concentrates containing between 80 and 260 ppm germanium. High-grade ore may contain between and up to 600 to 800 ppm germanium (e.g., St. Salvy zinc mine in France) (Pell and Hora, 1990).

Yukon Occurrences

There are no gallium occurrences reported in Yukon Minfile 2001. One minor germanium commodity occurrence is referenced (Minfile 105B 133) in Yukon Minfile 2001. However, iron oxide deposits (magnetite skarns) and coals are well documented in the Yukon, but have not been systematically evaluated for trace elements. Sediment-hosted deposits are also known to contain anomalous amounts of gallium and germanium (Leighton et al., 1989) and offer potential exploration targets for gallium and germanium in the Yukon.

INDIUM IN

Chemical and Physical Characteristics

Indium (In) a silvery-white tetragonal element, is soft and malleable and occurs in very small quantities - mainly with zinc. It has a relatively low melting point (156°C). Indium metal takes a very high polish, and for this reason it has been used in plating special mirrors. The metal is not very reactive, is not corroded by moist air, but dissolves in acids to liberate hydrogen.

Deposit Examples

Selected world lead-zinc-copper deposits.

General geology

Indium occurs predominantly in solid solution in sphalerite and sulfide ores of zinc. Large quantities of indium are also contained in ores of copper, lead and tin.

World Production

World production of indium during 2001 is estimated at 340 tonnes an increase of over five tonnes from the year 2000. Major producing countries during 2001 were China (100 tonnes), France (65 tonnes), Japan (50 tonnes), Canada (45 tonnes) and Belgium (40 tonnes) (Brown, 2002).

End use

Indium is used in a variety of applications including as a thin-film coating on glass (accounts for about 50 percent of total use). Indium is also used as an addition to the combinations of bismuth, cadmium, lead, and tin to form low-melting-point alloys (33 percent of end use). These alloys are used in such applications as electrical fuses, fusible links, or as gripping material for the grinding of optical glass. Indium is also used as a strengthening agent for lead solders and in alkaline batteries to prevent the buildup of hydrogen gas in the sealed batter casing

Market Trends

The expanding liquid crystal display (LCD) manufacture kept demand strong for indium-tin oxide, while the use of indium phosphide for optical communications systems increased rapidly during 2001. The long-range outlook for the indium market remains promising despite possible near term market fluctuations caused by economic uncertainties (Brown, 2002).

Price

The ready availability of low-priced indium from China, with increases in both capacity and production, kept world prices down in 2001. The average price for indium was US$147 per kilogram (99.97 percent indium) down from an average price of US$188 per kilogram in 2000 (Brown, 2002).

Economic factors

World reserves, which are based on estimated indium content of zinc reserves, are anticipated to meet demand, beyond the first decade of this century. Canada has the greater resources of indium (about 27 percent) of world reserves totaling 2,600 tonnes (Brown 2000).

Yukon Occurrences

There are no reported indium occurrences listed in Yukon Minfile 2001. However, indium occurs as a minor constituent of polymetallic sulphide ores of zinc, lead and copper and is generally produced in association with the mineral sphalerite (ZnS). To establish indium potential in the Yukon, polymetallic sulphide deposits should be systematically evaluated for the element.

LITHIUM LIT

Chemical and Physical Characteristics

Lithium (Li) rich minerals and brines are the commercial sources of lithia (Li_2O) either as spodumene (4-7 percent Li_2O), petalite (3.5-4 percent Li_2O), lepidolite (3-4 percent Li_2O), amblygonite (8-9 percent Li_2O) or bikitaite (6-8 percent Li_2O) concentrates or as lithium carbonate ($LiCO_3$). The average percentage of LiO_2 is described in Table 132.

Table 132

Lithium Minerals and Brines

Mineral	Chemical Formula	%Li2O
Spodumene	LiAlSi2O6	8.0
Petalite	LiAlSi4O10	4.9
Lepidolite	K(Li,Al)3(Si,Al)4O10 (OH,F)2	6.2
Amblygonite	LiAlPO4(F,OH)	10.3
Bikitaite	LiAlSi2O6H2O	11.8
Eucryptite	Li2O·Al2O3·2SiO2	11.9
Montebrasite	LiAlPO4F	7.0

Deposit Examples

Spodumene mine Bernic Lake (Tanco Property), Manitoba; Big Mack petalite project, northwestern Ontario (Canada); Cachoeira Mine, Araçuaí, (Brazil); Salar de Atacama brine operations (Chile).

General Geology

See under Volatile-Rich Granites in this Chapter.

World Production

World lithium production during 2001 is estimated at 15,100 tonnes. Leading producers included Chile (6,400 tonnes), China (2,500 tonnes), Australia (2,400 tonnes), Russia (2,000 tonnes), Canada (700 tonnes) and Zimbabwe (700 tonnes) (Ober, 2002).

Global consumption of lithium minerals was estimated to be about 158,000 tonnes in 2000.

The only lithium producer in Canada was the Tantalum Mining Corporation of Canada Ltd., which operates a mine and concentrating plant near Bernic Lake (Tanco property), Manitoba (Canada). The company produced 22,500 tonnes of spodumene concentrates in 2001 (Ober, 2001).

End Use

Producers sell lithium as mineral concentrate, metal, chemical or as brine depending on the end use. Approximately 60 percent of lithium compounds and minerals are consumed in the production of ceramics, glass, and primary aluminum. Other uses include the use of organic lithium compounds as industrial catalysts and lithium batteries.

Market Trends

The lithium industry is closely tied to the performance of the primary aluminum, ceramics and glass industries, and the economy in general. Consumption of lithium in these industries determines the performance of the entire lithium industry. With nearly one-third of the American aluminum capacity idle in 2001, lithium consumption suffered. Because these uses represent such a high percentage of the total lithium market, growth in other areas has a much smaller influence, although battery and catalyst applications have become more important. For example, rechargeable lithium batteries are growing in popularity for using to power portable computers, telephones, video cameras, and cordless tools. Nonrechargeable lithium batteries are used in calculators, cameras, computers, electronic games and watches.

Lithium demand could increase dramatically if the technology for nuclear fusion is perfected but this is not expected to take place within the next 25 years and may in fact never occur (Ober, 2001).

Price

The estimated 2001 year-end annual average price for lithium carbonate was US$4.47 per kilogram; lithium hydroxide, monohydrate averaged US$5.74 per kilogram (Ober, 2002).

Economic Factors

Table 133 illustrates the typical composition of lithium ore concentrates from Canada Tanco and provides a model for any new lithium deposit development.

Table 133

Typical Chemical Composition of Lithium Ore Concentrates (%)

	Canada Tanco Standard	Canada Tanco Glassmakers	Canada Tanco Spodumene -200 mesh	Canada Tanco Amblygonite	Canada Tanco Montebrasite
Li2O	7.25 min.	6.80 min.	7.10 min.	7.75min.	7.0
Fe2O3	0.07 max.	0.01 max.	0.12 max.	0.10 max.	0.2
SiO2					
Al2O3	26.00	25.00	25.00	27.50 min.	26.0
K2O	0.20	0.25	0.20		
Na2O	0.30	0.35	0.30		
CaO					
P2O5	0.25	0.2	0.35	20.0 min.	8.0

Source: adapted after The Industrial Minerals HandyBook II, pg. 97

Yukon Occurrences

There are no reported lithium occurrences in Yukon Minfile 2001. However, potential areas for rare-element pegmatite, including the element lithium, in the Yukon were identified by Groat et al (1996). These pegmatites include the McQueston River Region, Central Yukon; Clea Pluton, Selwyn Pluton Suite, Yukon; Ice Lakes Area, Cassiar Batholith; Little Nahanni Pegmatite Group (on Yukon/N.W.T. border); O'Grady Batholith (on Yukon/N.W.T. border); Seagull Batholith; Thirtymile Pluton and Ork Stock; Mount Mye Batholith, Anvil Plutonic Suite; Sekwi Mountain Area; Macmillan Pass; Whitehorse area, and mid-Cretaceous suite; Emerald Lake.

MAGNESIUM MM

See under magnesite in this report.

MERCURY MER

Chemical and Physical Characteristics

Mercury (Hg) sometimes referred to as quicksilver, is the only common metal that is liquid at room temperature. It can occur in nature as a native metal or in some 25 different minerals, but is most commonly recovered from the red sulphide mineral cinnabar (HgS). Mercury is usually obtained from its ore, cinnabar by roasting in an oxidizing atmosphere, whereby the sulphur is oxidized to sulphurous acid, and the freed metal volatilized and condensed.

Deposit Examples

Pinchi Lake Mine, British Columbia (Canada).

General Geology

Mercury deposits are generally formed at relatively low temperatures in the world's major orogenic belts. In the Canadian cordillera, cinnabar (HgS) occurs in very low-temperature hydrothermal deposits as veins or impregnations and replacement deposits in sedimentary rocks. It may also be present as a sublimate in active craters and as a chemical deposit of hydrothermal, probably alkaline springs. Worldwide, there are also placer-type concentrations of cinnabar resulting from the erosion of primary cinnabar sources.

World Production

The estimated mine production of mercury during 2001 was 1,400 tonnes with leading producing countries of Spain (500 tonnes), Kyrgyzstan (260 tonnes), and Algeria (240 tonnes).

There is no primary production of mercury in North America as the last producer in Canada, Cominco Limited’s Pinchi Lake mine in British Columbia, ceased production in 1975.

During the past 10 years, annual world mercury production has average about 2,000 tonnes, nearly all of which was produced at mines where mercury has been the primary product. However, most countries do not report their mercury production and world production values have a high degree of uncertainty. In some countries, a few base-metal operations recover small quantities of mercury to meet environmental standards and to avoid, environmental releases of the metal.

End Use

In 2002, Canada consumed approximately three tonnes of metallic mercury that was used primarily for applications in electrical apparatus (fluorescent lamps), industrial and control instruments, and for the electrolytic preparation of chlorine for use in the pulp and paper industry.

Market Trends

Environmental regulations and the development of new technology are expected to be the primary factors affecting mercury supply and demand in the near future. Environmental standards and technological advances likely will work in tandem to reduce the demand for mercury in commercial products.

Price

The commercial unit for handling mercury is the “flask” which weights 34.47 kilograms (76 pounds). Prices for mercury averaged US$140 (average price per flask) in 2001 (Reese, 2002).

Economic Factors

World mercury resources are estimated at about 600,000 tonnes, principally in Kyrgyzstan, Russia, Slovenia, Spain and the Ukraine.

Yukon Mercury Occurrences

Twenty-three mercury occurrences are described in Yukon Minfile 2001. Of these, two are listed as major commodities (Table 134; Figure 8).

Table 134

Yukon Mercury Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105C 003	105C/9	BAR	YT	SEDEX	60º30’16’’/132º14’26”
2	105C 022	105C/14	LINDSAY	YT	?	60º55’39’’/133º03’07”
3	105C 055	105C/5	EAGLENEST	CCT	V	60º22’02’’/133º53’22”
4	105D 025	105D/3	GODDELL	CPC	V	60º11’32’’/135º16’55”
5	105D 035	105D/2	MILLHAVEN	NST	V	60º05’51’’/134º58’17”
6	105D 161	105D/6	VESUVIUS	CPC	V	60º15’50’’/135º16’19”
7	105F 012	105F/7	ARNOLD	CP	VOLC.	61º27’29’’/132º38’32”
8	105K 092	105K/5	BEYON	TV	V	62º22’28’’/133º55’16”
9	105M 037	105M/11	GORDON	SB	V	63º35’32’’/135º12’07”
10	105M 058	105M/13	HALFWAY	SB	?	63º48’26’’/135º47’49”
11	106B 015	106B/15	NECO	MP	V	64º31’27’’/131º53’38”
12*	106C 079	106C/2	HIGHHAWK	SB	V	64º06’16”/132º52’49”
13	115H 042	115H/10	SNAP	TV	V	61º31’20’’/136º31’47”
14	115I 055	115I/6	EMMONS HILL	NST	V	62º16’13’’/137º03’14”
15	115I 085	115I/3	CAR	NST	P	62º05’20’’/137º01’36”
16	115I 086	115I/2	LEE	NST	V	62º08’27’’/136º57’19”
17	115I 122	115I/3	GRIZZLY	YT	V	62º06’35’’/137º05’09”
18	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36’’/140º55’14”
19	115N 041	115N/15	PER	CV	V	63º59’01’’/140º47’04”
20	115O 071	115O/14	BOX CAR	YT	V	63º54’59’’/139º03’27”
21	116A 027	116A/14	IDA	SB	V	64º09’00’’/137º38’06”
22	116B 126	116B/3	GC	YT	?	64º01’26’’/139º21’19”
23*	116C 082	116C/2	WY	YT	V	64º00’22’’/140º50’43”

** Listed as a major commodity in Minfile 2001.*
YT (Yukon Tanana), CCT (Cache Creek Terrane), CPC (Coast Plutonic Complex), NST (Northern Stikine Terrane), TV (Tertiary Volcanics), SB (Selwyn Basin),MP (Mackenzie Platform), CV (Carmacks Volcanics),; V (Vein), VOLC. (Volcanic), P (Porphyry), ? (Deposit type unknown)

Exploration Guidelines

Low-temperature hydrothermal systems along major fault zones.

MOLYBDENUM MOL

Molybdenum is usually grouped with the major metals and is a conventional exploration target. A brief discussion of it properties, use and occurrence in the Yukon is discussed in this report because of its many important industrial applications.

Chemical and Physical Characteristics

Molybdenum does not occur in a metallic form in nature and is extracted from three principal minerals: molybdenite (MoS_2), wulfenite ($PbMoO_4$) and powellite $Ca(MoW)O_4$.

Molybdenum is a refractory metallic element used principally as an alloying agent in steel, cast iron, and super alloys to enhance hardening, strength, toughness, wear and corrosion resistance. To achieve these desired metallurgical properties molybdenum, principally in the form of molybdic oxide or ferromolybdenum, is used in combination with chromium, niobium (columbium), manganese, nickel, tungsten or other alloy metals.

Deposit Examples

Endako Mine, Highmont Mine, British Columbia (Canada); Thompson Creek Mine near Challis, Idaho (United States); Chuquicamata and El Teniente deposits, (Chile); La Caridad deposits, (Mexico).

General Geology

Molybdenum occurs as the principal metal sulphide in large low-grade porphyry molybdenum deposits and as an associated metal sulphide in low-grade porphyry copper deposits. Molybdenum also occurs in pegmatite and very high-temperature pneumatolytic veins. It is also found in cavities in granitic or dioritic rocks and in contact metamorphic deposits associated with scheelite skarns.

World Production

Most molybdenum is produced as a byproduct of porphyry-type copper mines. The estimated world mine production of molybdenum during 2001 was 133,000 tonnes. The leading producers included the United States (38,300 tonnes), Chile (35,000 tonnes) and China (28,900 tonnes). Canada produced an estimated 6,800 tonnes during this same period.

End Use

Molybdenum is used principally as an alloying agenda in steel, cast iron, and superalloys to enhance hardening, strength, toughness, and wear and corrosion resistance.

Market trends

Because of the world's abundant supply and production of molybdenum, the existing world producers should easily meet future requirements for molybdenum. The principal use for molybdenum will continue to be in chemicals/catalysts and as an additive used in steel manufacturing.

Price

The average major production price per kilogram of molybdenum contained in technical-grade molybdic oxide during 2001 was US$5.20 (Blossom, 2002).

Economic Factors

Identified resources of molybdenum amount to about 5.5 million tonnes in the United States and about 12 million tonnes worldwide. Resources of molybdenum are adequate to supply world needs for the foreseeable future (Blossom, 2002).

Yukon Molybdenum Occurrences

One-hundred-sixty-eight molybdenum occurrences are described in Yukon Minfile 2001. Interested readers are referred to this comprehensive Minfile listing of commodity occurrences for information about individual molybdenum deposits/occurrences.

In general, although there are numerous molybdenite deposits and occurrences in the Yukon, none have been placed into production largely because of the low value received for the metal on world markets.

NIOBIUM (COLUMBIUM) AND TANTALUM NIO

Niobium and columbium are synonymous names for the chemical element with atomic number 41. Columbium was the name given in 1801, and niobium (Nb) was the name officially designated after considerable debate, by the International Union of Pure and Applied Chemistry in 1950 by a majority decision. However, the "old name" columbium, is still in common use in the Americas, complicated by the fact that one of the two most common minerals of niobium is universally known as 'Columbite'.

Chemical and Physical Characteristics

Niobium (Nb) is the 33rd most abundant element in the earth's crust, which contains 24 ppm on average. The principal niobium-bearing mineral is pyrochlore, a niobium-titanium-calcium oxide although other niobium-bearing minerals such as columbite and fersmite, are also known.

Most of the world's niobium production is from the mineral pyrochlore which is an end member of the pyrochlore-microlite isomorphous series $(Na,Ca)_2 (Nb,Ta)_2O_6 (OH,F)$ having a maximum of 65 percent niobium/columbium. Pyrochlore is a pale-yellow, reddish, brown or black mineral occurring in carbonatites and also in pegmatites derived from alkalic igneous rocks. The other important niobium mineral columbite, is an end member of the columbite-tantalite group of oxides $(Fe, Mn) (Nb, Ta)_2O_6$.

Tantalum is a relatively rare element, where it has an average abundance of 2.1 ppm. It is generally present in the mineral pyrochlore. The element is ductile, easily fabricated, and highly resistant to corrosion by acids. It is a good conductor of heat and has a high melting point. In some pegmatites, tantalum may be an exploration and mining target for the minerals tantalite and microlite (Tanco deposit, Manitoba, Canada; Harding pegmatite, New Mexico, United States).

Deposit Examples

Aley Carbonatite, British Columbia; Thor Lake, Northwest Territories; Tanco Pegmatite, Manitoba; Niobec Mine near Chicoutimi, Quebec (Canada).

General Geology

Niobium is principally concentrated in carbonatites and related alkaline rocks. To a lesser extent, niobium is also found in alkalinegranite-syenite complexes, such as the Thor Lake deposit in the Northwest Territories and is associated with other minor metals or in pegmatite and tin deposits associated with volatile-enriched granite systems. Most of the world's identified niobium resources occur mainly as pyrochlore in carbonatite deposits. The columbite-tantalite group of oxides and hydroxides occur in granitic pegmatites rich in lithium silicates and phosphates and associated with spodumene, lepidolite, and beryl. It is often concentrated in sands and has a maximum content of 78 percent Nb_2O_5.

Tantalum, is generally associated with tin in skarns, greissens and pegmatite related to volatile-enriched granite systems. It may also be present in carbonatites and alkaline rocks.

World Production

The estimated world mine production of niobium during 2001 was about 32,500 tonnes. Leading producing countries included Brazil (30,000 tonnes), Canada (2,300 tonnes) and Australia (200 tonnes) (Cunningham, 2002).

End Use

Niobium in the form of ferrocolumbium is used worldwide, mostly as an alloying element in steels and in super alloys. Niobium in the form of high-purity ferrocolumbium and nickel-columbium are used in nickel, cobalt and iron-base super alloys for such applications as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment.

The major use of tantalum is as a metal powder for the production of tantalum capacitors and as metal wire for their connection to circuits. Other uses are as an ingredient of super alloys, for use in aircraft engines and spacecraft, and as the carbide in hard metal cutting tools.

Market Trends

On a worldwide basis, resources of niobium (columbite) are more than adequate to supply projected needs. Prices received for the metal will be most dependent on the market for aircraft engines.

With more than 60 percent of the tantalum consumed in the production of electronic components, mainly in tantalum capacitors, the market sector is expected to increase as the use of cellular telephones increases, and hence the demand for this metal (Cunningham, 2000).

Price

The published price for columbite ore was discontinued in October 2001 at a range of US$5.50-7 per pound of pentoxide content. The average reported price for niobium ore during 2000 was US$6.25 per pound. This material contained pentoxides having a Nb_2O_5 to Ta_2O_5 ratio of 10:1 (Cunningham, 2002).

Economic Factors

The Aley carbonatite complex in British Columbia has defined zones containing between 0.66-0.75 percent Nb_2O_5 and localized areas containing in excess of 2 percent Nb_2O_5 which are grades better than the Niobec deposit in Quebec (Pell and Hora, 1990). However, no reserve estimates are available, but must be very large. The Niobec Mine in Quebec has proven and probable ore reserves of 11.5 million tonnes, grading 0.51 percent niobium (Cunningham, 2000).

Yukon Occurrences

Three niobium occurrences are described in Yukon Minfile 2001. All are listed as major commodities (Table 135; Figure 8).

Table 135

Yukon Niobium (Columbium) Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	95C 051	95C/5	BEAU	SB	S	60º21’46”/125º48’32”
2	105F 080	105F/8	NOKLUIT	CP	S	61º29’21”/132º10’27”
3	105F 081	105F/8	GUANO	YT	S	61º29’28”/132º24’56”

SB (Selwyn Basin), CP (Cassiar Platform), YT (Yukon Tanana); S (Skarn)

Carbonatites generally are enriched in niobium but have a low tantalum content with a Nb:Ta ratio of about 100:1, (Currie, 1976). However, carbonatites known at Blue River, in British Columbia have a Nb:Ta ratio of 10:1. Good exploration targets for niobium in the Yukon are carbonatites and related alkaline ultrabasic rocks along a broad zone which extends from British Columbia (and contain the Aley carbonatite) into the Yukon, parallel to the Tintina Trench.

Tin-bearing mineralization is associated with specialty granites in northern British Columbia in the Cassiar and Atlin districts. Similar rocks are good exploration targets in the Yukon. However, little information is available on the tantalum potential of these rocks in the Cordillera. No tantalum pegmatite deposits are known in the Yukon.

PLATINUM GROUP METALS (PGM) PLAT

The platinum group metals (PGMs) or platinum group elements (PGE) are considered precious metals rather than minor metals. However, their importance to the world economy and occurrence in the Yukon, warrants a brief discussion of their use and characteristics.

Chemical and Physical Characteristics

The six platinum-group metals (PGM) include platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir) and osmium (Os). Platinum's wear and tarnish resistance characteristics make it a valuable jewelry material. Its other properties include resistance to chemical attack, excellent high-temperature characteristics, and stable electrical properties.

Deposit Examples

Wellgreen deposit (Minfile 115G 024), Yukon; Sudbury Basin, Ontario (Canada); Stillwater Mine, Montana (United States); Bushveld Complex, (South Africa).

General Geology

Precipitation and gravitational accumulation of sulphide minerals in a fractionating mafic-ultramafic intrusion, form many of the world's PGE deposits.

World Production

The estimated world mine production of platinum and palladium during 2001 was 163,000 kilograms and 177,000 kilograms respectively. Leading producers of platinum included South Africa (122,000 kilograms), Russia (29,000 kilograms), Canada (6,000 tonnes) and the United States (3,600 tonnes). The leading producers of palladium were Russia (90,000 kilograms), South Africa (59,000 kilograms), the United States (12,000 kilograms) and Canada (9,000 kilograms) (Hilliard, 2002).

End Use

Platinum, platinum alloys and iridium are used as crucible materials for the growth of single crystals, especially oxides. The chemical industry uses a significant amount of platinum and platinum-rhodium alloy catalyst in the form of gauze to catalyze the partial oxidation of ammonia to yield nitric oxide, which is the raw material for fertilizers, explosives and nitric acid. Ruthenium dioxide is used as coatings on dimensionally stable titanium anodes used in the production of chlorine and caustic. Platinum supported catalysts are also used in the refining of crude oil, reforming, and other processes used in the production of high-octane gasoline and aromatic compounds by the petrochemical industry.

Market Trends

Despite forecasts of a reduced world economic activity, demand for platinum is expected to continue due to increase in future demand, largely from the automobile sector.

Rising palladium prices in 1999-2000 led to increased substitution of base metals for palladium in the electronics and dental industries and automobile manufacturers purposely decreased their dependence on palladium. Thus the demand for palladium is expected to drop in the next several years to historical levels (Hilliard 2,000).

Price

The average prices for PGE per troy ounce during 2001 were (Hilliard, 2002):

- Platinum US$540; Palladium US$770; Rhodium US$1,800; Ruthenium US$130

Yukon PGM Occurrences

A substantial price increase in 1986 led to aggressive worldwide exploration for PGM. In Canada layered ultramafic intrusions were commonly evaluated. In the Yukon, 19 PGE occurrences are described in Yukon Minfile 2001. Of these, platinum and/or palladium are listed as major commodities in ten occurrences while other platinum group elements (PGE) are listed as minor or trace commodities (Table 136; Figure 9).

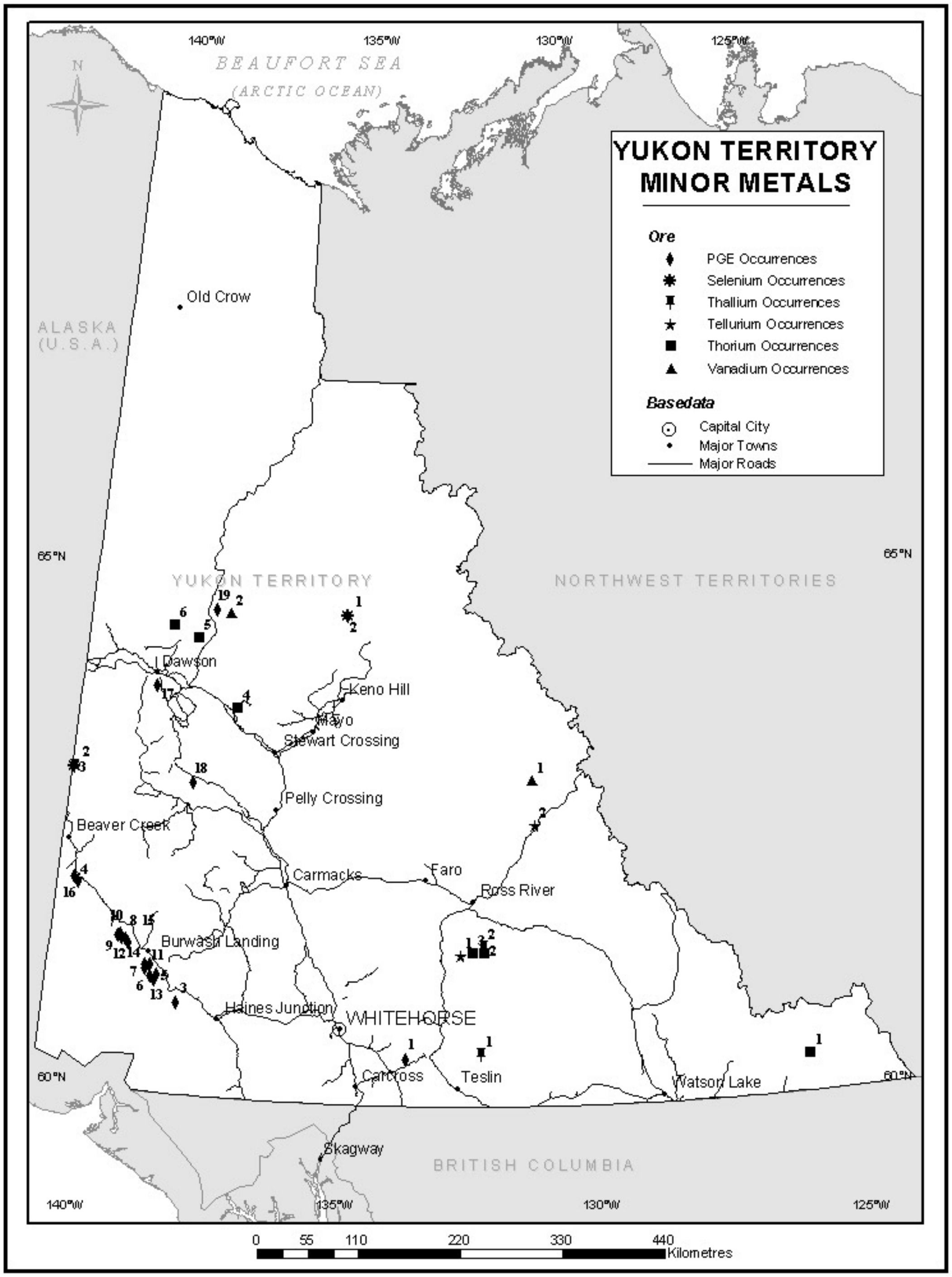


Figure 9. Yukon PGE, Selenium, Tellurium, Thallium, Thorium and Vanadium Occurrences Fig9

Table 136

Yukon PGE Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105C 012	105C/5	SQUANGA	CCT	M	60º27’32”/133º43’25”
2	106D 092	106D/11	NICK	SB	SEDEX	64º44’11”/135º12’59”
3	115B 008	115B/16	TELLURIDE	WT	VOLC.	60º53’16”/138º18’24”
4*	115F 045	115F/15	MICRO	WT	UM	61º57’11”/140º32’16”
5*	115G 003	115G/2	CONGDON	WT	UM	61º08’08”/138º44’51”
6	115G 005	115G/2	DICKSON	WT	UM	61º07’02”/138º53’05”
7	115G 006	115G/2	DESTRUCTION	WT	UM	61º13’45”/138º59’19”
8*	115G 024	115G/4	WELLGREEN	WT	UM	61º27’55”/139º31’39”
9*	115G 025	115G/5	AIRWAYS	WT	UM	61º28’56”/139º35’47”
10	115G 027	115G/12	SWEDE JOHNSON	WT	V	61º30’10”/139º33’36”
11*	115G 084	115G/2	BOCK	WT	UM	61º13’46”/138º53’30”
12*	115G 094	115G/6	LINDA	WT	UM	61º27’17”/139º26’41”
13*	115G 098	115G/2	TONY	WT	UM	61º05’32”138º46’54”
14*	115G 099	115G/2	DUKE SOUTH	WT	UM	61º11’15”138º58’45”
15*	115G 100	115G/6	WASH	WT	UM	61º25’25”/139º23’07”
16*	115K 077	115K/2	MICRO	WT	UM	62º00’10”/140º37’25”
17	115O 090	115O/14	BALD EAGLE	YT	V	63º55’17”/139º21’28”
18	115O 116	115O/1	PYROXINE	YT	?	63º01’16”/138º20’59”
19	116B 128	116B/9	REIN	SB	ST	64º42’39”/138º10’23”

** Listed as a major commodity in Minfile 2001.*
WT (Wrangellia Terrane), CCT (Cache Creek terrane), SB (Selwyn Basin), YT (Yukon Tanana) ; UM (Ultra Mafic),
M (Magmatic), Volc. (Volcanic), V (Vein), ST (Stratiform), ? (Deposit type unknown).

The largest reported PGE occurrence in the Yukon, is the Wellgreen property (Minfile 115G 024) which has had limited production and has current reserves of approximately 669,150 tonnes grading 2.04 percent Ni, 1.42 percent Cu, 0.07 percent Co, and 2.23 grams per tonne palladium and platinum (Craig et al, 2001).

A description of Yukon’s PGE occurrences, mineralization and anomalous areas as well exploration targets are described in Yukon Platinum Occurrences and Potential Open, File 2001-2 (Hart, Burke and Stronghill, 2001).

RHENIUM RHE

Chemical and Physical Characteristics

Rhenium (Re), discovered in 1927, was the last naturally-occurring element to be identified. However, the process was so complicated and the cost so high that production was discontinued until early 1950 when tungsten-rhenium and molybdenum-rhenium alloys were prepared. This very rare element occurs in trace amounts in molybdenite, niobium, and pyrolusite. It has a high melting point (about 3200ºC) and a high density of 21g/cm^3, and it is not particularly reactive.

Deposit Examples

World copper-molybdenum deposits.

General Geology

Rhenium compounds, incorporated in molybdenum concentrates are mined primarily from porphyry copper deposits. Rhenium is then recovered as a byproduct from roasting the molybdenum concentrates recovered from the porphyry copper mines.

World Production

World mine production of rhenium in 2001 was estimated to be 26,400 kilograms. Major producing countries included the United States (9,700 kilograms), Peru (4,800 kilograms), Kazakhstan (2,400 kilograms), Chile (2,200 kilograms), Canada (1,600 kilograms) and Russia (1,100 kilograms). Total world resources of rhenium are estimated to be 10,000 tonnes (Blossom, 2002).

End Use

About 40 percent of rhenium consumed is used in the development of petroleum-reforming catalysts for the production of high-octane hydrocarbons, which in turn are used in the development of lead-free gasoline. Approximately 50 percent of rhenium produced, is used in super alloys, improving the strength properties at high temperatures (1,000°C), of nickel-based alloys. Some of the uses for rhenium alloys were in thermocouples, temperature controls, heating elements, ionization gauges, mass spectrographs, electron tubes and targets, electrical contacts, metallic coatings, vacuum tubes, crucibles, electromagnets, and semiconductors.

Recently, small amounts of molybdenum-rhenium and tungsten-rhenium scrap are being recycled as are platinum-rhenium catalysts.

Price

During 2001, the average estimated price per kilogram of rhenium for metal powder (99.99 percent pure) was US$1,200 while ammonium perrhenate was US$840 per kilogram (Blossom, 2002).

Market Trends

Over the next five years, demand for rhenium metal is expected to follow the demand for turbine engines and petroleum. For the long term (10 to 20 years), recycling of rhenium-bearing waste and scrap is expected to increase (Blossom, 2000).

Yukon Occurrence

There are no major commodity rhenium occurrences reported in Yukon Minfile 2001. One minor occurrence is described (Minfile 106D 092) as forming in a low temperature organic-rich fluid similar to Red Sea-type brine pools in a rift environment. No grade or reserve estimates were reported.

SCANDIUM SCA

Chemical and Physical Characteristics

Scandium (Sc) is a metallic element of the lanthanide series. It occurs only in nature in the combined form in minerals such as monazite. Scandium reacts vigorously with water to liberate hydrogen, and has a melting point of about 1200ºC.

Deposit Examples

Originally produced from the mineral thortveitite $[(Sc,Y)_2\ SiO2O_7]$ which contains 30 to 40 percent Sc_2O_3, it was mined in Norway and Madagascar. Today, scandium is recovered as a byproduct from major nickel, cobalt, tin, tungsten, and uranium deposits.

General Geology

Scandium is rarely concentrated in nature due to its lack of affinity to combine with the common ore forming anions. It is widely dispersed in the lithosphere and forms solid solutions in over 100 minerals. In the Earth's crust, scandium is primarily a trace constituent of ferromagnesium minerals. Concentrations in these minerals (amphibole-hornblende, pyroxene and biotite) typically range from 5 to 100 ppm equivalent Sc_2O_3. Ferromagnesium minerals commonly occur in the igneous rocks, basalt and gabbro. Enrichment of scandium also occurs in rare-earth minerals, wolframite, columbite, cassiterite, beryl, garnet, muscovite and the aluminum phosphate minerals.

World Production

Not reported.

End Use

Scandium is used in metal halide lighting, scandium-aluminum alloys and its use is expected to increase in both these applications.

Market Trends

Resources of scandium are abundant, especially when considered in relation to actual and potential demand. The world demand for scandium is thought to be small. Future demand for the metal is expected for fuel cells, metal halide lighting and for scandium-aluminum alloys.

Price

The price of scandium materials varies and is based on purity and quantity. For example during 2001, scandium metal, at 99.0 percent purity, sold for US$700 per kilogram while 99.9999 percent purity was valued at US$4,100 (Hedrick, 2002).

Economic Factors

Recent North American production has primarily been from scandium-yttrium silicate minerals, thorveitite, and from byproduct leach solutions from uranium operations. As well, other scandium enriched minerals can include ores of fluorite, aluminum, cobalt, iron, molybdenum, nickel, phosphate, tantalum, tin, titanium, tungsten, zinc, and zirconium.

Yukon Scandium Occurrences

There are no reported scandium occurrences listed in Yukon Minfile 2001. To assess the element's abundance and economic potential in the territory, rare-earth, fluorite, cobalt, iron, molybdenum, nickel, phosphate, tin, zinc deposits should be systematically sampled for their scandium content.

Placer miner Peter Risby in 2002 assayed concentrates on his claims and reported anomalous values of Sc (See Titanium in this report for reported values).

TELLURIUM AND SELENIUM TEL

Chemical and Physical Characteristics

Tellurium (Te) is a rare element that is in the same chemical family as oxygen (O), sulphur (S), selenium (Se) and polonium (Po). While oxygen and sulphur are non-metals and polonium is a metal, selenium and tellurium are semiconductors (i.e. their electrical properties are between those of a metal and an insulator). However, both tellurium and selenium are usually referred to as a metal when in elemental form.

Deposit Examples

World copper and other sulphide deposits. Gold deposits are frequently associated with tellurium minerals.

World Production

Both selenium and tellurium are byproduct metals usually associated with copper production. World production of contained selenium and tellurium during 2001 is estimated at 1.46 million kilograms and 22,000 kilograms respectively. Leading producers for selenium were Japan (612,000 kilograms), Canada (350,000 kilograms), Belgium (200,000 kilograms) and Germany (100,000 kilograms) while major producers of tellurium were Canada (80,000 kilograms), Japan (36,000 kilograms), and Peru (22,000 kilograms). Estimated production of both metals by the United States was withheld for proprietary reasons (Brown, 2002).

End Use

During 2000, about one-half of tellurium produced was used as an additive in free-machining steel. Chemical and catalyst usage made up about 25 percent of the market. Additives to nonferrous alloys accounted for about ten percent of the total use and photoreceptors and thermoelectric applications accounted for about ten percent of usage.

Estimates for selenium's end-use by application are as follows:

- Twenty-five percent in glass (as decolourant in container glass);
- Twenty-four percent metallurgical applications (additives to steel, copper, lead alloys and to improve machinability, casting, and forming properties);
- Fourteen percent miscellaneous chemical uses (this nutrient is essential for human health and dietary supplements);
- Ten percent in photoreceptors;
- Eight percent pigments (which produce colour changes in cadmium-sulphide-based pigments). Other uses include agricultural feed at 19 percent.
- About fifty-five percent of the tellurium is used as free-machining additives in steel. Other uses included catalysts, nonferrous alloys, thermoelectric devices and digital video discs (Brown, 2000).

Market Trends

Tellurium supply and demand has remained relatively constant over the past decade. Large increases are not anticipated in the immediate future. However, a demand for high-purity tellurium for solar cells and electronic devices could increase which would have a major impact on tellurium consumption.

In the late 1990's, selenium (usually combined with bismuth) was used as an additive in plumbing brasses, to meet no-lead environmental standards which became an important consumer (Brown, 2000)

Price

During 2001 the average price for selenium was US$3.85 per pound (100-pound lots) (Brown, 2002). Tellurium averaged US$14 per pound during 2000 (Brown, 2000).

Economic factors

As a byproduct of copper production, the outlook for tellurium and selenium supply and price could be significantly affected by events in the copper industry. When a copper plant, which produces tellurium and selenium concentrate closes, the ultimate amount of tellurium and selenium that can be produced is decreased. Thus, if current demand levels remain steady or should increase, prices could rise above the prices received over the last decade.

Yukon Occurrences

Two minor/trace selenium commodity occurrences (Table 137; Figure 9) and three minor tellurium commodity occurrences (Table 138; Figure 9) are described in Yukon Minfile 2001.

To assess Yukon's selenium and tellurium occurrences, the territory's gold, copper and other sulphide deposits should be systematically sampled and tested for both elements.

Table 137

Yukon Selenium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	106D 092	106D/11	NICK	SB	SEDEX	64º44'11"/135º12'59"
2	115N 024	115N/2	MOOSEHORN	NST	V	63º03'36"/140º55'14"

SB (Selwyn Basin), NST (Northern Stikine Terrane); V (Volcanogenic)

Table 138
Yukon Tellurium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105F 012	105F/7	ARNOLD	CP	VOLC.	61º27'29''/132º38'32''
2	105J 008	105J/11	MT SHELDON	SPS	V	62º43'06''/131º05'29''
3	115N 024	115N/2	MOOSEHORN	NST	V	63º03'36''/149º55'14''

CP (Cassiar Platform), SPS (Selwyn Plutonic Suite), NST (Northern Stikine Terrane); VOLC. (Volcanogenic), V (Vein)

STRONTIUM ST

See under Strontium in this report.

TUNGSTEN TUN

Chemical and Physical Characteristics

Tungsten (W) is a whitish-grey metal with many unique properties and has a wide variety of uses, the largest of which is as tungsten carbide in cemented carbides (also called hard metals). Tungsten does not occur in native form, but is produced in the form of a greyish black powder, with a specific gravity of about 19. One method in which the metal is obtained is by the reduction of its ores by carbon. The principal tungsten minerals ores being wolframite (Fe,Mn) WO_4, and scheelite, $CaWO_4$.

Deposit Examples

MAR property (Minfile 106D 027), Yukon; MacTung Mine, N.W.T. (Canada).

General Geology

Tungsten is recovered from two minerals: scheelite ($CaWO_4$), and wolframite (Fe,Mn) WO_4. Ferberite ($FeWO_4$) and heubnerite ($MnWO_4$) are two end members of wolframite group, and only rarely occur as independent minerals. Scheelite deposits occur in high-temperature pegmatitic and hydrothermal veins, in alpine fissures and medium-grade metamorphic rocks including some skarn. Wolframite is a solid solution, intermediate in composition, between iron-rich ferberite and manganese–rich heubnerite.

Wolframite is found in pegmatites and medium-to-high temperature hydrothermal veins and in altered pneumatolytic zones (greisen). It can also concentrate in alluvial placers.

World Production

World mine tungsten production during 2001 was estimated at 44,600 tonnes with China leading world producer (37,000 tonnes). In Canada, CanTung Mine in southwestern Northwest Territories, near the border with the Yukon, began production of tungsten concentrate in 2002 (Shedd, 2002).

End Use

Tungsten is an important alloy component in hard and tough steel products. In the form of a carbide, it is an important component in cutting tools. These wear-resistant materials are used by the metalworking, mining and construction industries. Tungsten is also used in the production of metal wires (electrodes, and/or contacts used in lighting, electronic, electrical, heating, and welding applications). It is also used to make heavy metal alloys for armaments, heat sinks, and high-density applications such as weights and counterweights; super alloys for turbine blades; tool steels; and wear-resistant alloy parts and coatings. Tungsten composites are also used as a substitute for lead, in bullets and shot. Tungsten chemical compounds are used in catalysts, inorganic pigments, and high-temperature lubricants.

Price

Tungsten prices are quoted in metric ton units of tungsten trioxide (WO_3). The Metal Bulletin and Platt's Metals Week quoted prices during 2000 as between US$45-47.

Market Trends

World demand for tungsten tends to follow general economic conditions. Future consumption of tungsten in cemented carbides, which is the largest end-use sector, will depend on the performance of the automotive, aircraft, construction, mining, oil and gas drilling, semiconductor and other manufacturing industries.

Chinese production and exports dominate world tungsten supply. In 1999 and continuing into 2001 the Chinese government took steps to control the release of tungsten to the world market and this led to an increased price for tungsten concentrate. Higher prices have encouraged production of tungsten concentrates outside China. The re-opening of the CanTung mine in the Northwest Territories near the Yukon border, is a result of higher tungsten prices (Shedd, 2002).

Yukon Occurrences

During the 1970's, exploration for tungsten in the Yukon was intense and led to the discovery of many new tungsten occurrences. Yukon Minfile 2001 described 182 tungsten occurrences of which the MAR property, (Minfile 106D 027) has reported reserves of 1.36 million tonnes grading 1.2 percent WO_3.

THALLIUM THA

Chemical and Physical Characteristics

Thallium (Tl) a soft, bluish-grey, malleable heavy metal is reasonably abundant in the Earth's crust at a concentration estimated to be about 0.7 ppm. The major source of commercial thallium is in the trace amounts found in copper, lead, zinc and other sulphide ores. Several thallium minerals, containing 16 to 60 percent thallium, occur in nature as sulphide or selenide complexes with antimony, arsenic, copper, lead and silver. However, these are rare and have no commercial importance as a source of thallium. Thallium is also recovered as a byproduct from the flue dust and residues generated during the roasting and smelting steps in the processing of these ores.

Deposit Examples

World, antimony, arsenic, copper, lead, zinc and silver deposits.

General Geology

Thallium exists commonly in association with potassium minerals in clays, soils, and granites and is not generally considered to be commercially recoverable from these forms.

World Production

World resources of thallium contained in zinc resources total about 17 million kilograms. Most of these resources are located in Canada, Europe and the United States. An additional 630 million kilograms occur in world coal resources. During 2001, world thallium mine production was estimated at 15,000 kilograms (Smith, 2002).

End Use

Thallium metal and its compounds are consumed in a variety of applications. For example, thallium is used in semiconductor material for selenium rectifiers, in gamma radiation detection equipment, in infrared radiation detection and transmission equipment. It is also used in crystalline filters for light diffraction, in mercury-thallium alloy for low-temperature measurements, in glass to increase its refractive index and density and in high-density liquid for sink-float separation of minerals. Also, the use of radioactive thallium compounds for medical purposes in cardiovascular imaging to detect heart disease is increasing.

Market Trends

Research and development activities of both a basic and applied nature, were conducted during 2001 to improve and expand the use of thallium. These research activities focused principally on the development of high-temperature superconducting materials for such applications as magnetic resonance imaging, storage of magnetic energy, magnetic propulsion, and electric power generation and transmission (Smith, 2002).

Price

Thallium was sold at a reported US$1,295 per kilogram, during 2001 (Smith, 2002).

Economic Factors

Thallium metal and its compounds are highly toxic materials and are strictly controlled, to prevent the threat to humans and the environment.

Yukon Thallium Occurrences

Three thallium occurrences, listed as minor or trace commodities in Ag and Au showings, are documented in Yukon Minfile 2001 (Table 139; Figure 9).

To better determine the Yukon’s potential for hosting thallium resources, the territory’s copper, lead, zinc and other sulphide ores and deposits, should be sampled and assayed for the metal.

Table 139

Yukon Thallium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic Element*	*Deposit Type*	*Latitude/Longitude*
1	105C 003	105C/9	BAR	YT	SEDEX	60º30’16”/132º14’26”
2	105F 055	105F/9	F2 ZONE	CP	V	61º32’38”/132º10’43”
3	115N 024	115N/2	MOOSEHORN	NST	V	63º03’36”/140º55’14”

YT (Yukon Tanana), CP (Cassiar Platform), NST (Northern Stikine Terrane); V (Vein)

THORIUM THO

Chemical and Physical Characteristics

Thorium (Th) is a soft, very ductile, heavy, silver-grey metallic element with a high melting point (1,750°C).

Deposit Examples

Monazite placers in Brazil, China, India, Malaysia and Sri Lanka.

General Geology

Thorium and its compounds are produced primarily from monazite, recovered as a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Monazite was recovered primarily for its rare-earth content. The largest reserves of thorium are contained in placer deposits. Primary thorium minerals occur in some pegmatites.

World Production

World refinery production estimates are not available. However, the use of thorium has decreased significantly since the 1980’s, when consumption averaged about 45 tonnes per year (Hedrick, 2002).

End Use

Because of thorium oxide’s high melting point, it is used in several refractory applications including ceramic parts, investment molds, and crucibles. It also has applications in incandescent camping lanterns, natural gas lamps and oil lamps and as chemical catalysts, in electron-emitting tubes, and in metallurgical applications. Thorium was used as a nuclear fuel in the Th^{232}/U^{233} fuel cycle in the United States.

Market Trends

Limited demand for thorium, relative to the rare earths, has continued to create a worldwide oversupply of thorium compounds and residues. Excess thorium not designated for commercial use has been either disposed of as a radioactive waste, or stored for potential use, as a nuclear fuel or for other applications (Hedrick, 2002).

Price

Thorium prices during 2001 were quoted at US$82.50 per kilogram for 99.9 percent purity and US$107.25 per kilogram for 99.99% purity (Hedrick, 2002).

Economic factors

Thorium’s potential for growth in non-energy applications is limited by its natural radioactivity. Its greatest potential exists as a source of nuclear energy (atomic fuel). In the long term, high disposal costs, increasingly stringent regulations, and public concerns related to thorium’s natural radioactivity are expected to continue to depress its future use in non-energy applications.

Yukon Occurrences

Six thorium occurrences are described in Yukon Minfile 2001 (Table 140; Figure 9).

Table 140
Yukon Thorium Occurrences

Map #	*Minfile Number*	*NTS*	*Name*	*Tectonic element*	*Deposit Type*	*Latitude/Longitude*
1	95C 051	95C/5	BEAU	SB	S	60º21’46”/125º48’32”
2	105F 080	105F/8	NOKLUIT	CP	S	61º29’21”/132º10’27”
3	105F 081	105F/8	GUANO	YT	S	61º29’28”/132º24’56”
4	115P 014	115P/13	CLEAR CREEK	SPC	P	63º46’47”/137º33’25”
5	116B 058	116B/7	BETA	TPC	P	64º25’04”/138º32’17”
6	116B 098	116B/11	WAD	TPC	P	64º31’10”/139º07’19”

SB (Selwyn Basin), CP (Cassiar Platform), YT (Yukon Tanana), SPC (Selwyn Plutonic Complex), TPC (Tombstone Plutonic Complex); S (Skarn), P (Porphyry)

To evaluate the Yukon’s known thorium occurrences and their economic potential, an assessment of known occurrences is required.

VANADIUM VAN

Chemical and Physical Characteristics

Vanadium (V) does not occur naturally. It is a whitish silvery metal, melting at about 1720ºC. It has a great affinity for oxygen, acting as a scavenger for oxygen, and also imparting special properties of toughness, in metallurgy applications.

Deposit Examples

Titanifeous magnetite deposit, Lac Dore, Quebec; Alberta Tar Sands, Alberta (Canada); Bushveld Complex, (South Africa).

General Geology

Vanadium occurs in deposits of titaniferous magnetite, sedimentary phosphate rock, natural asphalt and tar deposits and uraniferous sandstone and siltstone. Vanadium minerals include carnotite

($K_2O.2U_2O_3 \cdot V_2O_5 \cdot 3H_2O$), roscoelite [$2K_2O \cdot 2Al_2O_3(Mg,Fe)O \cdot 3V_2O_5 \cdot 10SiO_2 \cdot 4H_2O$], titaniferous magnetite, [$FeO \cdot TiO_2 \cdot FeO(Fe,V)O_3$], descloizite [$4(Cu,Pb,Zn)O \cdot V_2O_5 \cdot H_2O$], phosphate rock [$Ca_5(PO_4)3(F,Cl,OH)$] with VO_4 replacing PO_4. Significant amounts are also present in bauxite and carboniferous materials, such as crude oil, coal, oil shale, and tar sands.

World Production

The estimated 2001 mine production of vanadium was 43,000 tonnes. Leading producers included South Africa (17,000 tonnes), China (16,000 tonnes), and Russia (9,000 tonnes) (Reese, 2002). Canada presently has no domestic vanadium mine production.

End Use

Vanadium is primarily used as an alloying agent for iron and steel (approximately 80 percent of the total consumption). Its non-metallurgical use, is in catalysts for the production of maleic acid (used in textile dyeing and finishing) and sulphuric acid.

Market Trends

World demand for vanadium will continue to fluctuate in response to changes in steel production. However, the overall trend for consumption is expected to increase owing to anticipated growth in demand for stronger and lighter steels including the demand created by new applications, such as the vanadium battery (Reese, 2001).

Price

In 2001, the average price per pound of V_2O_5 was US$1.40 (Reese, 2002).

Economic factors

The world’s major production is from titaniferous iron ores in the Bushveld Complex of South Africa. Typically these deposits contain about 1.8 percent V_2O_5.

Yukon Vanadium Occurrences

Two minor vanadium commodity occurrences are reported in Minfile 2001 (Table 141; Figure 9). A systematic sampling and assay documentation of the territory’s magnetite, coal, and phosphate occurrences is required to assess the Yukon’s potential for hosting significant vanadium deposits.

Table 141

Yukon Vanadium Occurrences

Map #	Minfile Number	NTS	Name	Tectonic Element	Deposit Type	Latitude/Longitude
1	105O 023	105O/3	DRIZZLE	SB	SEDEX	63º09’28”/131º08’18”
2	116A 024	116A/12	SANGUINETTI	SB	SEDEX	64º41’27”/137º52’54”

SB (Selwyn Basin)

YTTRIUM

YTT

See under Rare Earth in this report.

Exploring for Minor Metals in the Yukon Exp

Minor metals or ‘high-tech’ elements as they are sometimes referred to, are commonly hosted by, or associated with, the rock types illustrated in Table 142. A description of each type is provided as they represent good exploration targets for minor metals in the Yukon.

Table 142

Minor Metals/Associated Rock/Deposit Type

Rock Type/Deposit Type	***Associated Elements***
Carbonatite-syenite complexes	Nb, Y, REE, Zr (Ta)
Volatile-rich granite systems	Be, Ta, Y, REE, Nb
Peralkaline and peraluminous granite systems*	Be, Ta, Y, REE, Zr, Ga
Carbonate-hosted lead-zinc deposits	Ga, Ge
Zinc-rich volcanogenic massive sulphide deposits	Ga
Sediment-hosted, copper-rich breccia pipes and oxidized equivalents*	Ga, Ge
Bauxite deposits*	Ga
Coals	Ge
Iron oxide deposits	Ge
Sedimentary phosphorites	Y

*Source: adapted after Pell and Hora, 1990. * Not known to occur in the Canadian Cordillera*

Carbonatite-Syenite Complexes

Carbonate/syenite complexes are mined for REE and zirconium and can be anomalous in tantalum. In Africa, Brazil and Russia they are also mined for associated copper, phosphate (apatite), iron and vermiculite. Nepheline syenite is quarried in Ontario for use in the glass and ceramics industry (Currie, 1976). In the Jordan River area of British Columbia, near Revelstoke, molybdenum associated with nepheline syenite gneiss complex, was extensively explored in the 1960’s (Fyles, 1970).

Carbonatites are igneous rocks composed of more than 50 percent primary carbonate minerals, predominantly calcite or dolomite. Common accessory minerals include olivine, pyroxene, amphibole, phlogopite, apatite, magnetite, ilmenite, zircon, columbite and pyrochlore. Other minerals such as feldspars, fluorite and REE carbonates may also be present.

Carbonatites occur most commonly as intrusive bodies; they may form as dykes, sills, plugs, veins or segregations in other alkaline rocks. Less common are extrusive carbonatite flows, tuffs or agglomerates. Metasomatic rocks (fenites), which are generally enriched in sodium and ferric iron and depleted in silica, are often developed marginally to intrusive carbonatites or carbonatite complexes.

In the field, carbonatites resemble marble or other carbonate rocks, but in the cordillera can be recognized by their unique orange brown to dark reddish brown weathering colour and unusual mineral assemblage (apatite, olivine, pyroxene, magnetite, zircon, etc.). Other distinctive minerals such as purple fluorite may also be associated with carbonatite complexes. The most common associated igneous rock types are quartz-free syenite, and nepheline or sodalite syenites that are usually white to grey.

The fenites, or metasomatic alteration zones associated with intrusive carbonatite complexes, vary from being almost non-existant to forming halos extending several hundreds of metres into the host rocks. Their nature is also highly variable, dependant on the original lithology and the composition of the fluids associated with the alkaline rocks. In general, calcsilicate and biotite-rich host rocks are altered to sodic pyroxience and amphibole-rich rocks; quartzo-feldspathic protoliths (granites or quartz and feldspar-rich rocks) are altered to rocks of syenitic or monzonitic composition; and carbonate host rocks are altered to iron and magnesium-rich carbonates that may contain fluorite and rare-earth minerals.

Geochemically, carbonatites and related alkaline rocks are undersaturated with respect to silica and may contain high concentrations of elements such as strontium (generally 1000 ppm), barium, niobium and REE. Mineralization generally occurs in primary magmatic deposits; commonly, rare metal enriched phases, crystallized directly from the melt, occur as accessory or less commonly, rock forming minerals.

Distribution

Pell and Hora in 1990, described carbonatites, syenite gneisses and related alkaline rocks present in a broad zone following the Rocky Mountain trench occurring in three discrete areas: along the western edge of the Foreland Belt, east of the Rocky Mountain Trench; and immediately east of the trench in the Cassiar Mountains (northeastern Omineca Belt). It is reasonable to assume that this zone extends north into the Yukon following the northern extension of the Rocky Mountain trench namely, the Tintina Trench. This Yukon portion of the zone would be a good exploration target for locating carbonatite-syenite systems hosting occurrences of minor metals and REE.

Volatile-Rich Granites

In many parts of the world, 'specialty' or volatile-enriched granitoids of 'topaz rhyolite' affinity are metallogenically linked to deposits of a variety of high-tech metallic and non-metallic minerals such as beryllium, yttrium, rare-earths, niobium and to deposits of tin, tungsten, molybdenum and possibly gold. Important deposits types include: Climax-type molybdenum-tungsten porphyries; silver-lead-zinc manto deposits, such as Santa Eulalia, Mexico and Midway, in northern British Columbia; tin skarn deposits; replacement fluorite deposits, for example Las Cuevas, Mexico or beryllium deposits such as in Spor Mountain, Utah.

Description

Volatile-enriched granites may be of two types.

The first are generally not true granites, in the strictest petrographic sense, but are commonly alaskites (alkali feldspar granites). They have a low colour index and contain few mafic minerals; biotite is the most common and alkaline clinopyroxene (aegirine) or alkaline amphibole (riebekite or arfvedsonite) may also be present. Accessory minerals may include titanite (sphene), magnetite, apatite, zircon, allanite, fluorite, melanite garnet and monazite. Associated mineralization generally consists of one or more of molybdenum, tungsten, tin, fluorine, uranium, thorium, niobium, tantalum, yttrium or rare-earth elements in vein, greisens, skarn, porphyry or pegmatitic deposits (Anderson, 1988).

Two-mica granite or more accurately, quartz monzonites may also be enriched in volatile elements. These rocks commonly have low colour indexes and contain plagioclase, potassic feldspar, quartz, muscovite, biotite and accessory tourmaline, fluorite, ilmenite, monazite and topaz. As is the case with alaskites, quartz syenites are common plutonic associates. Mineralization related to these granitic rocks may consist of tin, tungsten, copper, beryllium, zinc and to a lesser extent molybdenum in skarn, greisens or vein deposits.

In both cases, the granitic rocks are characterized by high silica content (SiO_2 greater than 70 percent), K_2O is greater than Na_2O, relatively low TiO2 and high concentrations of associated volatile-enriched elements such as fluorine. In general they are peraluminous to peralkaline in composition As well, $^{87}Sr/^{86}$ isotopic ratios are commonly greater than 0.708, although the alaskites may have strontium ratios as low as 0.703. In western North America, most volatile-enriched granitoids are late Cretaceous to early Tertiary in age (Anderson, 1988; Barton, 1987).

Distribution

Granitoids with Sr isotopic signatures and with trace element chemistry typical of S-type plutonism, are localized in the Omineca and Foreland belts. Largely the products of partial melting of older Precambrian and Paleozoic supracrustal rocks during regional compression and thickening, they denote a mid-Cretaceous plutonic event represented in the northern Cordillera by the Selwyn and Cassiar plutonic suites. Plutons of this suite are occasionally associated with Sn-tungsten skarn mineralization. For some of these occurrences, aplite and pegmatite dykes are most abundant in high-grade zones (e.g. MacTung deposit). Despite extensive work upon skarn mineralization, little has been done to assess the rare element potential of associated pegmatite (Groat and Ercit, 1996). The following characteristics may be used to identify pegmatite with rare element potential in the Yukon:

1. Parent granites are usually isolated, small stocks, typically less than thirty square kilometres in size; however, they are sometimes found as apophyses and at the margins of larger intrusions (batholiths).
2. They are S-type granites, meaning that they are derived from supracrustal (often sedimentary) source material.
3. For the Cordillera, fertile granites rich in rare elements are usually mid-Cretaceous in age.
4. They are peraluminous (ASI index 1-2), often megacrystic and leucocratic.
5. They show initial 87Sr/86Sr ratios greater than 0.7100 (often 0.7200 to 0.7400) and they have large negative eNd values (typically –6 to –9).
6. They often have a peraluminous accessory mineralogy (two-mica granites, garnet-or analusite-bearing) or rare-element bearing accessory mineralization (lepidolite = Li).
7. Their whole-rock geochemistry is rich in large-ion lithophile elements (LILE) such as lithium, rubidium and cesium and high field-strength elements (HFSE) such as niobium, tantalum and tin.

The location of some granitic pegmatite with rare element potential are described by Groat and Ercit (1996) in Open file 1996-3(G).

Exploration

The volatile-enriched granite environment can be most easily recognized by its geochemical signature or by the recognition of petrologic features such as miaroli cavities or accessory minerals such as fluorite. Regional geochemical surveys are a good prospecting tool; granitic bodies with associated fluorine, tin, tungsten, uranium and molybdenum anomalies are potential hosts for deposits of minor metals, particularly rare earths, yttrium, beryllium, niobium and tantalum. As mentioned, the deposits can occur in many forms such as skarns, greisens, veins and pegmatites. In many cases, the mineralization is not obvious; some tin-fluorite skarns known as wrigglites look more like banded metasediments than conventional skarns (Kwak, 1987). In exploring for these deposits, unusual or altered rock should be carefully examined and, if in doubt, analyzed.

Lead-Zinc-Copper Deposits

Lead-zinc-copper deposits occur in many geological environments, forming carbonate-hosted (Mississippi Valley type) deposits, volcanogenic massive sulphide deposits (Kuroko type, Beshi type), sedimentary exhalative deposits (Sullivan type), skarns, mantos and veins. Trace metals, in particular gallium and germanium can be concentrated in these deposits. Commonly they will occur within the sphalerite lattice or as discrete mineral grains forming inclusions within sphalerite or along sphalerite grain boundaries. Concentrations can vary from deposit to deposit. Carbonate-hosted deposits, as a class, have the best potential for containing anomalous germanium concentrations. Zinc concentrates from these deposits may contain as much as 6000 ppm germanium. Individual carbonate-hosted or sedimentary exhalative deposits can be anomalous with respect to gallium (in excess of 600 ppm Ga in sphalerite concentrates), but volcanogenic massive sulphide deposits, on average, have higher gallium contents (Leighton et al.).

Any lead-zinc-copper prospect should be checked for the presence of trace metals; elevated concentrations of elements such as gallium and germanium could potentially raise a marginal prospect, to economic status.

Peralkaline granite-syenite complexes and copper-rich breccia pipes are important potential gallium and germanium hosts. Neither of these environments have been recognized in the Yukon, however there are no reasons as to why they could not occur in the territory, so a brief description of each type is provided.

Peralkaline Granite-Syenite Systems

A wide range of 'high-tech' elements, including beryllium, yttrium, rare earth elements, niobium, tantalum, zirconium and gallium, are associated with peralkaline granite-syenite systems. These deposits constitute an important end-member of a spectrum of deposits related to volatile-enriched granite systems. The systems are generally characterized by complex and diverse plutonic suites (multiphase intrusions) that may consist of peralkaline granites and related pegmatites, peralkaline rhyolitic extrusive, quartz syenites, undersaturated syenites and gabbros. Mineralization may occur in primary magmatic concentrations (pegmatites and other rare metal enriched igneous phases), in veins or in metasomatic alteration zones. Documented peralkaline granite-syenite complex are postorogenic and generally intrude stable cratonic environments. Two well-documented Canadian examples are the Thor Lake deposit in the Northwest Territories (Trueman et al, 1986) and the Strange Lake prospect in Labrador (Miller, 1986, 1988).

Sediment-Hosted Copper Sulphide Breccia Pipes

Sediment-hosted copper sulphide breccia pipes can be the host of anomalous concentrations of gallium and germanium, and sometimes uranium. They generally consist of solution-collapse (karst) breccias in carbonate rocks that have been mineralized by later circulating fluids. In these pipes, sedimentary lithologies form angular breccia clasts while sulphides and minerals such as quartz, barite and fluorite comprise the matrix (in unoxidized pipes). In some cases the breccia clasts may be altered or partly replaced. In oxidized pipes, oxides and clay minerals dominate the breccia matrix.

Copper sulphide breccias pipes are known to occur in western North America including Arizona, Utah and Alaska (Bernstein and Cox, 1986; Dutrizac et al, 1986, Wenrich and Sutphin, 1988). They are commonly small features, less than 100 metres in diameter; however, they may be as wide as 800 metres across. Their small size, combined with thick cover and vegetation could make discovery difficult.

Bauxite and Other Deposit/Rock Types

Bauxite deposits are not known to occur in the Yukon. Some minor showings may be discovered in Cretaceous or Eocene unconformity when warmer climates could have produced this deposit type. Other deposit types listed in Table 142 are traditionally less important sources of minor metals, but the prospector or geologist should not overlook them.

PART E

YUKON
ENERGY AND TRANSPORTATION INFRASTRUCTURE

INFR

YUKON ENERGY ENE

Yukon's Electrical Utilities

Yukon rivers have provided hydro electricity since 1906. Today, there are two electrical utility companies in the Yukon: the Yukon Energy Corporation (YEC) and the Yukon Electrical Company Ltd. (YECL). The Yukon Energy Corporation is a public utility owned by the Yukon Development Corporation, which in turn, is owned by the Yukon Government. Yukon Energy is the primary producer and transmitter of electrical energy in Yukon. It distributes electrical power to wholesale and industrial customers, and to retail customers in Dawson City, Faro, Mayo, Champagne and other rural Yukon areas.

The Yukon Electrical Company Ltd. is a private utility owned by Atco Electric, a division of Atco Ltd. of Alberta. YECL owns and operates all of other distribution systems in the Yukon, including the communities of Whitehorse and Watson Lake. It also owns and operates local diesel generation and distribution in the other non-grid connected communities. (See Figure 10).

Energy Generation and Consumption

Together YEC and YECL serve approximately 15,000 customers through an integrated system of about 1300 kilometers of transmission and distribution lines. Four utility-owned hydro electric facilities are able to provide an annual average of approximately 355 Gigawatt hours (GWh) of energy by hydro-electric generating stations. such as the one on the Yukon River at Whitehorse (Plate 7).

During 2001, approximately 254 GWh of hydro electrical energy were consumed leaving a hydro energy surplus of approximately 100 GWh, which could have been used by new resource industries. There is significant installed diesel–electric generating capacity in the Yukon capable of providing an additional 370 GWh of energy with an 80 percent capacity factor. In addition, there are currently three privately owned micro-hydro facilities in the region, with a fourth project which will be producing power soon. Past studies have shown that numerous sites located throughout the Yukon could support new hydro developments. Facilities smaller than 20MW are seen as the most likely to succeed. One study has identified thirty-three such sites (Yukon Energy Resources, 1997).

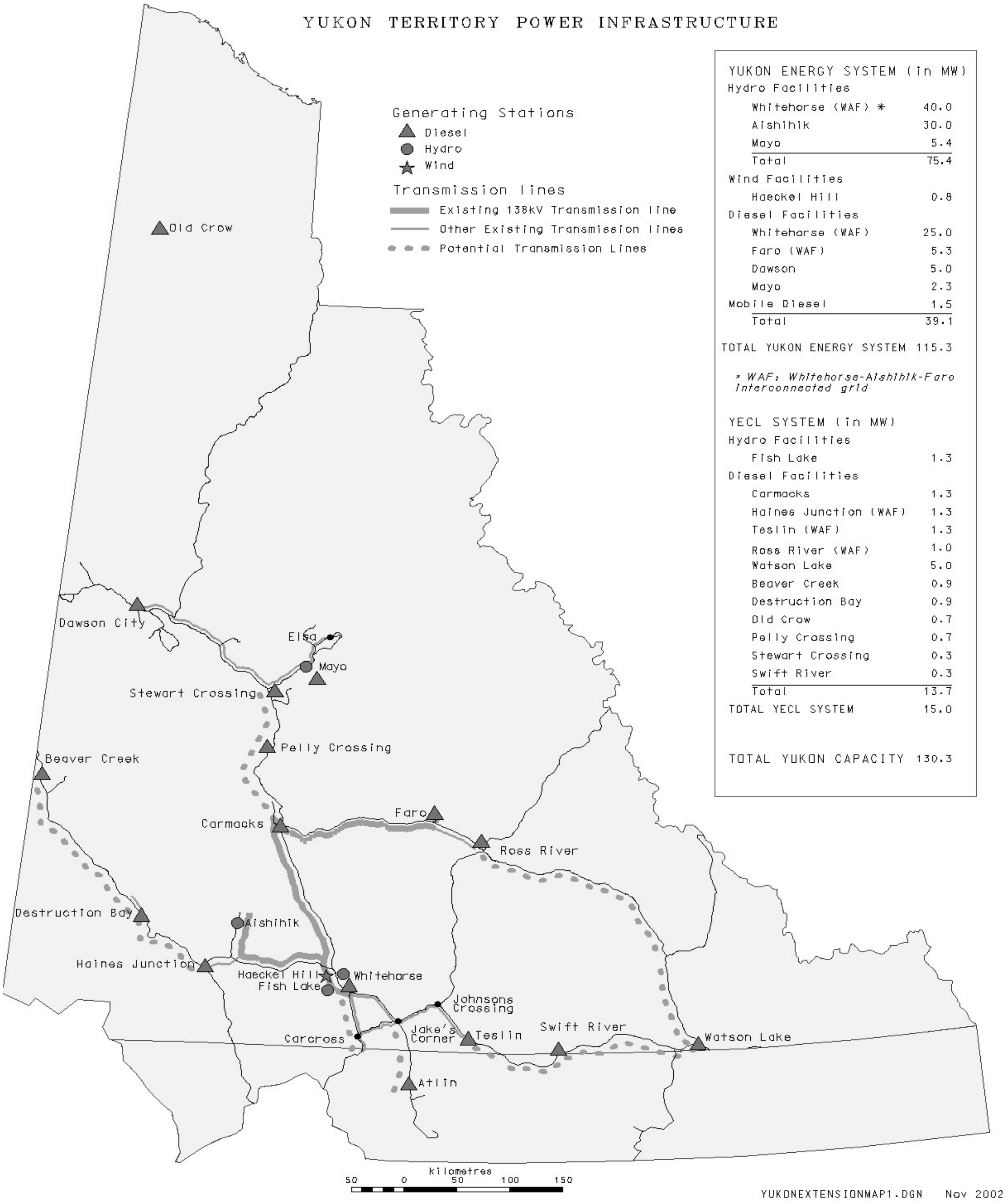
Industrial Electricity Rates

Essentially all of the hydro and transmission line development to date has been undertaken in response to mining development. With the permanent shutdown of the Faro mine the Yukon now has a surplus of hydro energy on the two largest electrical grids in the Yukon.

Industrial electricity (using 1 MW or more) rates in the Yukon follow a few basic principles:

- Industrial customers pay the actual cost of service (except during extended shutdowns);
- The cost of service is determined by treating all of the Yukon is treated as one rate zone (i.e. equalized rates);
- Industrial customers in the Yukon are encouraged to assess their complete energy requirements, both for heating and power, and work with the Yukon utilities for the optimum combination of grid power and on-site generation.

As the configuration of every development is unique it is recommended to contact Yukon Energy Corporation to obtain an energy cost forecast tailored to a specific industrial application.



YUKON ENERGY SYSTEM (in MW)	
Hydro Facilities	
Whitehorse (WAF) *	40.0
Aishihik	30.0
Mayo	5.4
Total	75.4
Wind Facilities	
Haeckel Hill	0.8
Diesel Facilities	
Whitehorse (WAF)	25.0
Faro (WAF)	5.3
Dawson	5.0
Mayo	2.3
Mobile Diesel	1.5
Total	39.1
TOTAL YUKON ENERGY SYSTEM	115.3

* WAF: Whitehorse-Aishihik-Faro Interconnected grid

YECL SYSTEM (in MW)	
Hydro Facilities	
Fish Lake	1.3
Diesel Facilities	
Carmacks	1.3
Haines Junction (WAF)	1.3
Teslin (WAF)	1.3
Ross River (WAF)	1.0
Watson Lake	5.0
Beaver Creek	0.9
Destruction Bay	0.9
Old Crow	0.7
Pelly Crossing	0.7
Stewart Crossing	0.3
Swift River	0.3
Total	13.7
TOTAL YECL SYSTEM	15.0
TOTAL YUKON CAPACITY	130.3

Figure 10. Map Showing the Existing and Potential Electrical Infrastructure in the Yukon Fig10

Plate 7. Whitehorse Rapids Hydro Generating Station on the Yukon River (Photograph Courtesy of Yukon Energy Corporation) Pla7

YUKON TRANSPORATION TN

Yukon Transportation Infrastructure

The Yukon has a modern, efficient infrastructure in the southern portion of the territory where most of the population and industry are located. Details of the infrastructure can be reviewed in greater detail in the Yukon Government's Review Panel Submission to the Canada Transportation Act, 2001. A brief discussion about the Yukon's infrastructure follows.

Highway System

The Yukon is served by an all weather modern highway system. Operated by the Yukon government, there are approximately 4700 kilometres of roads as well as a network of seasonal roads which, could be upgraded if necessary, to serve resource developers (Figure 9). This well maintained highway system permits efficient long-distance trucking within the territory and provides connections to Alaska, British Columbia and the Northwest Territories.

Rail

In 1982, the Faro mine which was located in the geographical centre of the Yukon, was closed and the railway between the mine and Whitehorse was shut down, due to lack of freight volume. Railway operations are now limited to the portion of the line between Skagway in Alaska and Fraser, British Columbia. However, connecting rail corridors in the Yukon still remain in place and railway owners have not applied for abandonment (more in-depth information about the Yukon's rail system is available in Transport Canada's publication "Canada-Alaska Rail Link, 2001).

Marine Transportation

Freight and other goods produced in the Yukon may be trucked to the ocean port in Skagway, Alaska, for transport to world markets.

Air

Business travel to and from the Yukon is primarily by air. The primary routes are scheduled Boeing 737, year round flights between Whitehorse, Vancouver, Edmonton and Calgary. Local airlines also provide scheduled services between Whitehorse, most Yukon communities as well as Alaska and the Northwest Territories.

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American Society for Testing and Materials (International)	*www.astm.org*	Mineralogical Society of America	*www.minsocam.org*
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INAC Mineral Resources	*www.ainc-inac.gc.ca*	Tantalum-Niobium International Study Center	*www.tanb.org*
International Cadmium Association	*www.cadmium.org*	World International Iron and Steel Institute	*www.worldsteel.org*
International Center for Aggregate Research (ICAR)	*www.ce.utexas.edu.org*	Yukon Government Geology Program	*www.geology.yk.ca*
International Chamber of Commerce	*www.iccwbo.org*	Yukon Mining Recorders	*www.yukonminingrecorder.ca*
International Chromium Association	*www.chromium-asoc.com*	Exploration for Diamonds in Yukon and the Cordillera	*www.yukonmining.com*
International Titanium Association	*www.titanium.org*		

ACRONYMS

ACR

API: American Petroleum Institute
ASTMI: American Society for Testing and Materials International
BD: Bulk Density
BTU: British Thermal Units
C: Celsius
CIF: Cost, insurance and freight
CIS: Commonwealth of Independent States (former Soviet Union)
Del: delivered
E.G.: for example
EPA: Environmental Protection Agency (United States)
I.E. : that is
IARC: International Agency for Research on Cancer
FGD: flue gas desulfurization
FOB: free on board
FOT: free on truck
HAR: high aspect ratio
KG: kilogram
KW: Kilowatt
LAR: low aspect ratio
LOI: loss on ignition
MM: millimetres
OCMA: Oil Companies Materials Association
OSHA: Occupational Safety and Health Administration
NA: not available
PCC: precipitated calcium carbonate
PGE: Platinum Group Elements
pH: used in expressing relative acidity and alkalinity. A pH of 7 is regarded as neutral.
ppm: parts per million
SG: Specific Gravity
µm: micrometre (micron) one millionth of a metre
USGS: United States Geological Survey
VMS: Volcanogenic Massive Sulphide

ELEMENT SYMBOLS

ELE

Element	*Symbol*	*Element*	*Symbol*	*Element*	*Symbol*
Aluminum	Al	Helium	He	Radon	Rn
Antimony	Sb	Hydrogen	H	Rhodium	Rh
Arsenic	As	Indium	In	Rubidium	Rb
Barium	Ba	Iridium	Ir	Scandium	Sc
Beryllium	Be	Iron	Fe	Selenium	Se
Bismuth	Bi	Lanthanum	La	Silicon	Si
Boron	B	Lead	Pb	Silver	Ag
Bromine	Br	Lithium	Li	Sodium	Na
Cadmium	Cd	Magnesium	Mg	Strontium	Sr
Cesium	Cs	Manganese	Mn	Sulphur	S
Calcium	Ca	Mercury	Hg	Tantalum	Ta
Carbon	C	Molybdenum	Mo	Tellurium	Te
Cerium	Ce	Nickel	Ni	Thallium	Tl
Chlorine	Cl	Niobium	Nb	Thorium	Th
Chromium	Cr	Nitrogen	N	Tin	Sn
Cobalt	Co	Osmium	Os	Titanium	Ti
Columbium	See Niobium	Oxygen	O	Tungsten	W
Copper	Cu	Palladium	Pd	Uranium	U
Fluorine	F	Phosphorus	P	Vanadium	V
Gallium	Ga	Platinum	Pt	Yttrium	Y
Germanium	Ge	Potassium	K	Zinc	Zn
Gold	Au	Radium	Ra	Zirconium	Zr

GLOSSARY OF TERMS GLO

Abrasive: a natural or artificial substance suitable for grinding, polishing, cutting, or scouring. Natural abrasives include diamond, emery, garnet, silica, and diatomite.

Acicular: a crystal or sedimentary particle that is needlelike in form.

Alaskite: a plutonic igneous rock consisting predominantly of alkali feldspar (microline) and quartz; plagioclase (oligoclase) subordinate; mafic constituents few or absent, also referred to as alkali granite.

Ashlar: in masonry, a roughhewn block of stone.

Aspect Ratio: the ration between the length of the crystal and its width.

Batholith: a large mass of granite that is predominantly medium to coarse-grained. The surface area exceeds 100 square kilometres.

Bedding: the arrangement of a sedimentary rock into layers of varying thickness and character.

Benefaction: involves either dry grinding or wet processing minerals.

Berylometer: a commonly portable instrument used to detect and analyze for naturally occurring beryllium.

Binder: the material that produces or promotes consolidation.

Calcined (diatomite): calcining removes organics, increases filtration rates (surface area is reduced by fusing more delicate structures of particles and sintering them into small clusters resulting in larger particle size and increased pore size), oxidizes iron (changing the buff to gray colours common crude ore to pink or white in diatomite), increases specific gravity, and increases particle hardness, but also disadvantageously produces free silica.

Coater: a mineral coater is a finely pulverized material that is spread on the surface to improve specific properties and appearance. The most common example is coated paper.

Coarse grained: individual grains or crystal in a rock are greater than 5 millimetres deep spaced about 5 millimetres apart.

Dimension stone: a natural rock, which has been quarried and shaped to meet specific requirements for use in the construction, building and monument industries.

Extender: a mineral extender is a finely pulverized material that when added to a composition that contains a prime pigment such as titanium dioxide, will not seriously degrade the physical, optical, and chemical properties imparted by that prime pigment.

Flagstone: a hard, evenly and thin bedded, usually micaceous and fine-grained sandstone (or firm shale or sandy limestone) that splits readily and uniformly along bedding planes or joints into large, thin, flat slabs suitable for making pavement or covering the side of a building.

Fine-grained: individual grains or crystals less than 1 millimetre in size.

Frasch (mining): a hydraulic method of sulphur mining in which superheated water that has been forced into the in-place deposit (in situ deposit) to dissolve the sulphur is pumped to the surface and treated to recover the sulphur.

Filler: a mineral filler is a finely pulverized inert material that is incorporated in a composition for some useful purpose.

Grain size: a description of the dimensions of individual mineral grains that make up a rock.

Granite (commercial definition): a visibly granular, igneous rock generally ranging in colour from pink to light or dark grey and consisting mainly of quartz and feldspar, accompanied by one or more dark minerals. The texture is typically homogeneous but may be layered (gneissic) or porphyritic.

Greissen: a granite altered by magmatic fluids producing a rock consisting of light green (lithium) micas, muscovite, quartz, kaolinite, fluorite and topaz. Often associated with ores of tin and tungsten.

Hardness (Moh's scale): a standard of ten minerals by which the hardness of a mineral may be rated. The scale includes from softest to hardest and numbered one to ten: talc; gypsum; calcite; fluorite; apatite; orthoclase; quartz; topaz; corundum; and diamond.

Humification: the process of development of humic acids, essentially by slow oxidation.

In situ: a mineral deposit formed in-place.

Lithophile: elements having a strong affinity for oxygen, which concentrate in silicate minerals.

Long ton: 2240 pounds

Mafic: dark-coloured minerals with magnesium (Mg) and iron (Fe) as major components.

Mica: a prominent rock-forming constituent of many igneous and metamorphic rocks, commonly occurs as flakes, scales, or shreds. Mica varies in colour from colourless, silvery white, pale brown, or yellow to green or black.

Kilogram: approximately 2.2 pounds.

Metasomic deposit: a deposit formed by metamorphic change involving the introduction of material (elements) from an external source.

Miarolitic cavity: a small vug in a plutonic rock formed by crystallization of magma trapping a gas bubble; generally lined by late-crystallizing minerals that often display well-formed crystal shapes.

Mischmetal: a mixture of rare-earth elements in metallic form, usually containing the same ratio of rare earth elements as found in the ore (usually 60 to 80 percent Ce and La).

Peralkaline: rocks in which Al2O3/(K2O + Na2) is less than one. The typical mafic minerals are sodic pyroxenes and sodic amphiboles.

Pigment: a mineral having economic value as a colouring agent.

Protolith: the unmetamorphosed rock from which a given metamorphic rock was formed by metamorphism; parent rock.

Quarry: a surficial mine; open workings; usually for dimension stone or gravel and sand.

Refractory: resistant to heat.

Schist: a strongly foliated metamorphic rock, which can be split into thin flakes or slabs due to well-developed parallelism of more than 50 percent of the minerals present.

Schlieren: in some igneous rocks, irregular streaks or masses that contrast with the rock mass but have shaded borders. They may represent segregation of dark or light minerals , or altered inclusions, elongated by flow.

Sedge: peat formed with remains of various sedges.

Skarn: a metasomatically altered rock formed at the contact of granitic to granodioritic intrusions by an interaction of elements from the magmatic fluids and the country rocks.

Slaked Lime: water added to calcium hydroxide.

Short ton: 2000 pounds

Specific Gravity (SG): the weight of the rock relative to an equal volume of water.

Sphagnum: peat composed mainly of Sphagnum moss remains.