HEAP LEACHING OF BORDER RESOURCES SERPENTINE

A Process for the Recovery of

Nickel, Cobalt, Magnesia, Silica

Report to Mr. G. W. Hornby, P. Eng., President,

Border Resources Ltd.

by H. E. A. von Hahn. Ph. D., P. Eng.

June 30, 1992

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INTRODUCTION: (by Peter Hall)

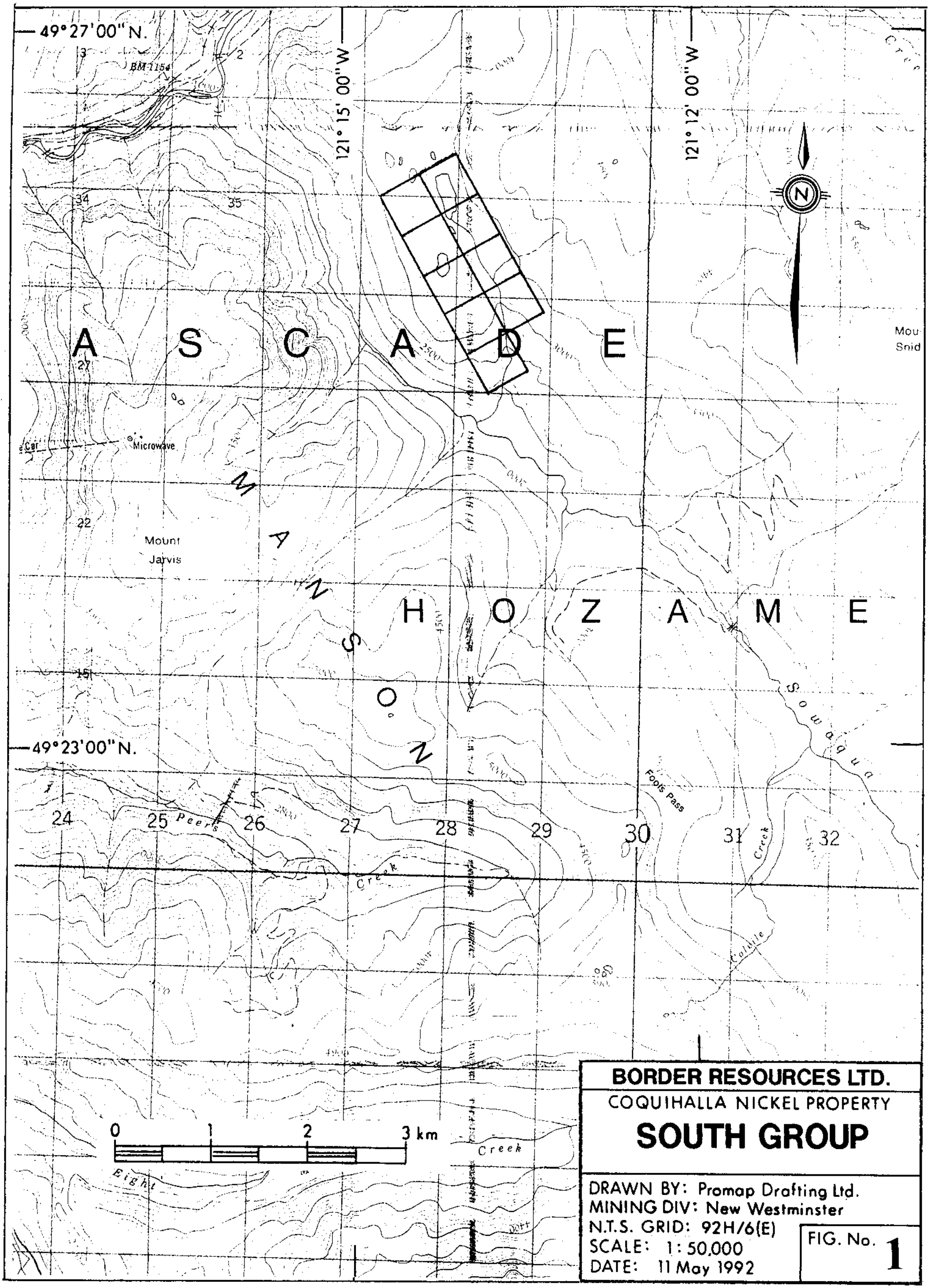
Those claims forming the SOUTH GROUP of BORDER RESOURCES' Coquihalla Nickel Property are located on NTS mapsheet 92H/6, approximately 12.5 km N.70°E. from the town hall in the town of Hope, B.C. Access is gained by following Hwy. #3 to a point approximately 6 km East of the Hope turnoff where the Coquihalla highway, Hwy. #5, begins. Thence one travels Northeasterly for approximately 12 km along the highway to the Sowaqua Creek turnoff and then through the PRITTY TIMBER gate and 7.1 km Southeasterly and upward along the Sowaqua Creek F.D. road to a point inside the South end of the TOY #9 m.c.

The SOUTH GROUP represents the Southern of two blocks of claims held by BORDER RESOURCES LTD. over the largest outcropping exposures of the "Coquihalla Serpentine Belt". From an original contiguous holding of 153 2-post claims staked in 1969, two residual key areas remain, the NORTH GROUP next to Fifteen Mile Creek containing 14 claims, and the SOUTH GROUP with 9 claims.

The value of the property lies in the presence of nickel-bearing sulphides along with Co, Fe, and Cr, concentrated in the serpentinized ultramafic host rock. The problem to date has been to devise an economic method to separate the microscopic needles of nickel from the serpentine.

Since 1981, metallurgical research has been conducted on the property by A-MIN-TECH RESEARCH of Vancouver, and others. Gravity flotation, magnetic concentration, and bacterial and acid leaching techniques have been investigated. This present report outlines the latest work in this evolution and suggests that the economic separation of the nickel metal is finally within reach through a new technique that allows for the full recovery and recycling of the spent leachate solutions.

This report is derived from the metallurgical evaluation of a 100 kg$^+$ bulk sample collected from mineral claims TOY 7 and 9 in the SOUTH GROUP on May 11, 1992. The collection of this sample was recorded as "physical work" on May 13, 1992, Event #3018017, in order that credit for collecting it would not be lost through the occurrence of the anniversary dates later that month. The work on the collected sample and the resulting report prepared by Dr. H. Von Hahn relates to the current anniversary year.



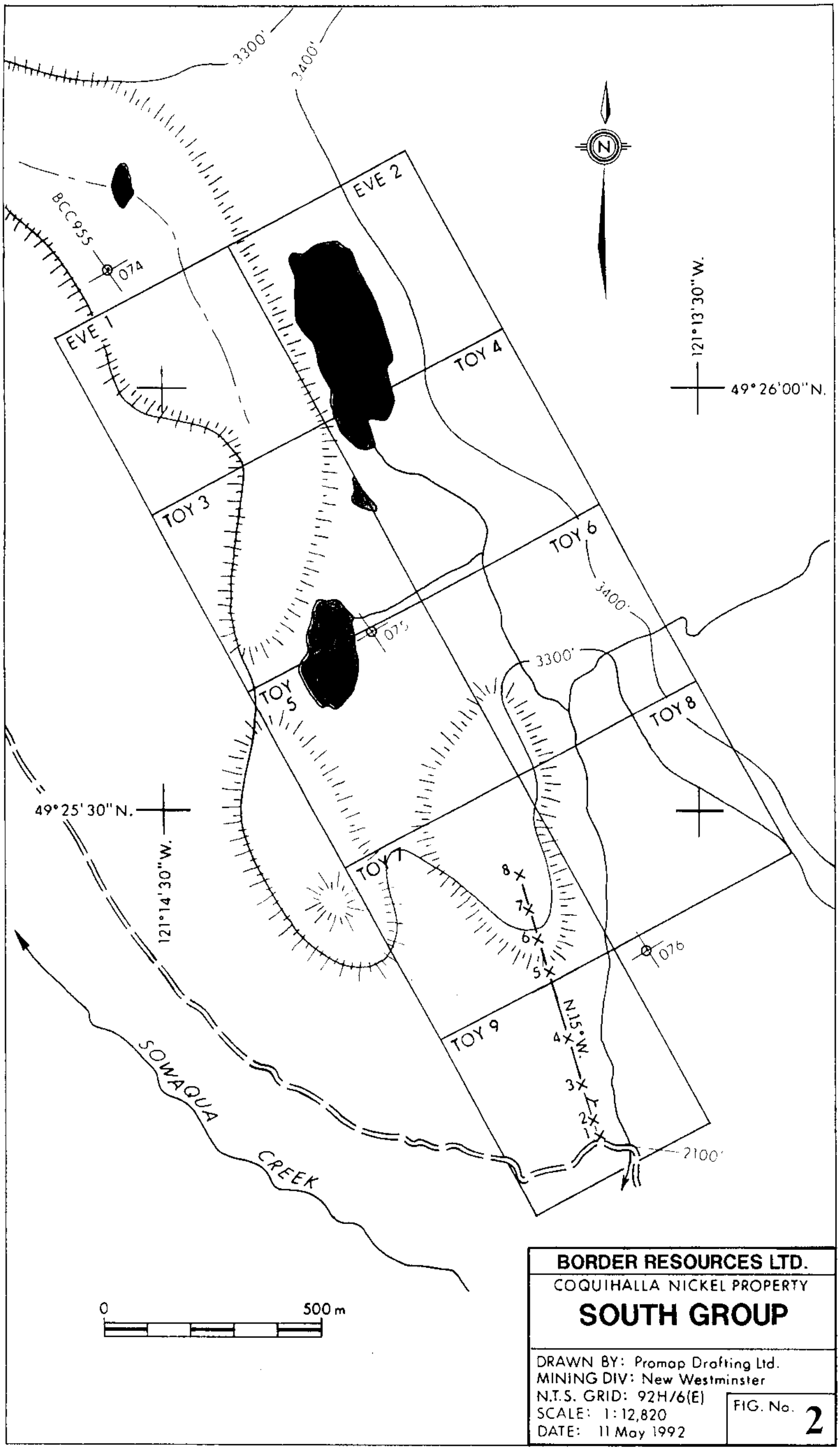
BORDER RESOURCES LTD.

COQUIHALLA NICKEL PROPERTY

SOUTH GROUP

DRAWN BY: Promap Drafting Ltd.
MINING DIV: New Westminster
N.T.S. GRID: 92H/6(E)
SCALE: 1: 50,000
DATE: 11 May 1992

FIG. No. 1


3300'
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SOWAQUA
CREEK
121°13'30"W.
49°26'00"N.
49°25'30"N.
121°14'30"W.
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500 m
BORDER RESOURCES LTD.
COQUIHALLA NICKEL PROPERTY
SOUTH GROUP
DRAWN BY: Promap Drafting Ltd.
MINING DIV: New Westminster
N.T.S. GRID: 92H/6(E)
SCALE: 1:12,820
DATE: 11 May 1992
FIG. No. 2

BORDER RESOURCES LTD.

FIG. 3: Dr. Von Hahn at site of collapsed adit on TOY 9 m.c.

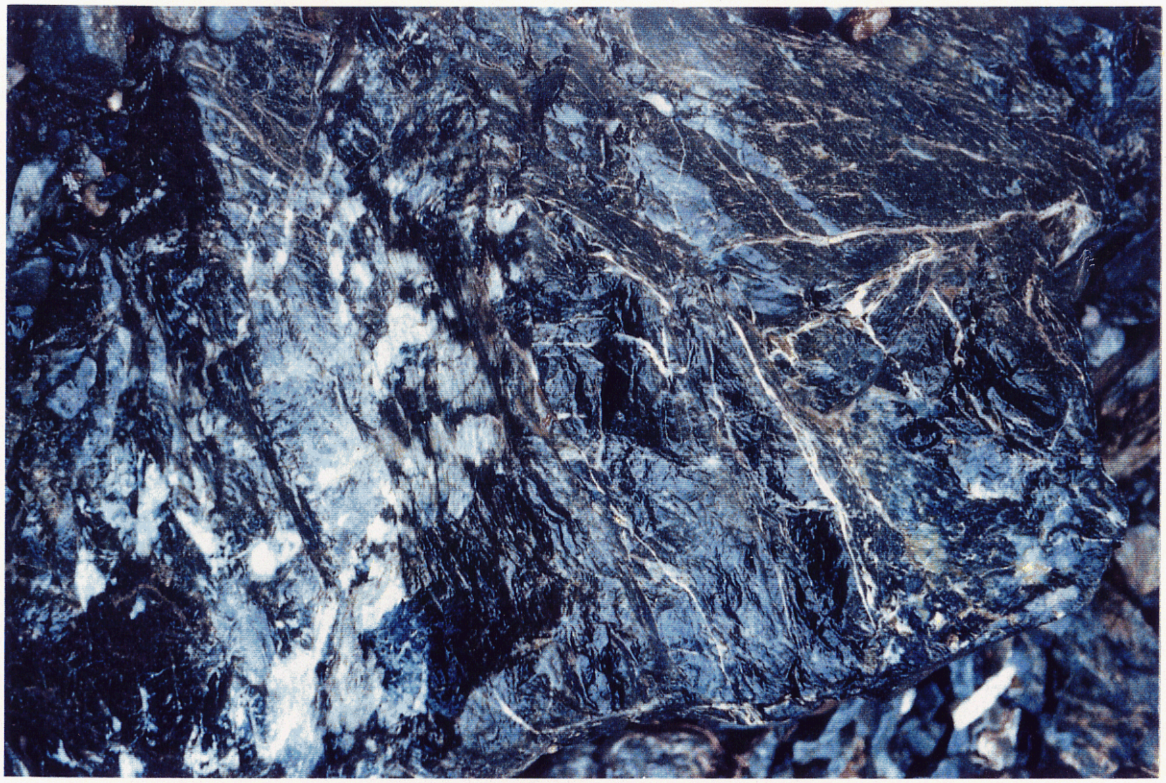

FIG. 4: Serpentine outcrop on TOY 9 m.c.

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INVOICE
(interim)

92-09-08

To:
Border Resources Ltd.,
4547 West 5th Ave.,
Vancouver, B.C.,
V6R 1S6

Attention: Mr. Geoffrey W. Hornby, P.Eng., President.

For:

Preparation of a report entitled: "**Heap Leaching of Border Resources Serpentine**: A Process for the Recovery of Nickel, Cobalt, Magnesia, Silica", dated June 30, 1992.

My fee	$6,000.00
Less advance	1,000.00
Amount payable	$5,000.00

Signed: H. von Hahn
H. E. A. von Hahn, Ph.D., P.Eng.

PROFESSIONAL
PROVINCE OF
H. E. A. VON HAHN
BRITISH COLUMBIA
ENGINEER

Copy 2

- INTRODUCTION AND PACKAGING -

STATEMENT OF AUTHOR'S QUALIFICATIONS

I, Peter S. Hall, of the City of Vancouver, British Columbia, do hereby declare that:

1) I am a graduate of:-
   a) The University of British Columbia in Resource Geography; and,

   b) The B.C. & Yukon Chamber of Mines Prospecting School (1972); and,

   c) The B.C. & Yukon Chamber of Mines Placer Mining Programme (1988); and,

2) I have worked in the B.C. Mining Industry at mineral exploration and land management since 1969; and,

3) I participated in the fieldwork referenced in this report and attest that the work done corresponds to the claims made.

Signed at Vancouver, B.C.
this 16th day of September 1992

P. Hall

Peter S. Hall, BA

HEAP LEACHING OF BORDER RESOURCES SERPENTINE

A Process for the Recovery of

Nickel, Cobalt, Magnesia, Silica

A Report submitted to Mr. G.W. Hornby, P. Eng., President,

Border Resources Ltd.
4547 West 5th Ave.,
Vancouver, British Columbia,
V6R 1S6

June 30, 1992

prepared by

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CONTENTS

SUMMARY

Border Resources Ltd., a British Columbia company, has claims to a large nickel bearing serpentine deposit near Hope, British Columbia.

The deposit is of interest as a potential source of nickel. Other metals and minerals of interest are cobalt, chromite and magnetite. A considerable fraction of the nickel an cobalt are present as sulfides.

Considerable geological and metallurgical work has been done over the past 24 years to determine the extent of the deposit, the mineralogy, and the recoverability of the minerals of interest.

In recent years the metallurgical work has focused on leaching the serpentine to extract the nickel, with the idea to develop a low cost heap leaching process. In particular, bioleaching was used.

It was found that good extraction of nickel, 65-87%, could be achieved. Results for cobalt were similar. This success was mitigated, however, by high consumption of sulfuric acid; caused by reaction with serpentine.

To make a heap leaching process economic it would be necessary to recover the acid.

A process was developed, on paper, that would recover sulfuric acid and at the same time produce magnesia and silica as marketable byproducts. These byproducts would pay for the cost of acid regeneration and provide additional profit.

This report presents the findings of this process development work and includes recommendations for further work.

PREFACE

The treatment of the Border Resources serpentine for the recovery of nickel and other valuable minerals, e.g., cobalt, chromium, has required considerable new metallurgical thinking ever since testwork was first started in 1968.

The attractive feature of this deposit is the presence of nickel sulfides, mainly pentlandite, which constitute a large part, 50-77%, of the overall nickel mineralization.

Flotation was expected to serve as the means by which the sulfides could be recovered. However, the need for very fine grinding and other factors precluded this approach from becoming economic. Bioleaching offered considerable encouragement because nickel extractions of 65-87% were achieved. However, sulfuric acid consumption was high, and this approach would only work if the acid were to be recovered.

In view of nickel being a valuable commodity, and in view of low-grade deposits expected to become interesting some day, the Border Resources management, in discussions with the author, decided to look further into the question of treating the serpentine, and to determine if a new approach could be found to make processing of this ore economic.

This report presents the findings of a study, done by the author, that examines this question. The study indicates that an economic approach may be feasible.

A heap leaching process is proposed, in which nickel is extracted and sulfuric acid recovered. The cost of acid recovery is met by the sale of magnesia (magnesium oxide, MgO), a byproduct. Other byproducts of potential value are cobalt and silica. Preliminary economics suggest added profit from the sale of the byproducts.

INTRODUCTION

Border Resources Ltd., a British Columbia company, has claims to a large, nickel bearing serpentine deposit located near Hope, British Columbia. The deposit contains also cobalt, chromium and iron as additional, potentially valuable metals. A unique feature of the Border Resources serpentine, relative to other serpentines, appears to be the high proportion of nickel occurring as sulfide, mainly pentlandite. Thus, 50 - 77% of the total nickel content, of about 0.22%, has been found to be present as sulfide, the remainder being present as silicate.

The presence of nickel sulfides led to efforts to recover these minerals, and during the past 23 years Border Resources has been active in pursuing various research and test programs to develop a viable process for the beneficiation of this ore. The main areas of effort were flotation and bioleaching.

In flotation some success was achieved, with recoveries being up to 77%; however, the need for very fine grinding and large amounts of gangue depressants made this approach uneconomic.

In bioleaching quite encouraging results were obtained, nickel extractions being in the range of 65 -87%. However, consumption of sulfuric acid, as a result of reaction with the basic serpentine rock, was too high to make a leaching process viable; unless the acid were to be recovered.

This report examines the question of acid recovery, and proposes a process by which recovery could be achieved profitably. Basically, this involves the recovery of magnesium sulfate, a byproduct of the leaching reaction, and treatment of the sulfate to produce magnesia and sulfuric acid. The recovery of silica, another byproduct, is also considered.

The economics of this process are preliminary. However, they look encouraging and further development work is proposed.

THE BORDER RESOURCES NICKEL-SERPENTINE DEPOSIT

Location: The deposit is located about 16 km north east of Hope, British Columbia, close to the Coquihalla highway. It is readily accessible from the highway by secondary- or logging roads.

Logistics: Factors of logistic interest are: Major electric power lines and gas- and oil pipelines pass in the vicinity of the property and highway. The property is within easy driving distance, of Vancouver, British Columbia.

Claims: The property comprises two groups of claims, one north- the other south of the highway. The north group consists of 15 claims with a total area of about 295 hectares, the south group consists of 9 claims with a total area of about 188 hectares; Chamberlain[11].

Size: The deposit underlying the claims is considered to be very large. It consists mainly of serpentine, but it also contains significant amounts of diorite, which may make up 30% of the rock mass; Chamberlain[11]. The deposit has been described by Chamberlain[11] as follows: "Regardless of the extent of the diorite component, it is clear that surface indicated reserves of ultramafic rock grading 0.2% nickel or higher are immense. The economics of a mining operation are more dependent on the development of a low cost metallurgical process to treat the nickel bearing rock than they are on proving the existence of an additional hundred million tonnes or so of reserves at these grades."

Geology: The deposit is part of what is known as the Coquihalla ultramafic complex, Chamberlain[11], or the Coquihalla serpentine belt, Ray[27].

Exploration: Surface exploration, mapping, drilling, mineralogical work, and airborne geophysical exploration have been done on the property. This work has been reported on by Chamberlain[7,8,9,11], and Crosby & Steele[18].

Metals and Minerals of Economic Interest: Nickel, cobalt, chromium and iron are the metals of interest. With the possibility of heap leaching, serpentine has also become of interest as a source of magnesia and silica. Precious metals were found to be too low for economic interest[33].

However, some upgrading of silver and platinum into nickel flotation concentrates was noted by Cristovici et al.[16].

Nickel content is 0.18 - 0.24%, cobalt 0.010 - 0.015%, chromium 0.27 - 0.33% , iron 5 - 7%. Serpentine contains about 40% magnesia and about 40% silica; Mainwaring[25].

Nickel occurs partly as sulfides, 50-77%; Chamberlain[7,8,9] Sinclair[28], von Hahn[31,35], Cristovici et al.[16], Mainwaring[25]; and partly as silicate[7,25]. The main sulfide mineral is pentlandite; Chamberlain[9], Mainwaring[25]. Cobalt occurs as sulfide and silicate in about the same proportion as nickel; von Hahn[34]. Also, it is in association with nickel, as shown by flotation evidence; von Hahn[35,36], Cristovici et al.[16]; in particular with pentlandite as shown by scanning electron microscopy; Mainwaring[25].

Chromium and iron occur as chromite and magnetite; Chamberlain[7,8,9], Sinclair[28]. Silicate chromium is unlikely to be present; Chamberlain[10]. Chemical evidence suggests that there is also no silicate iron present;von Hahn[37].

PRIOR METALLURGICAL TESTWORK

Introduction: The discovery of nickel sulfides in the Border Resources serpentine led to considerable efforts toward upgrading this material. These took two main directions: Flotation and bioleaching. In addition magnetic separation tests were done. These efforts and the results achieved are briefly reviewed below.

Flotation: Testwork to upgrade the ore by flotation was done by Britton[3,4], von Hahn[32,35,36,38], and Cristovici et al.[16]. Although some upgrading was achieved, including the production of high grade - up to 20% Ni - concentrates, there were considerable difficulties associated with this approach. These included the need for very fine grinding, excessive requirement of gangue depressants, inadequate recoveries. It was decided flotation should be left to a time when better ore material could be found.

Magnetic Separation: Magnetic separation tests were done on flotation tailings by von Hahn[37] and Cristovici et al.[16], to investigate the recoverability of magnetite and chromite, both of which occur in the serpentine. Some success was achieved, however, recoveries and grades were low. Further work is required for these minerals.

Bioleaching: In view of the difficulties associated with flotation, the Border Resources management decided to investigate bioleaching to extract nickel. The advantage in leaching is the possible use of low cost heap-leaching, which offers substantially improved chances for developing a commercially viable process.

Preliminary, laboratory scale, bioleaching testwork by Hackl[21] gave quite encouraging results, and further work was undertaken by Lawrence[24] which produced nickel extractions of 64 - 87% in 51 days of leaching.

This was very encouraging. However, the results were mitigated by a high consumption of acid during leaching. Sulfuric acid is required in bioleaching to maintain the pH at about 2. It is consumed by reaction with the ultrabasic serpentine rock. It was realized that a process based on leaching would require the recovery and recycling of the acid.

A NEW APPROACH

Current Situation: The results of the bioleaching tests in terms of nickel extraction were the most encouraging yet obtained. This was the first time after many years of efforts that a ray of hope appeared on the horizon for treating the Border Resdources serpentine; only to be darkened by the problem of high acid consumption.

What to do? Forget all efforts at this point? Or carry on and try to see if a solution can yet be found? It was decided to carry on.

The solution to the problem had to lie in recovering the sulfuric acid consumed during leaching. If that were economically possible, a low-cost operation, such as heap-leaching, might be developed to treat this ore successfully.

Heap-leaching would have considerable advantages over flotation: Capital costs would be substantially lower; the scale of operations would be much smaller, e.g., 2000-4000tpd instead of 30,000-40,000 tpd; fine grinding would be eliminated; tailings disposal would be simpler; environmental protection requirements would be easier to meet.

New Approach: A new approach had to be developed. Efforts were made to determine the options available. This report presents the findings of these efforts.

Previous Work on Treatment of Serpentine: Serpentine received considerable attention over the years as a potential source of magnesia and silica, and efforts made in various parts of the world to develop extraction processes.

A recent paper by Nagamori et al.[26] entitled: "The activation of magnesia in serpentine by calcination and the chemical utilization of asbestos tailings - a review" discusses the subject and cites 131 references including 25 patents. The efforts on process development are mainly concerned with the extraction of magnesia. They include leaching and the use of acids, such as sulfuric and hydrochloric acids.

More recently, Noranda Inc. and Lavalin Industries, of Quebec, developed the "Magnola" process to recover high purity magnesium chloride from serpentine asbestos tailings for production of magnesium metal. The process is said to be economic, and they are seeking financing to build a plant[19,22].

Serpentine has been proposed as a source of silica for the production of ferrosilicon; Udy[30].

<u>Process Option for Border Resources</u>: It is clear that treatment of the Border Resources serpentine will hinge on the economic recovery of sulfuric acid consumed during leaching. This means that magnesium sulfate is to be recovered in addition to nickel and cobalt. Magnesium sulfate is a product of leaching serpentine with sulfuric acid.

A new concept was developed as follows: Nickel and cobalt would be extracted in a heap leaching process which would include the use of bacteria.

Sulfuric acid would be recovered by extraction of magnesium sulfate from the leach solutions, and decomposition of the latter to produce magnesia and gaseous sulfur oxides. The sulfur oxides would be used to regenerate sulfuric acid. Magnesia would be recovered as a byproduct.

A study was done to examine the feasibility of this option. This report presents the findings of this study.

The study indicates that the recovery of sulfuric acid from leach solutions should be feasible. The sale of magnesia would pay for the cost of sulfuric acid regeneration and provide an additional profit.

Another byproduct of leaching is finely divided silica, known as micro silica. The recovery and sale of micro silica could provide a further profit.

The question of recovery of chromite and magnetite was also given consideration. It was decided that such recovery would have to occur after leaching, and probably after recovery of silica. Appropriate testwork is needed to determine the feasibility of recovery of chromite and magnetite.

THE MAGNESIA MARKET

Introduction: This chapter discusses briefly the market potential for magnesia. The subject is discussed in some detail in recent reviews by Coope[13,14,15]. The potential for this mineral appears to be promising .

Magnesia is a commodity traded worldwide. It is classed as an industrial mineral. Various grades exist, and the prices vary according to factors such as purity, crystal size and degree of calcination. In recent years there has been a trend toward the development of high purity materials having closely controlled size distributions. These materials tend to fetch the higher prices and are also less subject to the vagaries of the market place.

Production:The total world magnesia production is not readily available. The total world production of magnesite (magnesium carbonate) is about 13.4 million tons annually; Kramer[23]. This is equivalent to about 6.4 million tons of magnesia.

The 1989 world production capacity of magnesia from natural magnesite has been given as being over 7.8 million tons annually; Coope[14].

This capacity is somewhat in excess of the magnesia content of the magnesite being mined. It might reflect allowance for future demand growth and/or differences in estimates by different authors.

Magnesia is also recovered from seawater and brines. The world production capacity for magnesia from these sources is given as being over 2.3 million tons annually; Coope[14].

About 85% of these capacities is for the production of dead-burned magnesia. The rest is for the production of caustic calcined magnesia.

Uses: Dead burned or refractory magnesia is used primarily for the manufacture of refractory bricks. Purity and control of crystalline microstructure are essential in these applications.

Caustic calcined magnesia is used in agriculture, construction, pulp and paper, chemicals, phamaceuticals, functional fillers for rubbers, plastics, etc., environmental applications.

Specifications vary greatly depending on end use. Agricultural magnesia may have 80-85% purity, whereas the higher quality materials have purities in the 97-99% range.

Market: The market for magnesia has cycles. The refractory magnesias are somewhat tied to the fortunes of other major commodities such as steel. The caustic calcined magnesias, having a wider range of uses, may be less affected by world economics.

In recent years the magnesia economic picture has improved markedly. Producers in various countries, including Canada, have done plant expansions; Coope[14].

Quality: There is a trend among some producers to go for higher quality and more specialized-use products to meet customer needs, and be more competitive. Examples are improvements in purity and microstructural control of refractory magnesias, and development of specialty grades of caustic calcined magnesias and magnesium hydroxide; Coope[14].

Prices: Prices for magnesia vary widely, depending on product quality. They range from US$232/st for 85% natural technical grade through US$409/st for synthetic deadburned grade to as high as US$1500/st for technical light neoprene grade[12].

Trade: Magnesia is a commodity traded worldwide. Shipping distances seem to be no problem, particularly for the higher grade products; Coope[13].

The United States has become a major importer in recent years. In the case of refractory magnesias, the main sources of supply have been China, Greece, the UK, Ireland, Japan, Canada and Mexico.

Competition: Competition is strong for markets in the lower grade materials. China, having very large magnesite deposits, has become a major competitor on world markets in recent years. High grade products, like those produced by Dead Sea Periclase, Israel, or Veitcher or Radex, Austria, have maintained their strong market positions; Coope [13].

Consideration for Border Resources: The main consideration in the context of Border Resources' process development will be to establish what magnesia products offer the best opportunities of market stability and growth at acceptable profits.

MAGNESIUM METAL PRODUCTION

This section is included to offer thoughts for a further use of the magnesia to be derived from the Border Resources serpentine. Such use could provide additional revenue to the project, and/or make it more stable economically. The idea is to use the magnesia as feed for a magnesium smelter.

The three main uses of magnesium metal are as alloying agent in aluminum, in die castings of automobile parts, and in the desulfurization of steel.

Magnesium metal is produced, for the most part, by fused salt electrolysis of magnesium chloride derived from seawater or brines. The Dow Chemical Co. process of long standing is the prime example in this context.

In recent years a trend has developed toward the use of magnesite and other materials, such as serpentine, as starting materials to make magnesium chloride for electrolysis. This trend is based on advances in chemical technology, which has made it possible to compete with the traditional seawater- or brine process routes.

In Canada, one commercial operation has been established that produces magnesium metal from magnesite: The Norsk Hydro plant in Becancour, Quebec, which uses raw magnesite imported from China as its starting material. Another, the MagCan operation under development in Aldershyde, Alberta, is to use magnesite mined from the Mount Brussiloff deposit near Radium Hotsprings, British Columbia[19].

A third, commercial operation, under consideration in Canada, is based on a process in which serpentine serves as the source for magnesium chloride. The socalled "Magnola" process, developed by Noranda Inc. and Lavalin Industries, is now at the stage where commercial development is being investigated[19].

These developments are of direct interest to the Border Resources project and should be considered in any feasibility studies.

MICRO SILICA MARKET

Introduction: Even though the possibility of recovering micro silica from the proposed leaching of Border Resources serpentine has not been proved out yet, it is worth to consider the market potential for this material. This is done in the following brief notes. Most of the information has been obtained from a recent paper by Coope[15].

Products: Micro silicas are silica products of very small particle size; in the range of 7 to 60 nanometers, or 0.007 to 0.060 microns, in diameter.

These product are known as precipitated silicas if obtained in a wet process, that involves the use of sodium silicate as an intermediate product; and as fumed silicas if obtained by a high temperature process, that involves the use of silicon tetrachloride as an intermediate. The silica raw materials are usually mined quartz or silica sand.

The term micro silica has been seen in the literature[1], and is used here for its clarity of definition.

Uses: Micro silica is a commodity that finds considerable application as a functional filler and extender in rubber, paints, plastics, paper, etc.[15]. Another example is its use as an additive in concrete to decrease permeability; an important factor in salt water applications[1].

Prices: The following prices have been quoted in British Pounds Sterling: "Precipitated silicas for rubber and general filler usage start at BPS500 per tonne. More specialized grades may sell for BPS1000 per tonne, or more."[15].

Production: Clear production figures for micro silica are not available at this writing. The bulk of the micro silicas is produced from sodium silicate. Western world production of synthetic silicas and precipitated silicates is about 650,000 tpa[15].

Markets: The main markets appears to be in industrialized countries. This is where all the producers for micro silicas and silicate products appear to be located.

Potential for Border Resources: Recovery of precipitated- or micro silica from the residues of serpentine leaching might offer advantages of economy over the products produced through the sodium silicate process route.

Therefore, the recovery of micro silica from serpentine leach residue, and its subsequent purification, should be included as part of any process development work.

THE PROCESS

Introduction: Figure 1 shows diagrammatically the process as envisaged for the Border Resources ore for the leaching of nickel and cobalt, the main base metal values of interest, and the extraction of magnesia and silica.

Heap Leaching: Heap leaching is envisaged to be done on pads. The ore is to be crushed to about -3/4 inch size. Leaching time may be 50 days, or longer, on the basis of current test results[11]. It will be necessary to establish the permeability of the ore under operating conditions.

Leaching of Nickel & Cobalt: The leaching of nickel and cobalt from serpentine ore is done with biologically active aqueous sulfuric acid solutions at pH about 2. The active bacteria are a suitable strain of thiobacillus ferrooxidans. The bacteria provide the oxidising environment for the decomposition of sulfides. Leaching also occurs in the absence of bacteria. This is the leaching of silicate nickel & cobalt caused by acid dissolution of serpentine.

Serpentine Leaching: Serpentine, being an ultrabasic rock, is leached by sulfuric acid solutions according to reaction 1:

$$Mg_6 \cdot (Si_4O_{10}) \cdot (OH)_8 + 6H_2SO_4 = 6MgSO_4 + 4SiO_2 + 10H_2O \qquad 1.$$

The serpentine formula shown is for the antigorite variety, the main variety found in the Border Resources deposit.

Reaction 1, page 19, is the cause of the consumption of sulfuric acid. The main reaction products are magnesium sulfate in aqueous solution, and precipitated, or micro silica; von Hahn[39].

Nickel, Cobalt Recovery: Two options are available to recover nickel and cobalt. Solvent extraction and precipitation. The choice would depend on economics and on convenience of operation.

It appears, at first glance, that precipitation would be the choice. It would be relatively simple to precipitate these metals as hydroxides from condensed leach solutions after crystallization of magnesium sulfate.

Adjustment of the required pH for precipitation of the hydroxides will be easy to achieve, because of the ready availability of basic serpentine and/or magnesia.

In addition, purification steps will be needed, which could include redissolution of the hydroxides and reprecipitation as sulfides.

Magnesium Sulfate Recovery: Magnesium sulfate is removed from the leach solution by crystallization as $MgSO_4 \cdot 7H_2O$, also known as epsom salt. The solution is condensed, by evaporation at about 85°C, to achieve a sufficiently high concentration of magnesium sulfate for crystallization of epsom salt to occur at room temperature.

Magnesium sulfate serves as the starting material for the pruduction of magnesia and regeneration of sulfuric acid.

Magnesia Recovery: Epsom salt is heated to drive off the water of hydration. Anhydrous magnesium sulfate is decomposed to magnesia, sulfur oxides and oxygen according to reaction 2.

$$2MgSO_4 = 2MgO + SO_2 + SO_3 + 1/2O_2 \qquad 2.$$

The technology for producing chemical grade magnesia is well established, and a number of commercial operations exist to produce high quality products of various grades and specifications. Magnesium chloride serves as the starting material in many instances. Reports and reviews have been published on the subject by Benbow[2], Canterford[5,6], and Coope[13].

A process has been developed by Cross et al.[17] for the use of sulfuric acid to produce high grade magnesia.

The sulfuric acid route for magnesia production has some advantages, relative to the hydrochloric acid route, in that a greater amount can be recovered from solution by crystallization. The hydrochloric acid route is simpler in the recovery of the acid, and is well established.

Two grades of magnesia are of interest. Technical chemical, or caustic calcined grade, and deadburned refractory grade. The latter is also known as periclase. The main difference between the two is the temperature of calcination, the refractory grade requiring a higher temperature.

Purity of 97%-99%+ is essential to meet customer specifications and be competitive in the marketplace. Crystallized epsom salt is an excellent starting material for producing high purity magnesia. If necessary, dissolution and recrystallization of epsom salt can be done to increase purity.

Of importance also is the crystal size and structure of the products. For the refractory magnesias crystals of sufficient size and even structure are desired to produce high density, high quality refractories; Coope[7.1]. Such products command higher prices.

The choice of product for the Border Resources operation would depend on market evaluations. The technical chemical, or caustic calcined grades are more easily produced. They are also less costly because of lower calcination temperatures.

Sulfuric Acid Regeneration: Sulfuric acid is regenerated from the gaseous decomposition products of reaction 2 in a suitable sulfuric acid plant.

Silica Production: Silica is a byproduct of serpentine leaching, according to reaction 1, page 19.

Leaching of silicate minerals with acids can produce a silica gel or a siliceous residue. Serpentine is a sheet silicate, and as such is said to leave a siliceous residue; Terry[29]. This is important for process development. A silica gel residue would "blind" the ore and eventually prevent further leaching.

A recent test, done by von Hahn[39], on residue from the earlier bioleaching work, indicates that a siliceous residue rather than a gel is produced in leaching of Border Resources serpentine, and that it should be recoverable. This is encouraging.

The siliceous residue was of submicron particle size and appeared to be amorphous.

Siliceous residue is also known as precipitated silica or micro silica. Micro silica can be quite valuable, depending on specifications, such as purity and particle size distribution. Smaller particle sizes fetch higher prices; Coope[15].

Micro Silica Recovery and Purification: The recovery of micro silica from the Border Resources leach residue should be considered as part of process development for the purpose of gaining additional revenue.

The process will probably involve scrubbing and filtration.

This approach was used by von Hahn[39], who found that, after scrubbing the leach residue, a milky white supernatant liquor resulted which contained the micro silica.

Following recovery, purification steps will be required to make a silica product of about 99% purity to meet market specifications. These could include redissolution of the silica as sodium silicate and reprecipitation with sulfuric acid; Coope[15].

Chromite, Magnetite Recovery: Chromite and magnetite will not be leached under the relatively mild leaching conditions contemplated for this process. To recover these minerals, it will be necessary to employ separation methods, such as magnetic separation or flotation. The treatment will have to be done on the leach residue after silica separation. Detailed testwork will be required to determine the feasibility of recovering these minerals.

PROCESS ECONOMICS

Introduction: The question arises: Is the process idea to leach serpentine for nickel and cobalt recovery, and to regenerate sulfuric acid from the magnesium sulfate produced, economic?

Various cost factors have been calculated to obtain an approximate understanding of the costs and revenues that can be expected from the process of treating this ore.

Here are the basic assumptions: The cost of mining, crushing and heap leaching is to be paid for by the value of recovered nickel and cobalt. The cost of sulfuric acid recovery is to be paid for by the value of recovered magnesia. Further value is added if micro silica, produced during leaching, is recovered and sold.

The following is a brief summary of preliminary cost and profitability calculations for the process; on the basis of price and cost figures, as recently published[12] and as obtained from other sources.

Nickel, Cobalt: Ore grades are taken to be 0.22% for nickel, 0.012% for cobalt. Recoveries are taken to be 65% for both metals. Recovered values, on the basis of current prices[40], are C$13.12/mt for nickel and C$2.97/mt for cobalt, giving a total of C$16.09/mt.

The costs of mining, crushing and heap leaching are estimated to be C$5.51/mt, and the costs of recovery and purification at C$2.00/mt[40]. This gives a total cost of C$7.51/mt.

Nickel, Cobalt Profit: On the basis of the above figures, an operating profit of C$8.58/mt is calculated for nickel and cobalt.

Magnesia: Magnesia is to be recovered from magnesium sulfate, following the latter's decomposition. The product is to be sufficiently pure so that no further processing is required. It is then to be calcined to the desired degree for market purposes.

What kind of magnesia is to be produced? Technologically, the most convenient is the technical-chemical grade. Deadburned refractory grade can be produced at a higher cost; however, it fetches higher prices.

The magnesia value has to pay for the cost of sulfuric acid recovery. This point is examined now.

The of amount of magnesia recovered depends on the amount of sulfuric acid regenerated. The bioleaching testwork had shown an acid consumption of about 350kg/mt; Lawrence[24]. The equivalent magnesia amount is 144kg/mt. On this basis and at the current prices for technical-chemical-grade and deadburned magnesias (Appendix 1) the value of recovered magnesia is estimated at C$65.90/mt of ore.

<u>Cost of Sulfuric Acid</u>: This cost is calculated from price data shown in Appendix 1. It is C$15.05/mt of ore. It is the cost of producing sulfuric acid from the sulfur oxide gases resulting from decomposition of magnesium sulfate; as per reaction 1, page 19.

To this have to be added energy cost items 1. to 3. for recovery and decomposition of magnesium sulfate, as shown below. They amount to a total of $4.33/mt of ore. Thus, the total cost of sulfuric acid regeneration will be $19.38/mt of ore.

The cost of sulfuric acid production is based on the assumption that a regular contact sulfuric acid plant will be used involving the catalytic oxidation of SO_2.

In the context of the proposed process, a possible alternative is worth considering. It has been reported in the literature[20] that decomposition of magnesium sulfate in the presence of steam will yield sulfuric acid directly. This approach could be simpler and more cost effective. An example of actual use of this principle is the recovery of hydrochloric acid by high temperature steam decomposition of magnesium chloride in the production of magnesia from brine in the so-called Aman process of Dead Sea Periclase, Israel; Coope[13].

Energy Cost: The cost of energy, in particular thermal energy, will be an important item in the process. Some idea of this cost is of value. Estimates have been made of major thermal energy cost items occurring in the process, and listed below. The figures were calculated on the basis of energy costs provided by B.C. Hydro; Appendix 1. No allowances have been made for heat losses or for recapture of latent process heat.

1. Heating and evaporation of leach solution at 85^oC prior to crystallization of epsom salt: $l.54/mt of ore.

2. Dehydration of epsom salt at 200^oC to the monohydrate, $MgSO_4 \cdot H_2O$: $1.19/mt of ore.

3. Dehydration of the monohydrate and decomposition of $MgSO_4$ at 1100^oC to magnesia, sulfur gases and oxygen as per reaction 2, page 18: $1.60/mt of ore.

Magnesia Profit: Deducting the cost of sulfuric acid gives a net value for magnesia of C$46.52/mt of ore. However, it does not allow for items such as plant operating costs, or any possible further processing that might include an additional calcination step. These need to be determined in some detail to arrive at a more accurate magnesia profit.

Micro Silica Profit: This profit is difficult to assess at this point. However, it is worth while to get a figure for potential gross revenue derivable from micro silica.

Based on the lower price shown in Appendix 1, and assuming a recovery of 40%, a gross revenue of C$19.35/mt of ore, before costs, would be realizable. If the higher price and/or higher recoveries apply, the gross revenue could be much higher.

The main cost factors in micro silica production will be recovery and purification. Of the two, recovery will be the lower one. Recovery will involve process steps, such as srubbing, settling and filtration. Purification may involve conversion of micro silica to sodium silicate, dissolution, solution purification, and reprecipitation of micro silica with sulfuric acid.

Size of Operation: The size of the Border Resources serpentine heap-leaching operation will be controlled in large measure by the amount of magnesia produced and sold on the world market.

For example, on the basis of laboratory scale test results[24], a 2000 ton/day operation could yield up to about 100,000 tons of magnesia per year. This could be sold all or in part, depending on economic requirements and conditions.

Microsilica could add to the profit of the operation, and thereby provide some flexibility in production and sales. This could be useful in cushioning economic swings among the products.

Capital and Financing Costs: These costs have not been considered in the context of this report.

ENVIRONMENTAL CONSIDERATIONS

The process will be environmentally friendly. All leach solutions are completely recycled, and the acid is recovered. There will be no problem of acid mine drainage. Serpentine is a basic rock, and any potential acid production by oxidation of sulfides will be quickly neutralized. Gaseous products derived from magnesium sulfate decomposition are to be fully recovered.

RECOMMENDATION

Research and Testwork: Further work is necessary to develop the process and ideas presented in this report.

In particular, laboratory scale and semi-pilot scale leaching tests are to be done. The main purpose is to determine the recoverability of magnesia and silica and to obtain further data on nickel and cobalt extraction.

The question of chromite and magnetite recovery should also be addressed.

In addition, more detailed cost data have to be developed.

Patentability: The ideas for the serpentine leaching process, proposed in this report, were developed by the author on the basis of research into the matter and discussions with Mr. G. W. Hornby of Border Resources Ltd. It is possible that there are novel features in part or all of the process which may be patentable.

It is recommended that the question of patentability be investigated.

ACKNOWLEDGEMENTS

I wish to thank Dr. J. A. Chamberlain, of Chamberlain Geological Associates Inc., Vancouver, B.C. and Mr. P. Hall of Land Ranger Explorations Ltd., Vancouver, B.C., for valuable discussions and advice given to me in the preparation of this report.

I also wish to express my appreciation to the many technical experts in the field with whom I had occasion to discuss various questions relating to this project, but whose names have not been mentioned.

I also wish to express my appreciation to Mr. G. W. Hornby, President, and Mr. P. Stursberg, Director, Border Resources Ltd. for their continued support of this project.

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40. see Appendix 1

APPENDIX 1

COST DATA & CALCULATIONS

Definitions: st = short ton, mt = metric ton
Epsom Salt: Hydrated Magnesium Sulfate, $MgSO_4 \cdot 7H_2O$
Magnesite: Magnesium Carbonate, $MgCO_3$
Magnesia: Magnesium Oxide, MgO
Micro Silica: Precipitated or fumed silica of very small particle diameter; in the range of 0.007 to 0.06 microns

Conversion Factors : US$1.00 = C$1.15
1.0 st = 0.907 mt

Commodity prices: These were obtained from current pertinent publications[12] and discussions with appropriate sources.

Nickel: US$3.62/lb

Cobalt: The price of cobalt is arbitrarily assumed to be US$15.00/lb. Current cobalt prices are quoted at around US$30.00/lb, whereas the official producer price is around US$11.00/lb. The reasons for these large price changes are difficulties in Zaire, where the major world cobalt producer, Gecomines, is located.

Magnesia: US$330/st for technical chemical grade; US$392/st for deadburned refractory grade; average of the two: US$361/st.

Micro Silica: US$265/st for 98% grade, under 10 micron size. However, Coope[15] mentions prices starting at BPS500/tonne for precipitated silicas for rubber and general filler usage. These silicas are of submicron size, i.e., in the range of 0.01 -0.06 microns. The Border Resources silicas are expected to be in the submicron size range.

Sulfuric Acid: For this process, we are not considering virgin sulfuric acid, the most expensive variety, but rather recycled sulfuric acid for which the cost of sulfur can be omitted. Accordingly, it was decided to look at the price of smelter acid, which has no sulfur cost, because its raw material source is the smelter off gases. Also, it is available at lower strengths, such as 60° Be., which reduces the price still further. Prices for smelter gas sulfuric acid, of 100% strength, range from US$20 through $48 to $63/t ex works. For 60° Be. acid, prices are multiplied by 0.7767. Choosing an average figure of US$43.67/t and converting to 60° Be., because 100% strength acid will not be needed in this project, one obtains an acid cost US$33.91/st. This translates to C$15.05/mt of ore.

Energy: The cost of thermal, natural gas derived, energy is taken as $3.47 - 4.21 per gigajoule. These figures are based on discussions with B.C. Hydro.

The energy requirements for the process steps, like dehydration, thermal decomposition, calcination of the various magnesium compounds, have been estimated on the basis of appropriate specific heat data, and industry experience in the burning of limestone to produce cement.

Cost of Mining, Crushing: A quarrying operation is assumed, and two stages of crushing to -3/4 inch size. The cost has been given as C$2.50/st , or C$2.76/mt.

Cost of Heap Leaching: The main cost items here are the operational cost and the cost of sulfuric acid.

The operational costs include crushed ore conveying, heap building, solution sprinkling, tailings removal. These are estimated at C$2.75/mt.

The cost of sulfuric acid is assumed to be negligible as it is to be paid for by the sale of magnesia.

The total cost of heap leaching would then be C$2.75/mt.

Cost of Nickel, Cobalt Recovery from Leach Solutions and Purification: This cost is not known in detail at this stage. It is not expected to be large. The process steps would include precipitation of hydroxides, solid/liquid separation, purification, and reprecipitation as sulfides, for example. The total cost is assumed to be C$2.00/mt.

Cost of Magnesia Production: The main cost is already paid for by the leaching operation and the recovery of sulfuric acid. One main additional cost would be the calcination of magnesia following decomposition of epsom salt. This could amount to about $2.00/mt of ore.

If a specialty product is to be made, like deadburned periclase of exact specifications in composition, crystal shape and size distribution, additional process steps and costs will be required and detailed evaluations will be necessary.

Cost of Silica Recovery: This has not been considered in the context of this report because insufficient test data are available at the time of this writing.

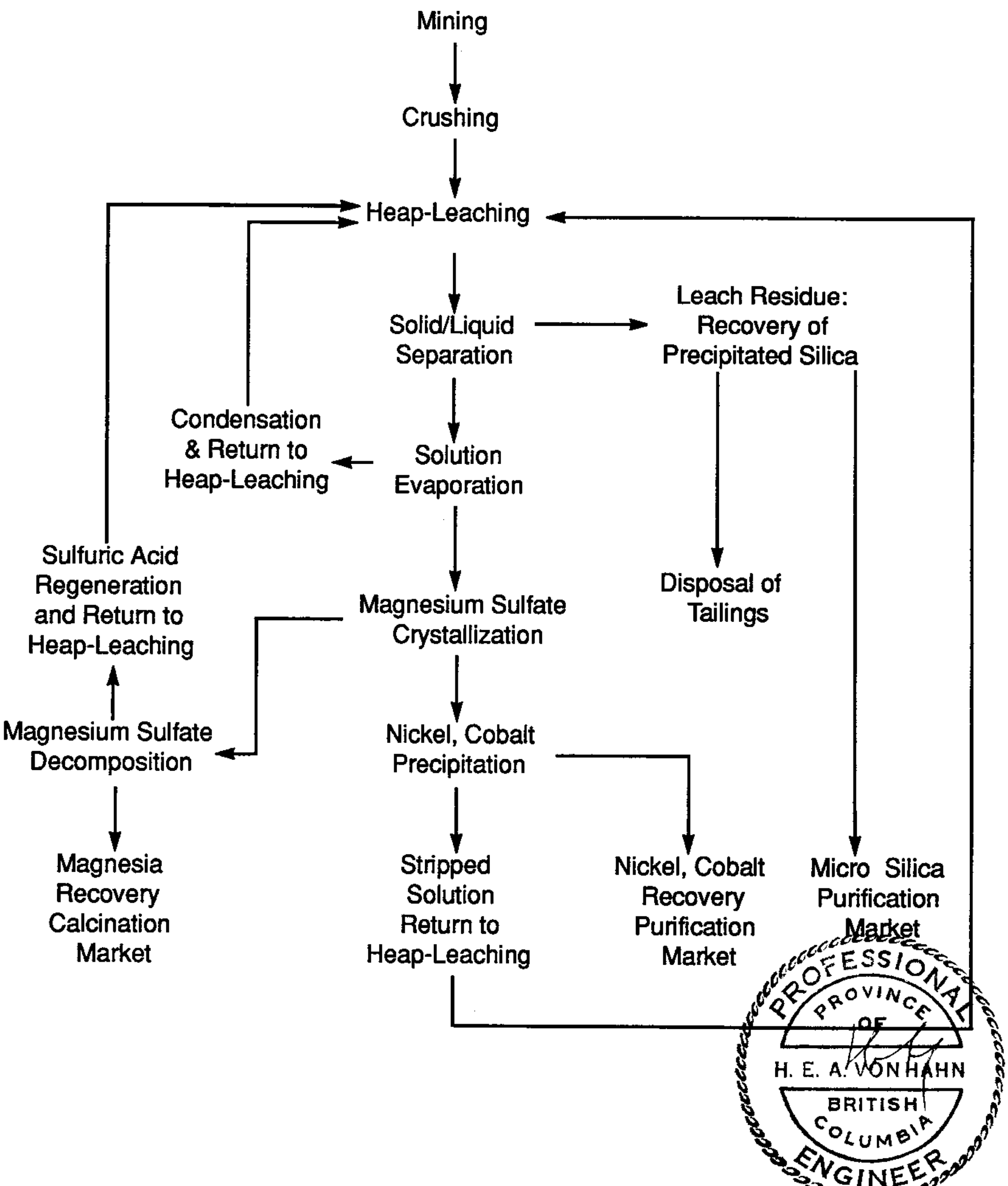

Figure 1: Process Flow Diagram for Heap-Leaching Border Resources Serpentine to Recover Nickel, Cobalt, Magnesia and Silica.

USE OF REPORT

The purpose of this report is to provide new thoughts and ideas for the treatment of the Border Resources nickel bearing serpentine for the recovery of various metals and minerals.

The report is preliminary, inasmuch as further work is required to prove out some of the ideas expressed. Similar considerations apply to the various cost and profitability estimates given.

On the basis of the foregoing, this report may be used in its entirety for purposes of providing information to interested parties.

The use of this report, in part or in whole, as part of other reports or in publications, is subject to written permission by the author.

AUTHOR'S CERTIFICATE

I, Hardwin E. A. von Hahn, of Vancouver, British Columbia, do hereby certify as follows:

1. I am a consulting metallurgical engineer.

2. I am a graduate of the University of British Columbia: 1958, BASc metallurgical engineering; 1960, MASc metallurgy; 1963, PhD metallurgy.

3. I am a registered Professional Engineer of the Province of British Columbia.

4. From 1963 to 1970 I have been engaged in research in extractive metallurgy for industrial companies and government institutions. From 1976 to the present I have been engaged as a consulting metallurgist to individual and company clients.

5. The attached report, entitled "Heap Leaching of Border Resources Serpentine" is based on personal research, done by me, on the basis of earlier reports to Border Resources Ltd. on serpentine leaching and other testwork and pertinent publications in the technical literature, as shown under "References" in this report, and discussions with technical experts in the field.

6. I have not received, nor do I expect to receive, any interest, directly or indirectly, in the Border Resources Properties described in this report.

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — H. E. A. VON HAHN

Signed: H. von Hahn

Hardwin E. A. von Hahn, Ph.D., P. Eng.

Vancouver, British Columbia, Canada

Date: June 30 1992.

Province of
British Columbia

Ministry of
Energy, Mines and
Petroleum Resources
GEOLOGICAL SURVEY BRANCH

ASSESSMENT REPORT
TITLE PAGE AND SUMMARY

TITLE OF REPORT [type of survey(s)]	TOTAL COST
METALLURGICAL EVALUATION OF A SERPENTINE BULK SAMPLE	$6000.

AUTHOR(S) Peter Hall SIGNATURE(S) P. Hall

NOTICE OF WORK PERMIT NUMBER(S)/DATE(S) NAN 92-0700285-36 YEAR OF WORK 1992

STATEMENT OF WORK - CASH PAYMENT EVENT NUMBER(S)/DATE(S)
16 September 1992

PROPERTY NAME Coquihalla Nickel (South Group #1475)

CLAIM NAME(S) (on which work was done) TOY #7 (21605-5) and TOY #9 (21607-5)

COMMODITIES SOUGHT Nickel

MINERAL INVENTORY MINFILE NUMBER(S), IF KNOWN 136 - TOY

MINING DIVISION New Westminster NTS 92H/6(E)

LATITUDE 49 ° 26 ' 00 " LONGITUDE 121 ° 14 ' 00 " (at centre of work)

OWNER(S)

1) BORDER RESOURCES LTD. 2)

MAILING ADDRESS

5132 Alderfeild Place,
West Vancouver, B.C.
V7W 2W7

OPERATOR(S) [who paid for the work]

1) as above 2)

MAILING ADDRESS

as above

PROPERTY GEOLOGY KEYWORDS (lithology, age, stratigraphy, structure, alteration, mineralization, size and attitude):

The ultramafic complex serpentinite is derived from rocks of varying composition from dunite to peridotite and pyroxenite. The nickel and cobalt are found as pentlandite and minor millerite.

REFERENCES TO PREVIOUS ASSESSMENT WORK AND ASSESSMENT REPORT NUMBERS

See bibliography starting on P.30 of HVH Report.

(OVER)