ECOLOGICAL ENGINEERING FOR GOLD AND BASE METAL MINING OPERATIONS IN THE NORTHWEST TERRITORIES

FINAL REPORT

BY

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SUMMARY

Mining activities in the Arctic are associated with environmental changes. However, the implications of these changes are not always understood, and it is often difficult to delineate the extent of the changes or, in fact, the nature of them, i.e. whether they are beneficial or detrimental. In general, the time frames in which the full application of the environmental changes are evident are longer and frequently more complex than first anticipated, due to powerful physical effects on ecological processes.

An evaluation of the long term environmental implications of active mining operations in the Northwest Territories has been carried out in an attempt to assess waste management strategies which could, at the termination of the mining operations, minimize potential environmental degradation.

The field investigations of the gold mine, Lupin, and the lead zinc concentrator at Nanisivik, primarily focused on the environmental conditions which might be encountered in the long term after the shut down of the operations. Secondly, emphasis was placed on the search within the waste management areas and at their boundaries to the environment, for suitable components of ecosystems which could be utilized in Ecological Engineering methods and Biological Polishing processes. These methods are being developed for southern regions with a goal to achieving an environmentally acceptable walk-away condition for mining operations. It was not possible to determine the applicability of such methods in the northern environment without a detailed assessment of mines located in the Northwest Territories.

The results and conclusions of this study are two-fold. An attempt has been made to determine realistically those environmental characteristics which would prevail at the time of close-out for the mine operation. This is followed by an evaluation of the applicability and the potential for the use of biological processes in this imagined close-out environment.

For Lupin, it was evident that the close-out plans in place are very well defined from a long term environmental point of view. A waste-rock and/or Esker material cover over the tailings surface slopes in such a way that minimal contact with run-off water is achieved. This will provide good water quality which might be further improved with biological processes. The low temperature of the tailings was found to be essential in effectively reducing the rate at which acid generation might occur. The tailings are likely to remain at low temperatures and thus no environmental implications from the waste management area is anticipated in the long term. However, the temperature behaviour of the tailings is important and remains to be considered.

For Nanisivik, located in the high Arctic on the northern tip of Baffin Island, the results of the investigation indicated that underwater disposal of tailings in a lake environment is the best possible method. Acid generation potential in the long term is curtailed to such a degree that it is unlikely ever to surface in a manner detrimental to the environment. The disturbance of permafrost by the mining activity has resulted in some point sources of heavy metals in surface seeps from waste rock piles.

Similar sources of metals were found under natural, undisturbed conditions during the investigation. Pyrite outcrops characterize the rock-dominated environment of this mineralized area. The neutralizing capacity of the country rock (shale and dolomite) provides natural amelioration measures which can be utilized to curtail any long-term detrimental effects of the mining activities. The effective use of the country rock, in conjunction with biological processes and physical efforts to encourage permafrost, appear to provide environmental conditions at the time of close-out which resemble those of the natural undisturbed environment of the area.

The field investigations of both a gold and base metal mine in the northern part of the Northwest.Territories led to an understanding of their fundamental nature which can be summarized as follows:

Mining in the northern environment introduces changes to drainage systems and permafrost conditions. However, the often-feared environmental degradation caused by acid generation and alterations in drainage patterns as a result of the disturbance of permafrost in this environment, is slowed down and retarded. This retardation of the degradation facilitates an ecological equilibration taking place in the North which can be assisted by man more effectively than in the South.

An holistic ecological approach, taking into account equally the behaviour of the environment and the mining wastes produced by the operation, which indeed is fundamental to Ecological Engineering, can lead to sound environmentally acceptable abandonment procedures. The Ecological

Engineering and Biological Polishing methods have also been considered in the context of Pine Point and Salmita. They are not required for the abandonment of Pine Point, however, they *are* certainly applicable to Salmita which has received only theoretical consideration in this report.

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This project was carried out in co-operation with **Echo Bay Mines Ltd.** and **Strathcona Mineral Services Limited.** Their support in providing all logistical services made our site visits very effective and extremely informative.

We would like to thank Mr. **H. Wilson** for his assistance and interest in many aspects of the project.

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1.0 INTRODUCTION

The rise in environmental awareness over the past decade has resulted in stringent demands respecting water quality control and regulations on land and water usage being placed on mining operations. The development of regulations which should lead to improved environmental protection is not necessarily concurrent with development of the technology required to provide such protection. At present, therefore, the rationale which appears to prevail is that the best protection is an undisturbed environment. This view is, of course, an unrealistic one. Mining is a necessary component of human existence. Its operation results in extensive changes in the environment on the surface around the mine, and it is possible that drainage patterns in the vicinity of the mine are altered as well.

Reclamation technology has been developed which, in many cases, provides effective environmental protection. **Peterson and Peterson (1977)** have provided a useful compendium on revegetation information for Northern Canada. Throughout the document, the different conditions encountered in Arctic regions are highlighted. In the North, restoration to the original vegetation and drainage patterns would require hundreds or perhaps thousands of years. Natural processes should be utilized in reclamation efforts. It was found that the reinvasion of native species was inhibited as the cover of introduced vegetation increased.

Waste water treatment technologies used during operation produce, in most situations, an acceptable discharge water quality. However, waste-water treatment plants need maintenance at various frequencies. This means that at the time of mine closure, because of the continuing demand for maintenance of the waste management area, an environmental and economic liability is imposed on mining companies and governments. The resulting economic burden associated with such maintenance is difficult to bear for the responsible parties. To date, approaches and detailed methods by which mining operations can be abandoned in an environmentally acceptable manner, and which take economic considerations into account while being acceptable to regulatory bodies, are not available.

Mine abandonment is particularly difficult for operations where the waste materials contain significant fractions of pyrite or pyrrhotite. The ore body exposed on the surface is acid-generating, and the mining and grinding activities have resulted in a larger exposed and reactive surface. Due to this acid generation, contaminants (e.g. heavy metals) are solubilized and can be carried into receiving water bodies and into the ground water.

Present-day treatment technology can provide environmental protection as long as maintenance programs and surveillance are sustained. The Research and Development community is actively addressing new options for the improvement of treatment technology and formulating methods to provide an environmentally acceptable close-out condition for the abandonment of mining operations.

Self-maintaining systems, capable of polishing treatment effluents from the waste sites and progressively curtailing adverse environmental conditions which could arise from the wastes, would provide an economically sound technology for long-term environmental protection.

Ecological Engineering and **Biological Polishing** are methodologies which are being developed for abandonment of mining operations, with the aim of providing self-maintaining biological systems. The concept was formulated, developed, and is at present being pilot-tested for tailings sites in Central and Northern Ontario by **Boojum Research Limited (Kalin, 1986a, Kalin and Smith, 1986, Kalin and van Everdingen, 1987).** However, the climatic and environmental conditions in the Arctic are very different from those in the areas where this methodology is currently being tested.

Based on a site visit to a gold operation located close to the Arctic Circle, and a lead-zinc and silver concentrator located on Baffin Island, in conjunction with a desk assessment of mining operations north and south of Great Slave Lake, it is .the overall objective of this work to evaluate the Ecological Engineering concepts and the applicability of them for mines in the Northwest Territories.

Realistic environmental scenarios were developed for the two mine sites to which field visits were made, and these could serve as models for future abandonment plans for other mining operations in the North.

2.0 METHODS AND MATERIALS

2.1 The basic concept of Ecological Engineering methods

In general, at close-out of a mining operation, several aspects have to be considered, with particular attention being paid to waste-management areas with acid-generating wastes. One of the most challenging aspects of reclamation is the provision of stable and enduring environmental protection against water quality degradation.

Many ecological studies of plant colonization patterns of mining wastes have indicated that, on waste sites, it is likely that species richness and the extent of the colonization will not change for decades or millennia (Kimmerer, 1981; Bauer, 1973; and Morrison & Yarranton, 1973). Ecological projections indicate that improvements due to natural recovery are unrealistic, despite some initial evidence of primary natural colonization of waste sites. The establishment of species, tolerant to the chemical and physical characteristics of the waste sites, appears to be a random process. Self-sustaining covers on waste areas are often limited to localized areas of the site where conditions happen to be favourable for germination and establishment (Kalin and Caza, 1983). Therefore, methods have to be developed to provide suitable conditions unilaterally favourable for self-sustaining vegetation covers comprised of those highly tolerant species.

Utilizing these observations and recognizing species-specific environmental tolerances of the indigenous biota, it became evident that altering the physical conditions alone, while maintaining waste-site chemistry, would yield more extensive establishment of indigenous populations. Once the germination and establishment phase has been assisted, growth controlling factors can be addressed, and finally, those factors which inhibit expansion of the populations may be dealt with.

After the indigenous populations have been established, a stabilized surface would result, using species which are tolerant to the harsh conditions of the waste site. Those conditions will then improve without maintenance, and further colonization of the new ameliorated habitat is expected. A self-sustaining waste-site ecosystem is thus created which can be either aquatic, semi-aquatic or terrestrial.

Ecological Engineering consists, therefore, of utilizing waste water and organic materials which initially ameliorate those stresses that limit the development of the indigenous populations. Establishment, growth and expansion on the waste-management area can then be expected. Biological polishing addresses water-quality improvements by introducing or promoting populations of specific species which, due to their characteristics, have the ability to remove hazardous substances from the waste-water stream.

Ecological **Engineering is** a three-staged approach:

Stage 1:

A brief feasibility study of the site is carried out to identify the rudimentary ecosystem characteristics, in addition to the determination of the chemical and physical conditions of the surface and water associated with the waste-management area. For areas devoid of species, a suitable source is selected. This feasibility assessment is followed by an experimental test phase for the site-specific conditions.

Stage 2:

Implementation of an experimental approach to ecosystem expansion and development. Experiments and biota are site specific. The experiments are designed based on the results of the feasibility study. The tests consist generally of alteration of the surface, such as irrigation with waste water, increasing surface relief, and the use of amendments for the promotion of the rudimentary pockets of indigenous biota on the site. Algae, mosses, cattails, sedges and rushes are the most frequently encountered indigenous species.

To complete the project, the results from the experimental stage are implemented on a large scale for the site.

Stage 3:

Implementation **of** the results of phase 2 for reclamation of the entire site, followed by gradual withdrawal of the supporting treatment system.

These three steps can be used to address problems of dry or wet, acid or alkaline tailings areas in seepage-water control and in polishing or settling ponds. The methods can be used during mine/mill operation, as a routing reclamation approach and, finally, as an abandonment or shut-down procedure.

2.2 **Mining Operations and their Waste Management** areas

At commencement of a mining operation, there are, in principle, very basic activities taking place. Access has to be provided to the site which can be a permanent or winter road, an airstrip, or both. Construction of living accommodation and warehousing space,.as well as mill buildings, takes place. These activities are not generally associated with significant environmental implications in the long term. They are regulated under the Northern Lands

Act, and are not addressed in the context of this report. This is the case for sewage disposal and waste dumps which are inevitable end products of a mining operation.

At the time of mine closure, all surface structures may be removed and abandonment procedures for below-ground workings are clearly defined so that the site is free of any hazards of a structural nature. From an environmental point of view, regulations commonly specify that the locations of the mining operation be rehabilitated in detail, and these requirements are included, in a general manner, as a condition of the water licence granted by the Water Board.

2.3 Potential long-term environmental implications of components of the waste-management areas.

Long-term environmental consequences after shut-down of hard rock mining operations, considered in this report in the context of Ecological Engineering, are those associated with waste products resulting from the mining. These are the tailings, waste rock, by-products of the waste-water treatment system, and areas where soil or borrow is contaminated with concentrate.

Each of these components of the waste-management area presents its own problems with respect to the possible creation of sources of long-term environmental degradation:

Tailings site:.

Two aspects of the tailings area are of concern at the time of mine closure - (a) the interface between the tailings confinement and the non-tailings environment, and (b) the tailings surface and tailings dams themselves.

Waste-rock piles:

Depending **on** their location within the topography of the site and the mineralogy of the material, these waste-rock piles may not present significant environmental concern. If the waste rock is acid generating however, they are a major factor in the long term. In this case, the implications for surface and ground water quality are similar to those of the tailings.

Waste-water treatment ponds:

At the time of shut-down, the quality of the water leaving the tailings area will change in comparison to the quality at the time of operation. After several years, the water balance of the area and the water quality will be representative of abandonment. Treatment facilities are generally designed to accommodate operating conditions and sludges have accumulated in the settling ponds for some time. These sludges contain high concentrations of the contaminants which were removed from the effluent. On abandonment, the sludges or the by-products of the water treatment can become another potential source of long-term environmental degradation.

Mine/mill site:

At the time of close-out, the immediate vicinity of the mill site for base-metal operations, where shipping and/or storage of concentrate have taken place, requires special attention. Borrow materials (soil or gravel) mixed with concentrate, can be a continuous source of metals which are solubilized during and following precipitation. This holds true for base-metal operations only however, and not for gold mines.

2.4 The environment in which the mine sites *are* located

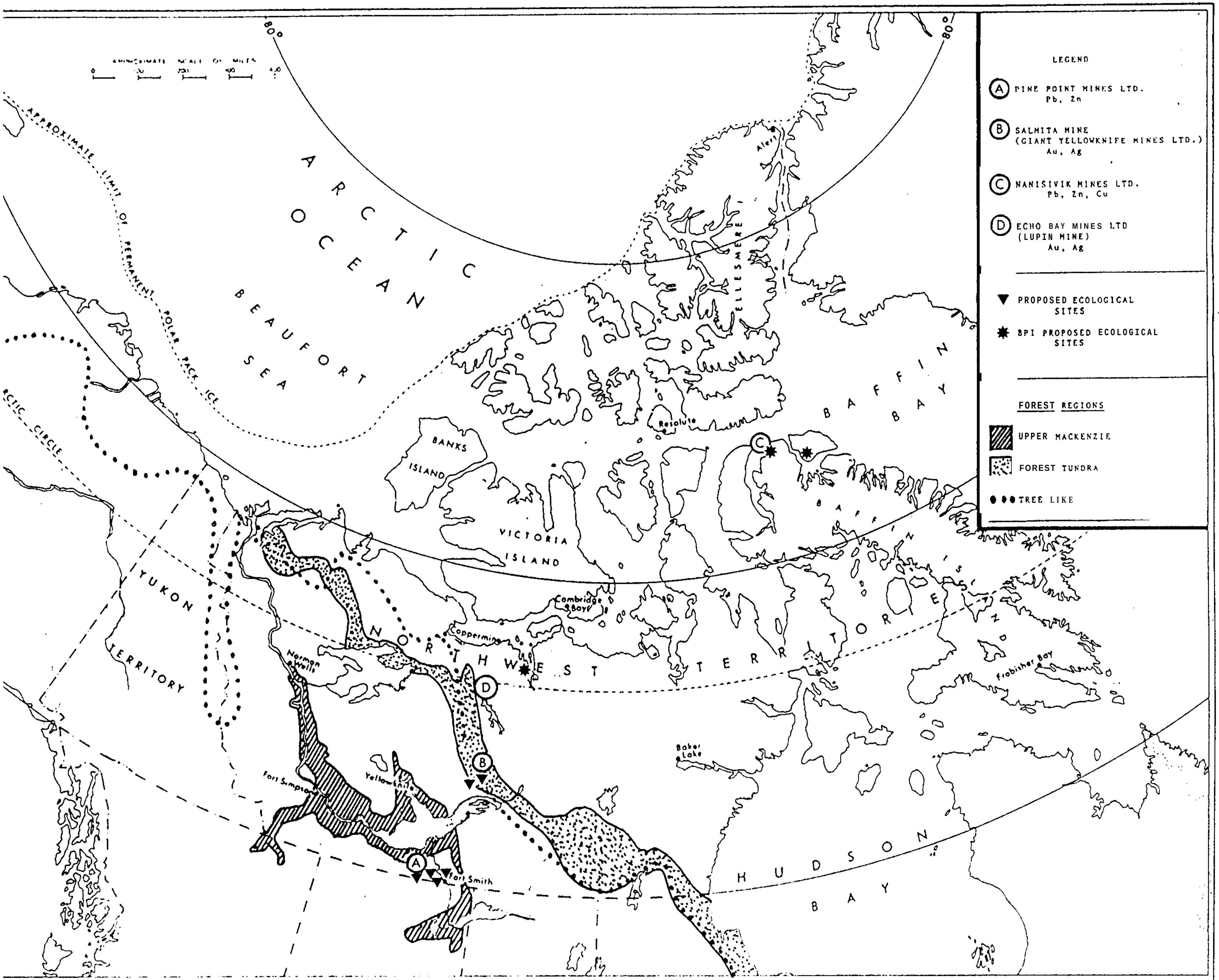
The locations of the mining operations evaluated in this report are given in **Map** 1. The four operations, **Lupin**, **Salmita**, **Pine Point** and **Nanisivik** differ widely according to their location within different vegetation regions.

Pine Point and **Salmita** are both located in forest regions, but with different characteristics. **Pine Point**, south of Great Slave Lake, is surrounded by the Upper MacKenzie forest region. This environment is described by Rowe (1972), **as** dominated by white spruce and balsam poplar on flat alluvial lowlands bordering the rivers, and jack pine, lodgepole pine, trembling aspen, black spruce and tamarack on the highlands.

Salmita is located in the Northwestern Transition of Forest and Tundra. This area is described by the same author as tundra barrens of **bog,** muskeg and rock, intermixed with stands of dwarf trees (black spruce, white spruce, white birch, tamarack, trembling aspen, willow and balsam poplar). The general ground cover is light-coloured foliose lichens. The operations of **Lupin**, located in the Mainland Tundra, and **Nanisivik**, located in the High Arctic Tundra, are situated above the tree line. The Mainland Tundra is dominated by dwarf shrub and heath, sedge tussocks or meadows, willows, lichens and areas of rock desert. The High Arctic Tundra is dominated by rock barrens with sparse vegetation confined to meadows within stream valleys, moss, lichens, wildflowers and willows.

A comparison of the climatological conditions is given in Table 1. The climatological parameters selected are relevant for abandonment if biological processes are to be applied. The averages are compiled from measurements ranging over a period from 1941 to 1960, or 1957 to 1964 (Hare and Hay, 1974).

From the temperature ranges, the differences between locations are relevant. Both Pine **Point** and **Salmita** have similar climatic parameters, as do the operations of **Lupin** and **Nanisivik.** Differences in climate are the main factors affecting growth and the biological processes which could be relevant in the long term. It appears that, based on the temperature, solar radiation, hydrology and growth season, **Nanisivik** is at a distinct disadvantage for the use of biological processes. One of the clear indicators is the annual growing degree-days which are lowest for the area of **Nanisivik** (<500 degree days).



Map 1: Locations of mining operations

MEASUREMENTS	PINE POINT	SALMITA	LUPIN	NANISIVIK
TEMPERATURE				
mean air screen temperature (°C)				
January	-25 to -30	-25 to -30	-30 to -35	-30 to -35
April	-5 to -10	-5 to -10	-10 to -15	-15 to -20
July	15 to 20	10 to 15	10	5 to 10
October	0 to -5	0 to -5	-5 to -10	-10 to -15
mean annual heating degree days (deg.F.days)	17000-8000	8000-9000	9000-10000	NA
mean length of frost free period (days)	70	70	70	70
SOLAR RADIATION				
annual mean global solar radiation (kly)	90-100	80-90	80-90	70-80
" " " absorbed (kly)	60-70	60-70	50-60	30-40
HYDROLOGY				
mean annual measured precipitation (cm)	20-30	20-30	20-30	10-20
mean annual measured snowfall (cm)	120-140	100-120	120	100
mean annual hours of freezing precipitation	25-50	25-50	10-25	10
percentage of above as freezing rain	10-20	10-20	10-20	10-20
mean annual evaporation from small lakes (cm)	41-51	20-30	10-20	NA
mean annual run-off (cm)	12.5	12.5-25	12.5-25	2.5-12.5
GROWTH SEASON				
mean annual growing degree days (deg.F.days)	1500-2000	1000-1500	500-1000	<500
annual mean hours of bright sunshine	1800-2000	1800-2000	1400-1600	1400-1600

Table 1: Climatic characteristics of minesite regions

However, for the other three operations, these climatic considerations indicate that biological processes cannot be entirely dismissed for the Northwest Territories. They should continue to function though at reduced rates when compared to more southern regions. In **Table** 2, values describing net primary production of various ecosystems are extracted from a tabulation by **Larcher (1980).** For the regions in which **Salmita** and **Pine Point** are located; the net primary productivity value would be between the Boreal Forest, with 700 $g/m^2/yr$ and the Tundra Alpine productivity of 140 $g/m^2/yr$. The value range for **Lupin** and **Nanisivik** would be between 140 $g/m^2/yr$ and 3 $g/m^2/yr$. The values for biomass and chlorophyll given in **Table 2**, will be represented by the same ecotypes for the primary productivity.

ECOSYSTEM	NET 1 PRODUCTION mean (g/m2/yr)	BIOMASS DRY MATTER mean (kg/m2)	CHLOROPHYLL mean (g/m2)
Temperate forest			
evergreen	1300	35	2.5
deciduous	1200	30	2
Boreal forest	800	20	3
Woodland and shrubland	700	6	1.6
Tundra and alpine	140	0.6	0.5
Extreme desert, (rock, sand, ice)	3	0.02	0.02

Source: Larcher, W. 1980. Physiological Plant Ecology. Springer-Verlag, New York. 303pp.

Table 2: Net primary production by Ecosystem Type

Although the productivity of the northern ecosystems might not be high, evapo-transpiration from a tundra ecosystem is estimated at around 55%, while drainage accounted for 45% of the annual precipitation of 18 cm, according to the values given by **Larcher (1980)**. That annual precipitation is in the same range (20 - 30 cm) as that given for the regions in which the mine sites are located **(Table** 1).

Water management is one of the main concerns at the time of close-out. The function, therefore, of a biological polishing system in evapo-transpiration is significant when considering its potential effect on the water balance during the growing season. This season is of most concern in water-quality protection, as in the remainder of the year, a large fraction of the potentially contaminated water is frozen, and further contamination is minimal due to greatly reduced flows. The applicability of Ecological Engineering and Biological Polishing processes in the Northwest Territories will depend, therefore, on the presence of functional species. The emphasis of field investigations was placed on the search for suitable indigenous ecosystems in areas immediately associated with the waste material.

3.0 RESULTS AND DISCUSSIONS: MINE SITE ASSESSMENTS

3.1 Lupin operation background

In order to give some background on the site, the following are some essential characteristics of the mining operations:

Location:

The mine is located on the west shore of Contwoyto Lake, 400 kilometres northeast of Yellowknife, N.W.T.

Ownership:

Lupin is the primary property of Echo Bay Mines Limited.

Metals Recovered:

Gold and minor amounts of silver.

Ore Reserves:

As of December 31, 1985, the proven and probable reserves to the 1,312 foot level were 2,725,000 tonnes, averaging 0.34 ounces per ton.

History:

In 1960 to 1963, Inco performed an extensive surface exploration and drilling program on the property. Echo Bay Mines Ltd. optioned the property in 1979, and started construction of an underground ramp. Production began in October of 1982 at an initial rate of 975 tons per day, with access by a shaft to 1,210 feet, and by ramp to 820 feet. In 1983, the milling capacity was increased to 1,450 tonnes per day. In 1987, the shaft was deepened to 792 meters.

Geology and Mineralogy:

Gold is found in an iron/sulphide formation within a highly folded amphibolite lens. 10 to 15% of the ore is quartz, which occurs as stringers and veins up to 1.5 meters in width. The ore also contains up to 15% pyrrhotite, 3 to 4% local arsenopyrite, and trace amounts of pyrite, scheelite and chalcopyrite.

Milling Process:

The milling process is straight cyanidation, with gold recovery by the Merrill-Crowe process (through Zn precipitation). The ore is ground to about 80%, minus 200mesh, and pre-aerated to oxidize the surface of pyrrhotite. After thickening, the gold is extracted with cyanide in a series of agitators. Pregnant liquor is recovered by two-stage filtration, and the solids are repulped and pumped to a waste pond. The gold is precipitated from the pregnant solution with Zn dust. The precipitate is filtered and smelted into bullion.

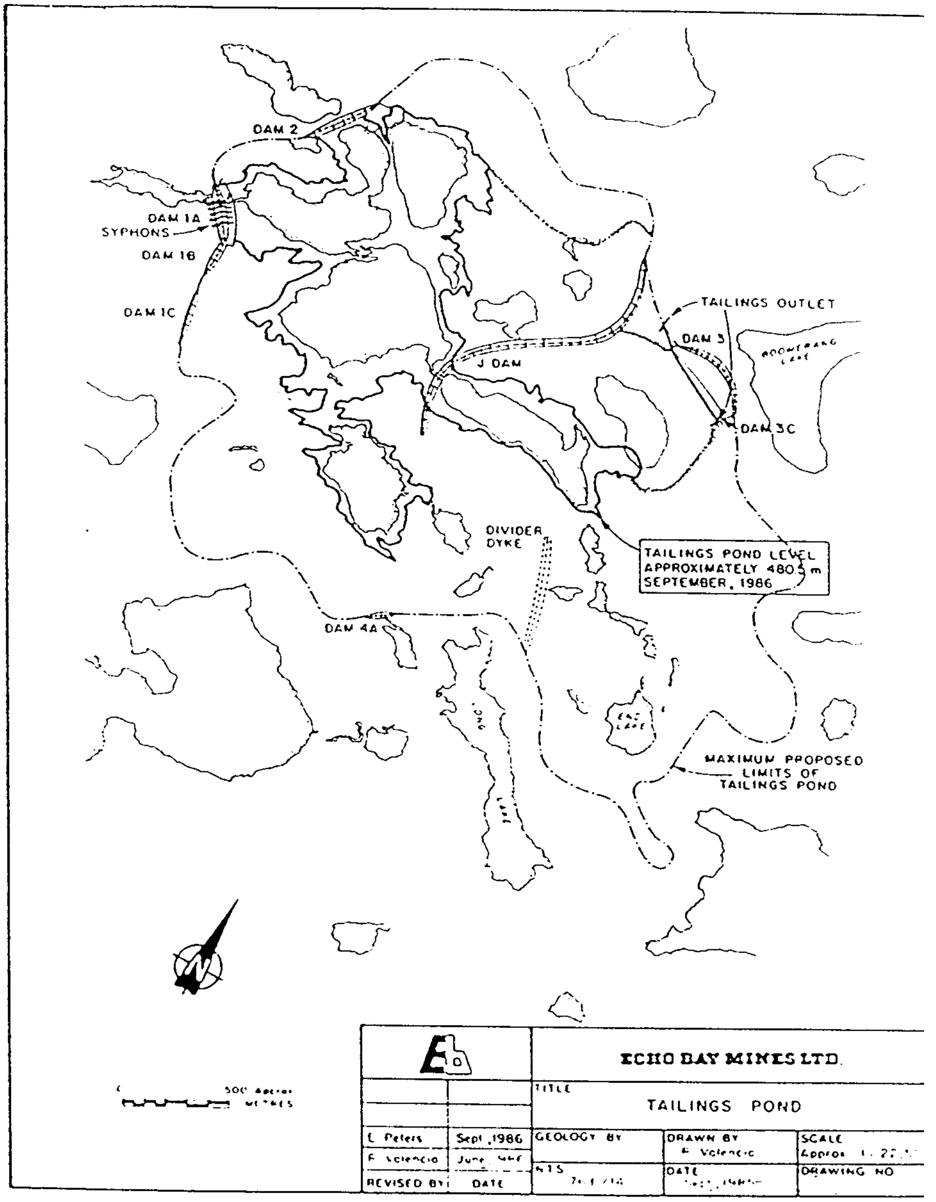
Annual Tonnage Milled and Production:

1982 - 145,000 tonnes
1983 - 323,000 tonnes
1984 - 494,000 tonnes
1985 - 568,000 tonnes
1986 - 557,000 tonnes

Total mined to date = 2,087,000 tonnes with a gold production in 1985 of 195,137 ounces, and a recovery rate which averaged 95.5%.

Tailings:

The gangue minerals consist mostly of amphibolite and quartz, which are inert. The sulphide minerals present, pyrrhotite, arsenopyrite, pyrite, and chalcopyrite, are subject to oxidation. Mine water contains sodium chloride (common salt) used to prevent freezing during drilling in the permafrost. The process reagents include hydrated lime, sodium cyanide, zinc dust and lead nitrate. An overview of the waste management area is given in Map 2.



Map 2: Overview of Lupin waste management area

3.2 Field investigation of Lupin

The site visit was carried out in mid-September, 1986, at which time a slight snow cover already existed. The following aspects of the waste-management area were found to be relevant to the close-out conditions.

Lupin is a gold operation, and the mine/mill area is not of concern. Therefore, only the tailings area, which has been planned to accommodate the tailings for the entire period of the mine life, needs to be addressed in terms of abandonment.

The waste-management area is well-defined within containment dams. The method of discharging the tailings into areas confined by divider dykes or dams to retain solids is well suited for the topography, and facilitates rehabilitation work during operations of the waste-management area. In the future, the dams will be raised to a higher level, ultimately providing a surface drainage pattern which is intended to flow towards Dam 1A **(Map 2).**

The interface between the dams and the non-tailings environment consists of waste rock. Two major vegetation types could be identified - hummock/hollow and a sedge/grass meadow. A reed-grass is naturally colonizing areas within the waste-management area (roadsides and dams), which were covered with material obtained from an esker. This observation serves as an indicator that recovery by indigenous species at this site does occur.

The micro-topography includes interesting stone structures, referred to as tombstones. These types of stone structures provide favourable microhabitats for 'indigenous vegetation. Most cracks are filled with dense cushions of moss.

Water bodies and creeks in the vicinity of the waste-management area are colonized by a dense periphytic community consisting of diatoms (*Eunotia, Fragilaria, Navicula, Pinnularia* and *Stauroneis*), and algae. Unicellular algae are *Chlorella* and *Chlamydomonas* and filamentous forms are *Mugeotia* and *Stigeoclonium*. It is possible that these filamentous forms could serve as biological polishing agents. These groups have also been found in association with southern mine sites.

In the outflow of Dam 1A, the periphytic community was present, but not as dominant as in other water bodies. A sparser population of periphytes would be expected in the discharge stream from the waste-management area, A more detailed investigation of the receiving waterways might yield more information on indigenous species, particularly when carried out during the snow free period.

Water quality, in relation to tailings and waste rock, requires some consideration. The pyrrhotite content in connection with the fine grind of the tailings could result in some undesirable surface characteristics. Some indications of oxidizing surfaces were noted on exposed tailings.

During the summer season, the tailings surface could be hot and dry, possibly facilitating wind transport; In the winter, the surface is frozen and snow-covered. Therefore, microbial oxidation of tailings is expected to occur for a very short period during the year. The pH measurements from the sampled tailings and associated water bodies ranged from 6.6 to 8.1, and the electrical conductivities from 120 to 1600 umhos/cm, indicating that the pH of the operating environment is neutral to alkaline. Acid generation is not evident.

The usage of waste rock and/or Esker is proposed for the final cover for the tailings. This might facilitate water retention under the waste-rock to some degree. Determinations of the water quality of run-off from underneath such a waste rock cover would be difficult, if not impossible. Some indication however, might be derived from long-term static-leach experiments, which were carried out, in the framework of this study, in the laboratory.

3.3 Long-term leach experiments

3.3.1 Method:

In November, 1986, 1 kilogram of tailings (fresh weight) was set up in a static-leach experiment with 1 litre of tap water. Two sets of containers of each were stored in the fridge (6 - 8°C), outside (frozen during winter) (15°C), and at room temperature in the dark (21 - 23°C). The pH in the tailings and the water above was measured 5 times over a 6-month period in each container stored at the different temperature regimes. All containers were remeasured after 1 year. After 3 to 6-month intervals, the water was filtered through 0.45 um filter, acidified with nitric acid and analyzed for total element concentrations by Inductively Coupled Plasma Spectrometry with Assayers (Ontario) Ltd.

3.3.2 Results:

The trends in pH in both solution (Figure la) and tailings (Figure 1b) are quite constant until May, representing a period of 6 months leaching. A decrease in pH (from 7 to 6.2) was measured in the containers stored in the laboratory at room temperature. At the cooler temperatures in the refrigerator and outside, no significant decline was noted.

After a period of one year, the water and the tailings in all temperature regimes indicated that acidification was progressing. Both the tailings and the solutions had a pH of 5 and 4.8, respectively, in the laboratory. The pH in containers kept outside and in the refrigerator had decreased considerably less.

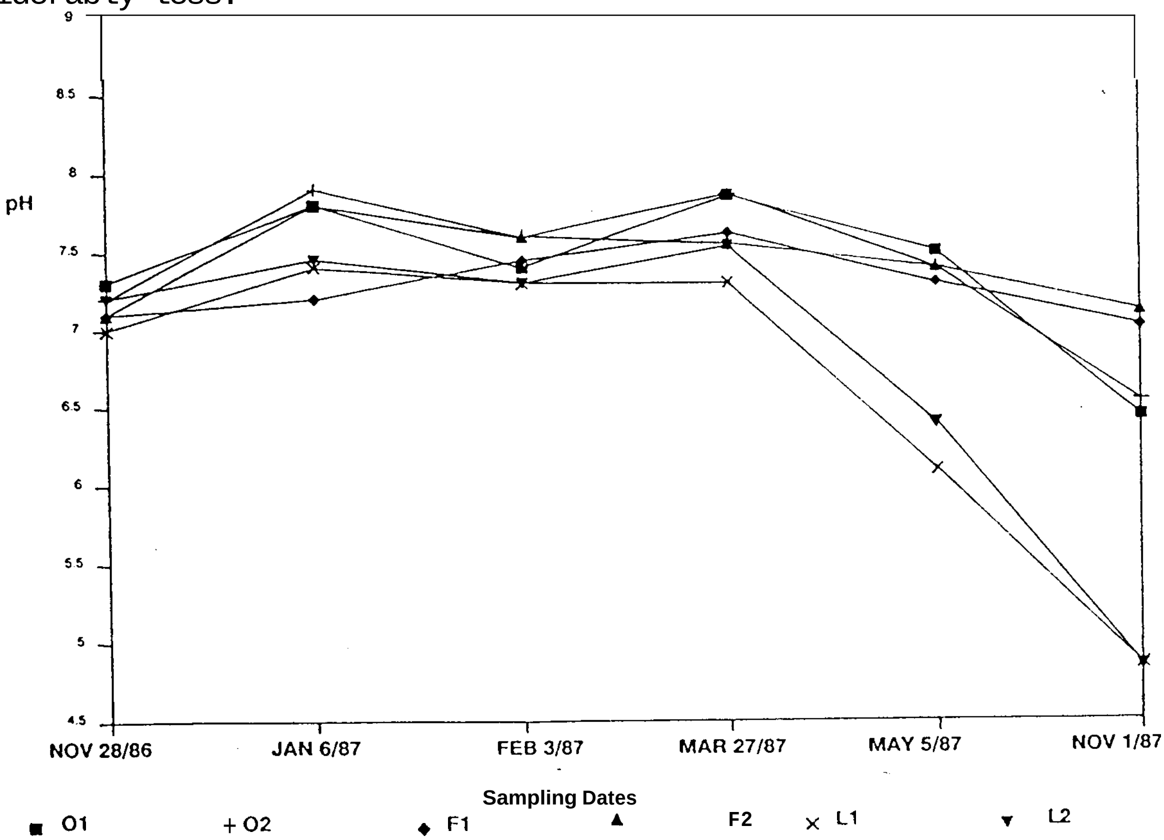


Figure 1a: pH values of water above the tailings.
Replicates are indicated by 1 and 2, and the temperature treatments are designated as O = outside; F = refrigerator, and L = laboratory

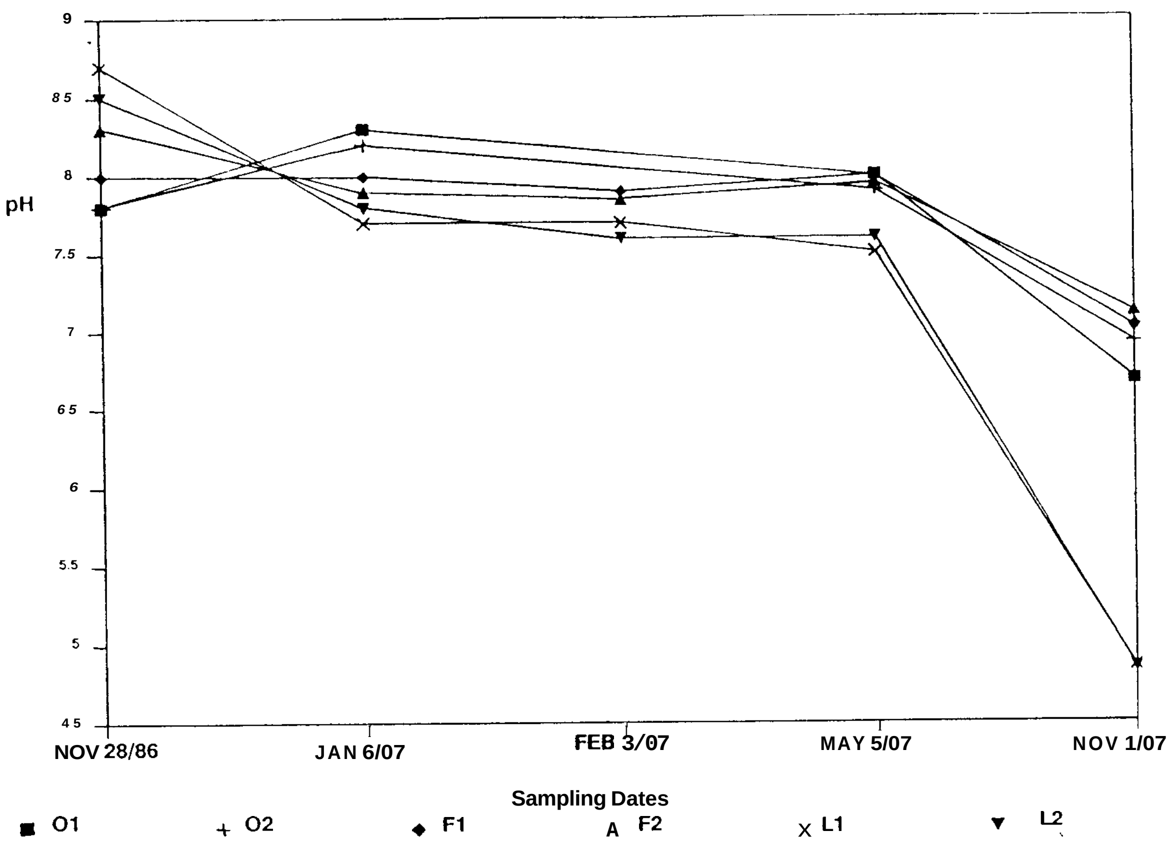


Figure lb: **pH values of tailings sediment**
Symbols as in Figure la.

Given the experimental design, these pH values indicate that acidification of water in contact with **Lupin** tailings is dependent at least in part on temperature. This acidification process is an extremely slow one when compared with base-metal tailings of similar pyrrhotite content where water acidifies within days, or at most, weeks. It is unlikely that water under the waste-rock/Esker material cover planned for close-out will reach temperatures warmer than room temperature and it is therefore unlikely that acidification is ‘arealistic possibility in the future.

The electrical 'conductivityof the solution remained essentially in the same range over the entire period of the experiment **(Figure** 2). This suggests that no solutes are stored in the tailings which increased electrical conductivity after the initial release to the tap water (270 umhos/cm) had occurred. The small differences noted (1,200 to 1,600 umhos/cm) are probably also a reflection of the temperature change.

The elemental concentrations in the water sampled after 6 months of static leach are presented in Figures 3a to 3c. For each solution, the average of two replicates of filtered (0.45 um) water is compared with that of the average concentration of unfiltered water. The three pairs of bars per element in the histogram represent the different temperature regimes of the experiment.

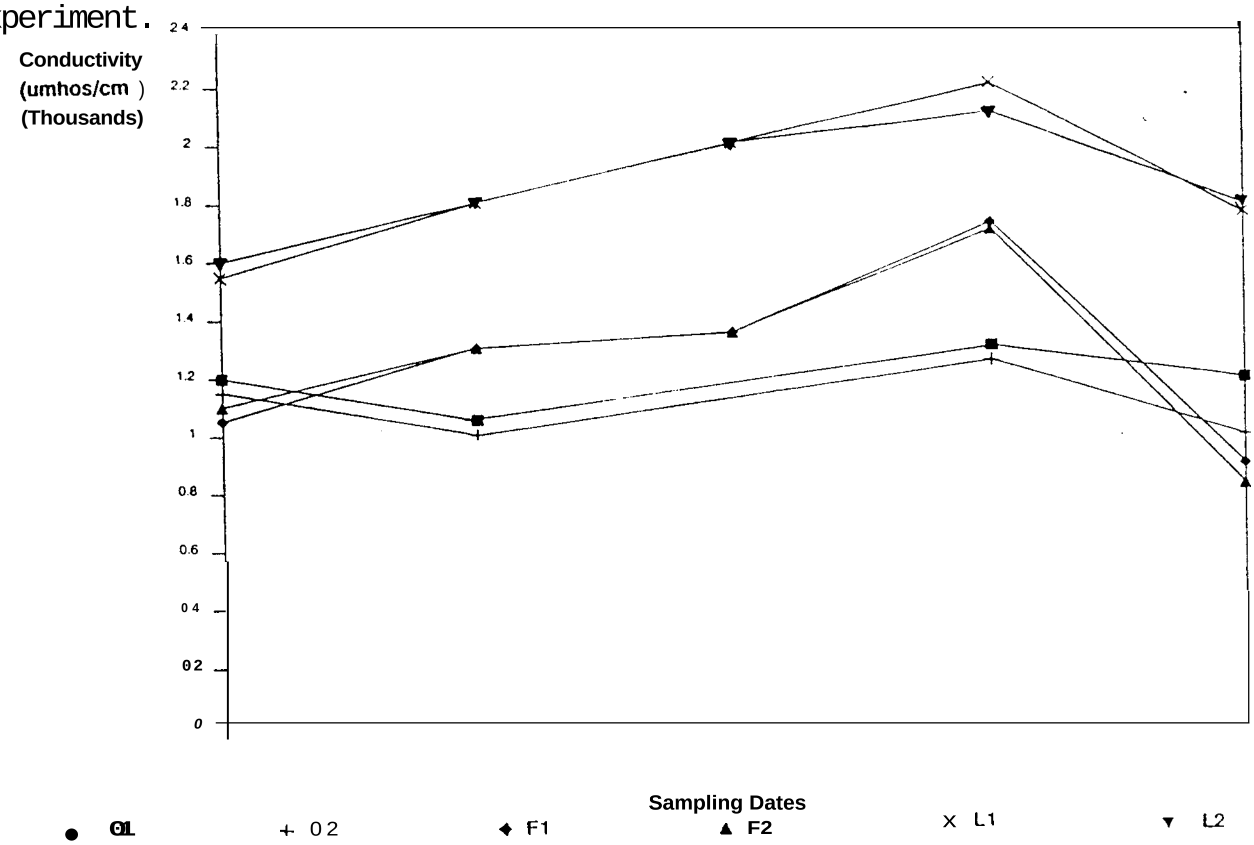


Figure 2: Electrical conductivity in leach experiment
Replicates are indicated by 1 and 2, and the temperature treatments are designated as O = outside: F = refrigerator, and L = laboratory

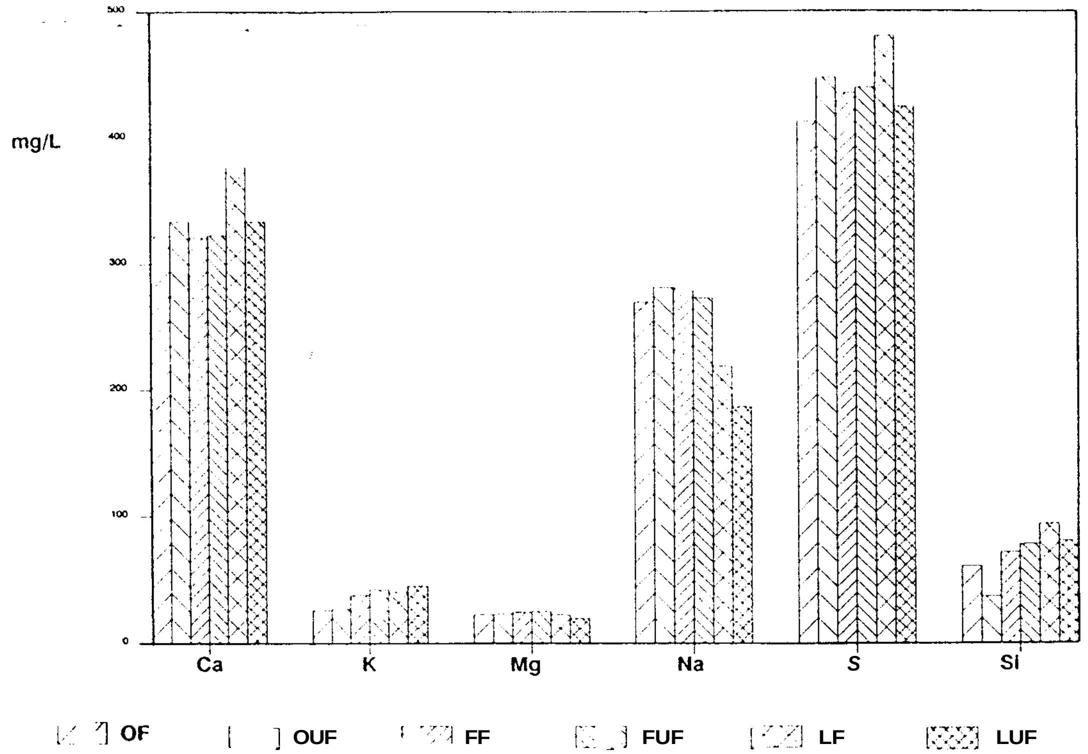


Figure 3a: Elemental Concentrations in Solution

OF = outside filtered OUF = outside unfiltered
FF = refrigerator filtered FUF = refrigerator unfiltered
LF = laboratory filtered LUF = laboratory unfiltered

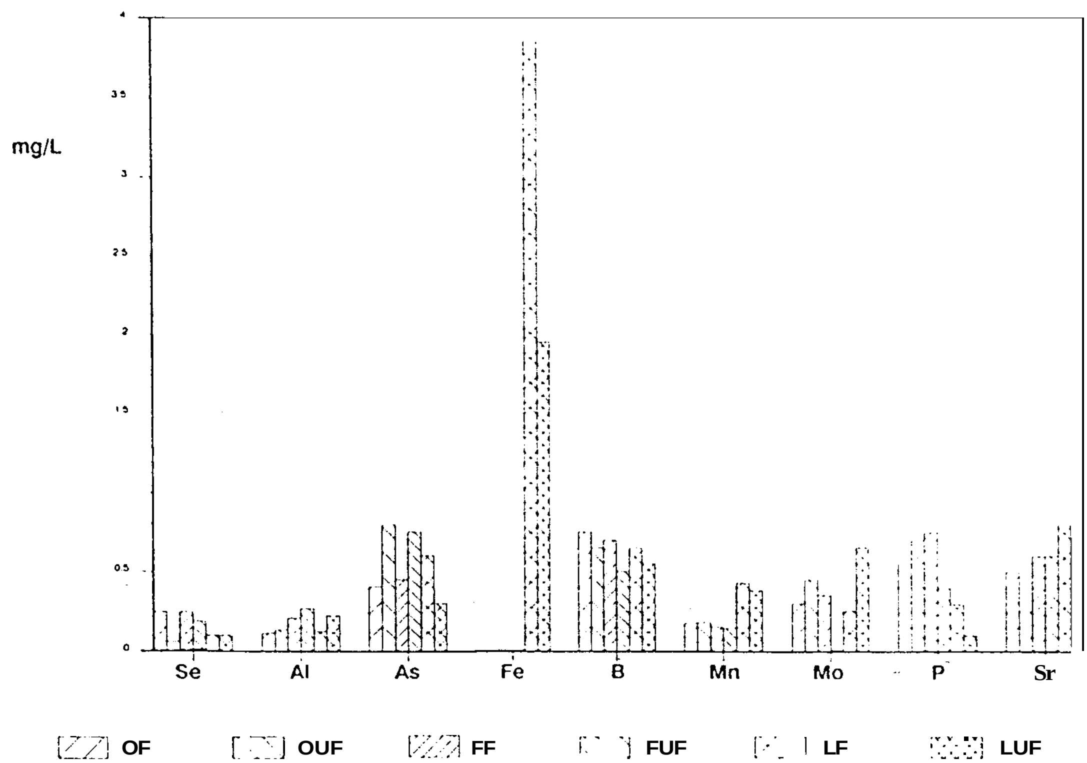


Figure 3b: Elemental Concentrations in Solution
Symbols as in 3a

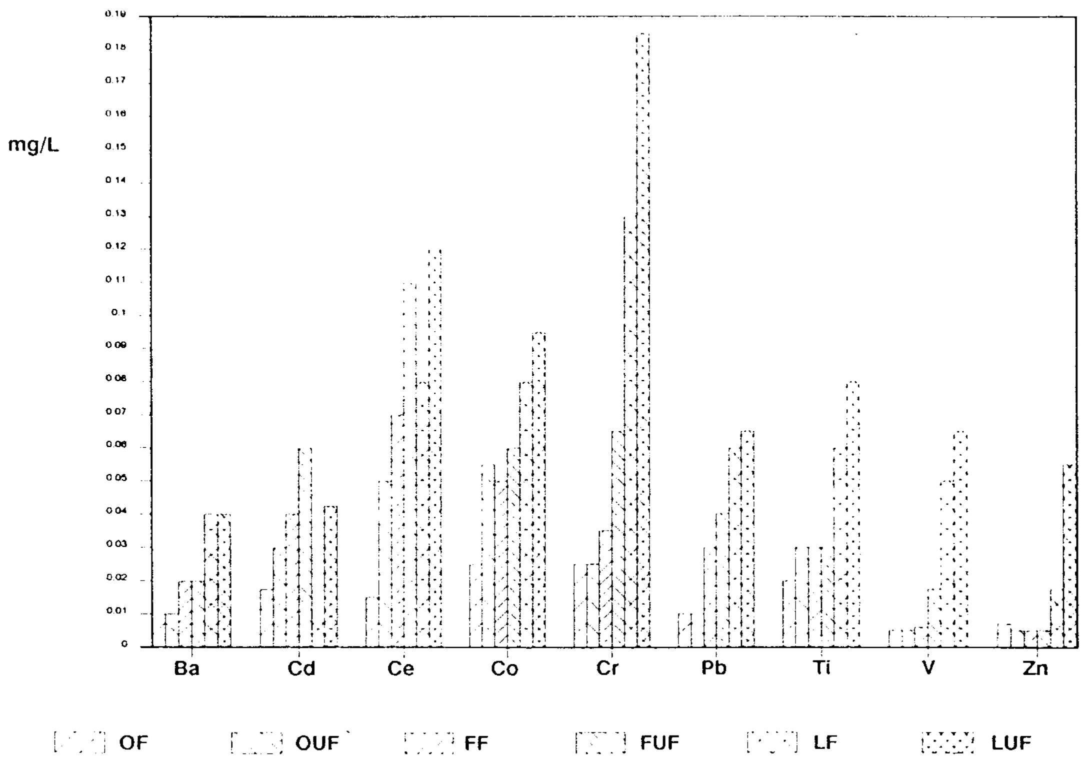


Figure 3c: Elemental Concentrations in Solution
Symbols as in **3a**

If the concentration of the elements is less in filtered than in unfiltered samples, these differences would indicate that the elemental concentrations are due to the presence of both the suspended particulate and the dissolved form of the element. As this experiment was designed to show trends of solubility of elements from the tailings to water being ponded underneath the waste rock cover, this aspect is essential to the evaluation of the data. The concentration differences between filtered and unfiltered water samples for each temperature treatment for most elements are insignificant **(Figures 3a** to 3c). The variability noted is within the experimental error expected, due to heterogeneity of the tailings and the analytical error. Iron is an exception, where the unfiltered concentration in the laboratory treatment is 'half of the filtered, representing contamination of the filtered sample. In the other two temperature treatments, the iron concentration was at the detection limit (<0.01 mg/l).

The elements are .grouped based on their concentration ranges. Ca, K, Mg, Na, S and Si (Figure **3a)** are present in concentrations ranging from 40 mg/l to 500 mg/l. The elements Se, **Al**, **As**, B, Mn, Mo, P and Sr in Figure **3b** are present in the solution below 1 mg/l, a lower concentration range than the elements in Figure **3a** (with the exception of iron). The elements Ba, Cd, Ce, Co, Cr, Pb, Ti, V and Zn are present in even lower concentrations than the previous two groups (Figures 3a and **3b**), with concentrations below 0.2 mg/l. Within these low concentration ranges, the expected trends of solubility due to the combined effects of temperature and acidification are clearly displayed. All concentration pairs of filtered and unfiltered waters are higher in the laboratory treatment. From this comparison, it is reasonable to suggest that most elemental concentrations in the water are dissolved elements or of a particle size smaller than 0.45 um.

In Figures **4a** to **4c,** the concentrations of elements in the solutions (filtered) are presented, comparing any differences between the analysis carried out in March with that in May. **As** the same solution remained in contact with the tailings and the containers were sealed tight to prevent evaporation, changes in concentration over time would indicate which elements are more likely to continue to be released to the water than others. **As** the experiment is not a kinetic but static design, differences noted would only indicate which elements are potentially released over time.

The elements Ca, K, 'Mg, Na, *s* and Si do not show any significant changes with time in the concentration in the leach water **(Figure 4a).** However, the elements **As** and Mo **(Figure 4b)** consistently show decreases in all temperature treatments after *3* months.

On review of the data base, it was noted that U was inadvertently missed during data analysis. The concentration range of uranium for the 3-month analysis in all temperature treatments was 1 to 2.2 mg/l, which decreased consistently by May to a concentration range of <0.01 to 0.8 mg/l.

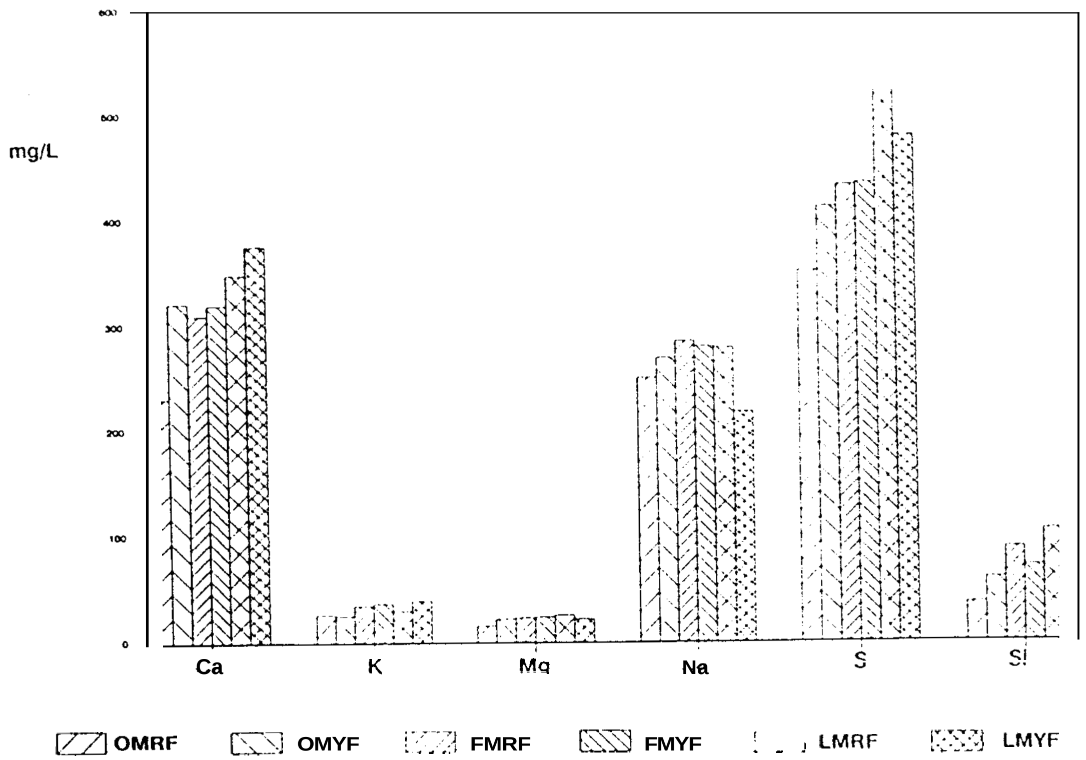


Figure 4a: Elemental Concentrations in Solutions

LMRF = outside March filtered
FMRF = refrig. March filtered
LMRF = laboratory March filtered
OMYF = outside May filtered
FMYF = refrig. May filtered
LMYF = laboratory May filtered

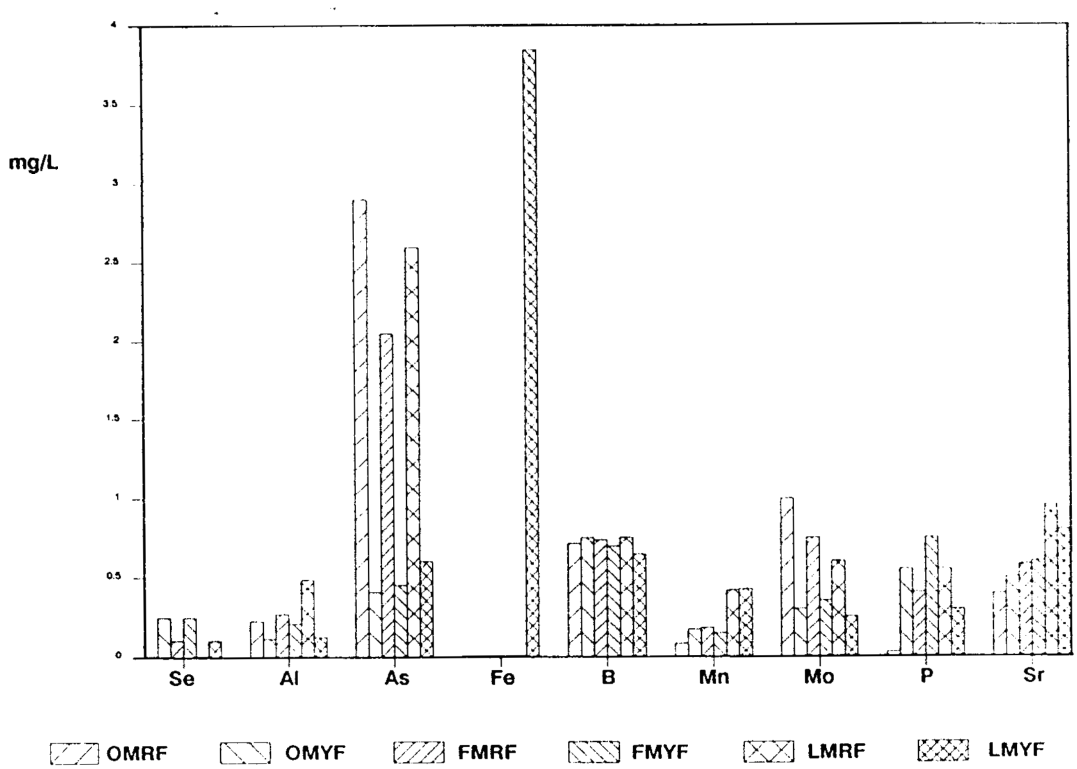


Figure 4b: Elemental Concentrations in Solutions

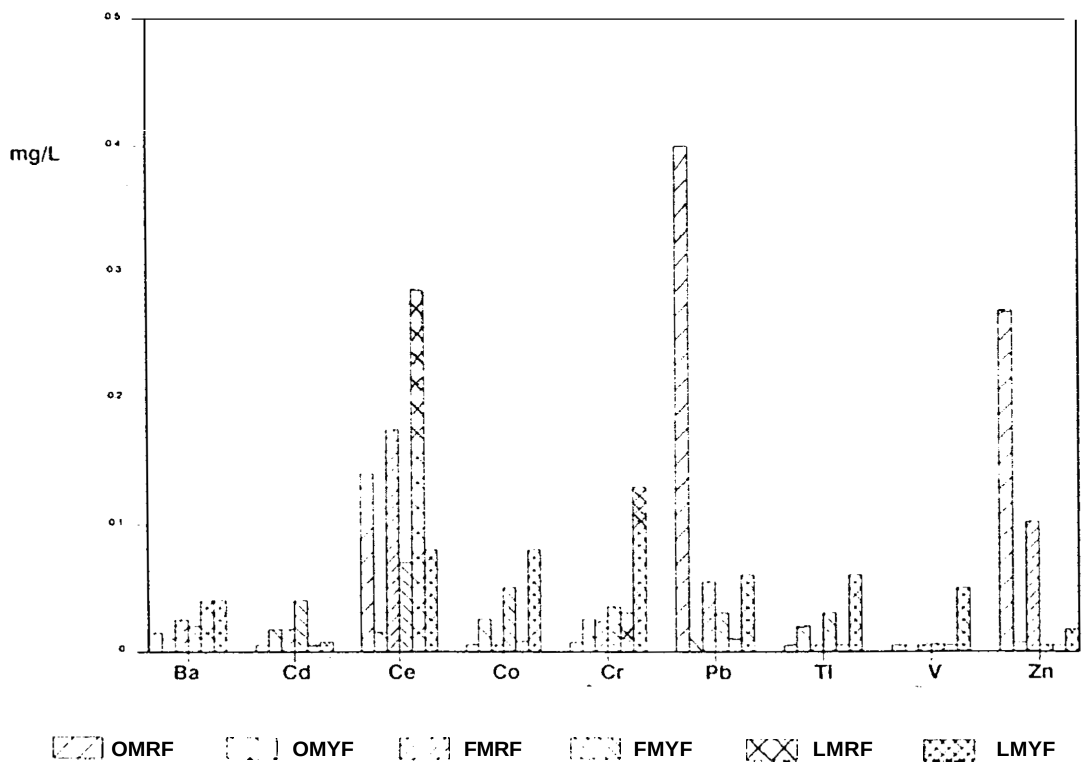


Figure 4c: Elemental Concentrations in Solutions

The removal process of these three elements might be microbial and chemical or physical, and cannot be explained within the context of this experiment. From a pragmatic point of view, the process is less important than the fact that it does occur consistently throughout all temperature treatments.

Similar observations on the removal of As were made in tailings leaching experiments carried out by Echo Bay, (p.c. H. Wilson), with pond water and distilled water under agitation, at different time intervals (weekly and monthly), addressing the behaviour of As. In the monthly tests, the pH dropped and As was removed from the solutions. Both leaching tests, static and with agitation, suggested slight acidification of water in contact with tailings. The temperature however, as indicated by the static leaching test, will inhibit the acidification process considerably.

The elements present in concentrations below 0.5 mg/l (Figure 4c), Ba, Cd, Ce, Co, Cr, Pb, Ti, V and Zn, show irregular patterns with time and with treatment. Exceptions may be the elements Ce, Pb and Zn, all indicating in two temperature treatments, lower concentrations after 3 months. It could be argued that this might be expected, given the experimental conditions of the static leach, but on the other hand, it may also indicate that indeed the leachability of elements from the tailings is curtailed with time. None of the elements determined in the scan analysis (40) increased over time, and those not present were at the detection limit. The metals Hg <0.01 and Ni <0.01 were also determined, but present below their detection limits with Inductively Coupled Plasma Spectroscopy. The elements given in Figures 3 and 4, were those which could be determined in the water in most treatments at concentrations consistently above the analytical detection limit.

The data obtained in the long-term leaching experiments therefore, suggest within the limits of the experimental design, that the elemental concentrations in water in contact with tailings from the Lupin operation appear to indicate no significant water-quality problem in the long term. However, the importance of the cold temperatures in the tailings is clearly indicated by the static leach experiment. The trends due to temperature treatment are consistent over time and therefore emphasize the environmental implications noted for the acidification.

3.4 Nanisivik operation background

The mining characteristics of the Nanisivik operation are:

Location:

The mine is located on Strathcona Sound on the northern tip of Baffin Island.

Ownership:

Nanisivik Mines Ltd. is a wholly owned subsidiary of Mineral Resources International Limited. MRI increased its interest by purchasing 6.5% of Nanisivik stock owned by Kidd Creek to bring MRI's interest to 59.5% as of March 31, 1985. Subsequently, MRI purchased a further 11.25% interest from Metallgesellschaft Canada and Billiton Canada. In 1986, Nanisivik purchased the 18% interest of the Government of Canada.

History:

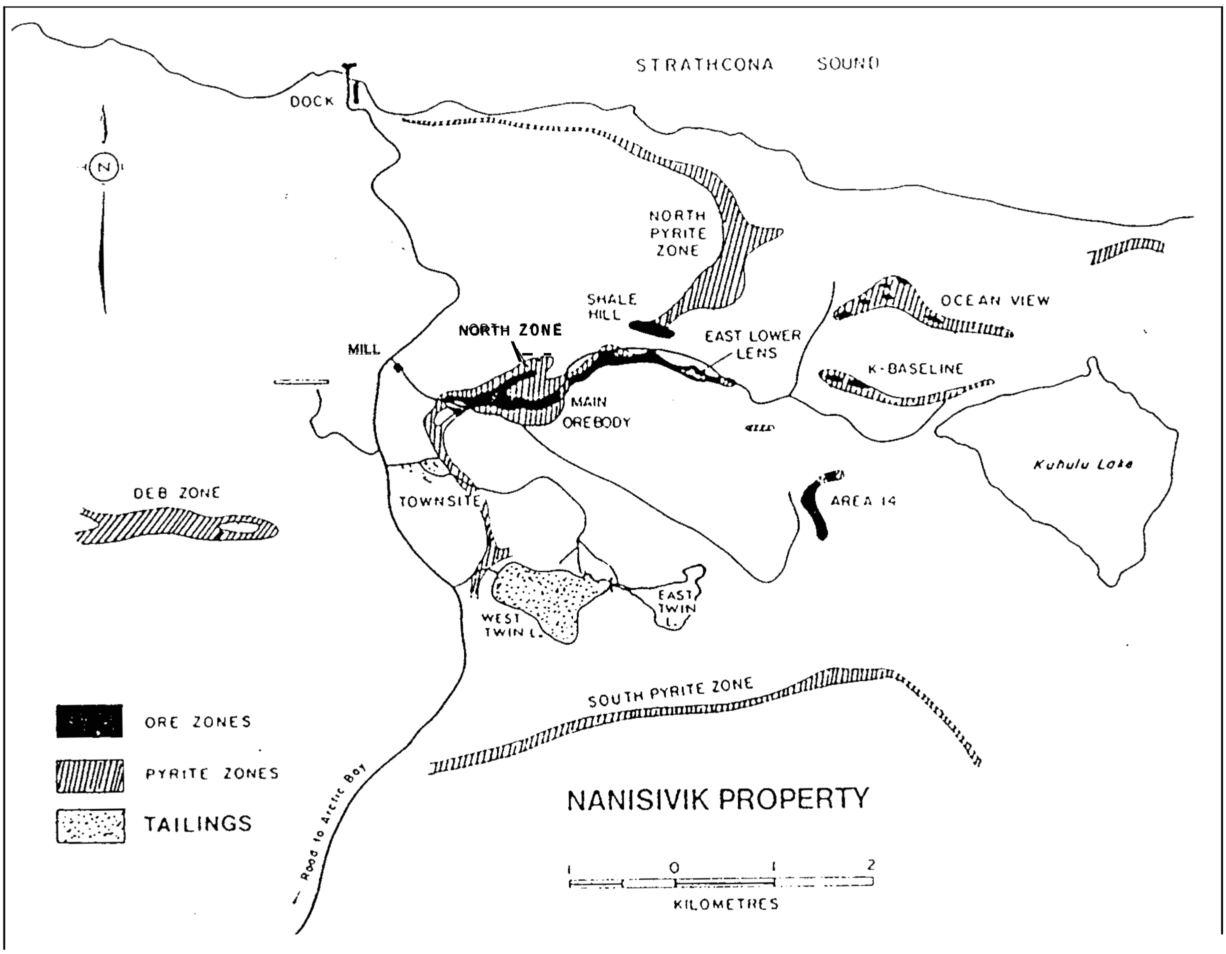
Ore treatment/concentrate production began by the end of September, 1976. On the 6th of December, 1976, an underground fire disrupted mining activities.

Mining was extended in 1984 .to a new deposit. discovered in 1982, located 5 km from the mill site where ore grades are above average. Mining also commenced in a new sulphide zone lying approximately 50 m below the main ore body.

Tailings:

By April, **1977,** the mill was treating 1,630 tonnes per day, which represents the average milling rate of the operation. By **1986,** this mine had produced about 4.5 million tonnes of tailings which assays an average 0.55% Zn, **0.08%** Pb, 36.3% Fe and **13** g/tonnes of Ag.

Tailings, recycle water and potable water is transported through a triple pipeline. Process water is recycled from the tailings area, West Twin Lake, located **3.7 km** from the concentrator. Fresh water is drawn from East Twin Lake located half a kilometer further east. **An** overview of the property indicating the tailings location and other relevant aspects of the site is given in **Map** 3.



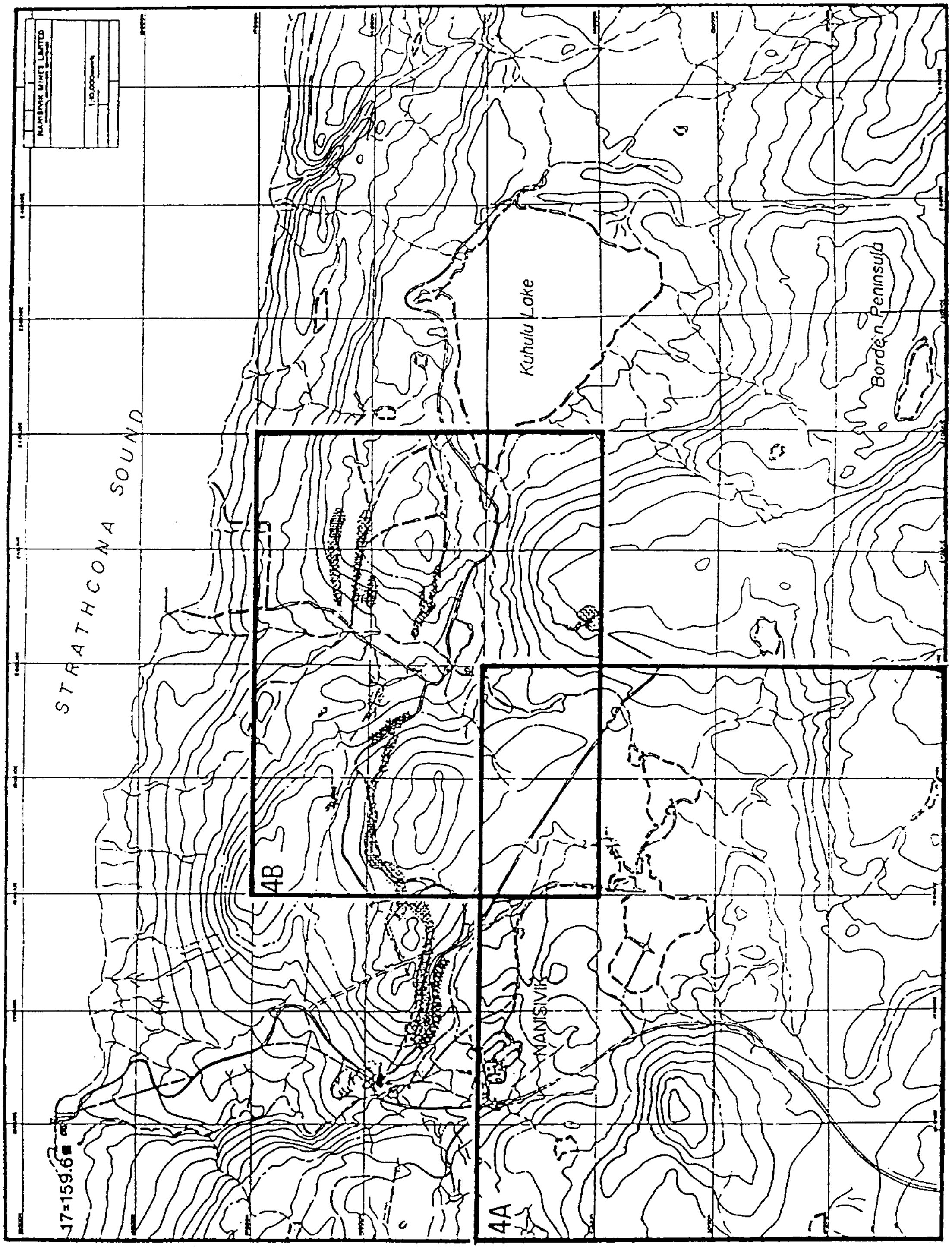
Map 3: Overview of Nanisivik Mineralization

3.5 Field investigation

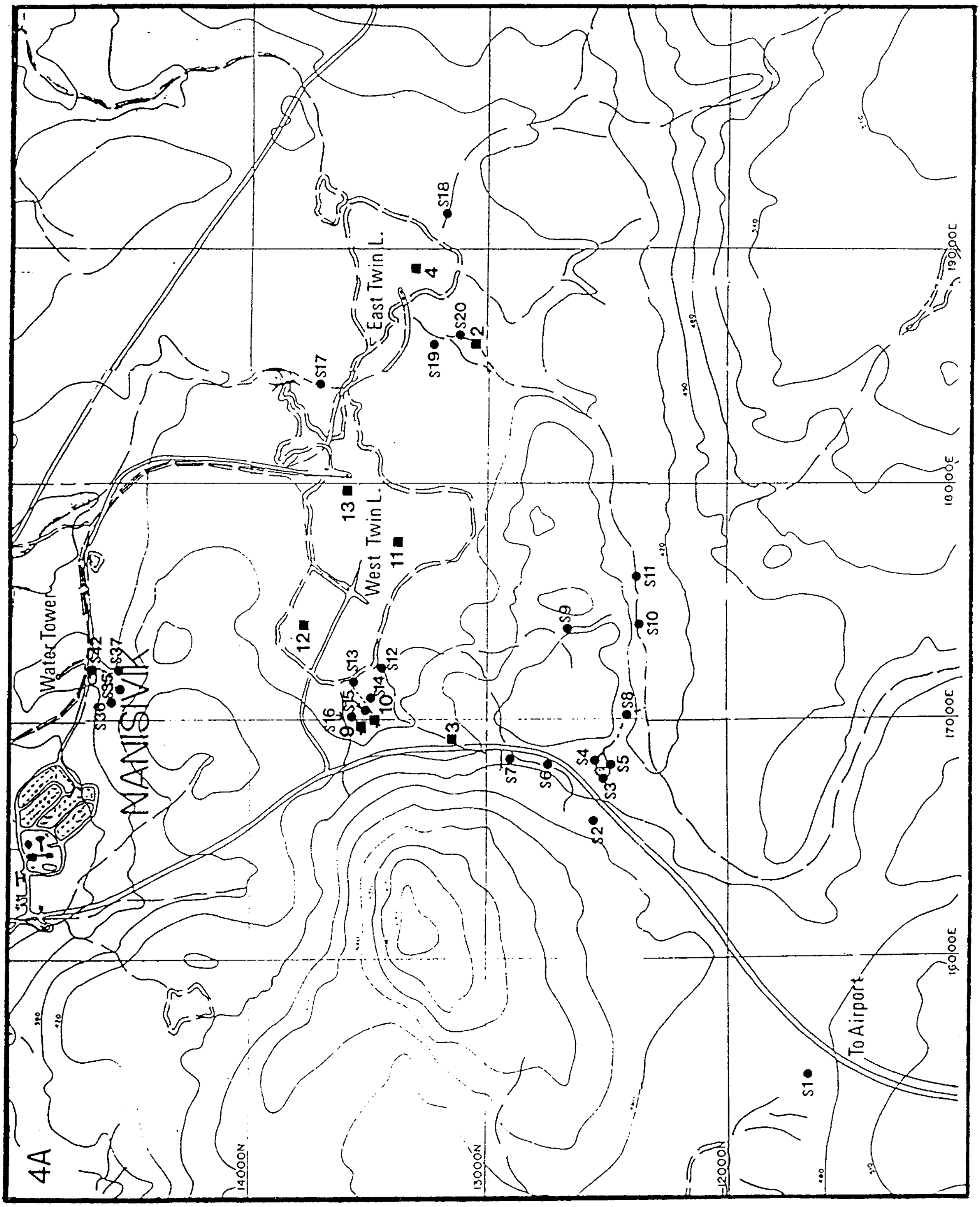
The landscape at Nanisivik is dominated by the presence of rocks and ice. The mining activities are barely noticeable, as adits, rock piles and some colourful pipelines appear as minor changes to the landscape of this rock dominated environment.

A characteristic of this area is the Occurrence of unmineralized and mineralized pyrite zones **(Map 3)**. An evaluation of areas where acid generation might occur under natural conditions unrelated to the mining activities, and areas where the same phenomenon occurs as a result of exposure to mining activity, is of interest. The environmental conditions which may prevail after shut-down of mining operations can be obtained from an understanding of the natural processes which take place in the pyritic exposed areas. The investigation was therefore functionally divided into two groups **(Map 4)**: natural conditions surrounding the tailings basins (Map **4a)** were described and then compared with areas with mining and exploration activity **(Map 4b)**.

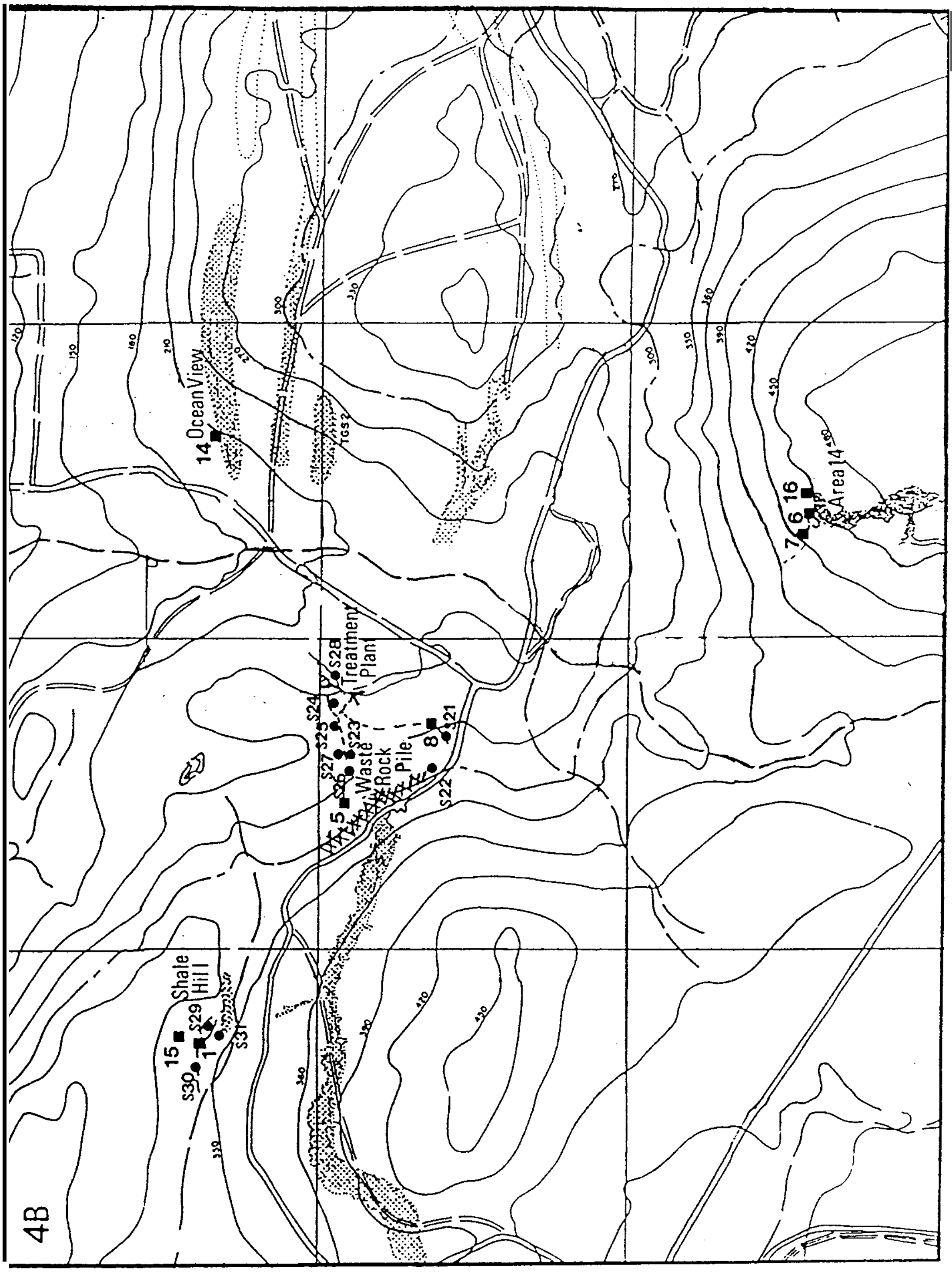
In **Table** 3, the values of measurements of pH and electrical conductivity in the East and West Twin Lake watersheds are summarized, together with those obtained in the vicinity of the waste-rock pile, the treatment plant in Shale Hill area, and around the water tower. The locations where the measurements were obtained are indicated on **Maps** 4a and 4b (code *S*). The creeks with small quantities of running water were differentiated on the basis of the presence or absence of pyrite showing. The creeks were followed downstream until they reached a major water body or until the creek disappeared into the ground.



Map 4: Overview of selection of investigated areas.



Map 4a: Sampling locations in West and East Twin Lake drainage basins



Map 4b: **Sampling locations in mineralized areas and those subjected to mining activity**

CODE	LOCATION	pH	COND. (umhos/cm)	TEMP. (°C)
	WEST AND EAST TWIN LAKE WATERSHEDS			
S1	WEST TWIN L.	6.5	120	a
S2	WEST TWIN L.	5.4	20	1
S6	WEST TWIN L.	5.6	30	6
S7	WEST TWIN L.	5.6	20	1
S12	WEST TWIN L.	7.5	150	4
S14	WEST TWIN L.	7.7	350	-
S13	WEST TWIN L. PYRITE	7.1	1000	5
S15	WEST TWIN L. PYRITE	7.9	800	-
S16	WEST TWIN L. PYRITE	3.9	1300	5
S3	EAST TWIN L.	5.9	140	6
S4	EAST TWIN L.	6.7	90	7
S5	EAST TWIN L.	6.4	180	7
S8	EAST TWIN L., ALGAL MAT	6.6	45	6
S10	EAST TWIN L.	5.6	75	6
S11	EAST TWIN L.	5.9	15	6
S17	EAST TWIN L. DISCHARGE	5.8	20	6
S18	EAST TWIN L.	6.9	40	6
S19	EAST TWIN L.	5.7	20	6
S20	EAST TWIN L., B-G MAT	6.5	20	5
S21	WASTE ROCK PILE SEEPAGE	6.8	6000	1
S22	WASTE ROCK PILE SEEPAGE	6.7	3700	4
S23	WASTE ROCK PILE SEEPAGE	6.9	2400	4
S27	WASTE ROCK PILE SEEPAGE NON-Fe SAMPLE	7.9	1200	-
S24	TREATMENT PLANT	8.4	1800	6
S25	TREATMENT PLANT	7.2	5000	-
S26	TREATMENT PLANT	7.9	900	-
S28	TREATMENT PLANT POND SEEPAGE	6.7	6000	-
S29	SHALE HILL POND	7.8	900	4
S30	SHALE HILL POND DISCHARGE	7.6	1900	4
S31	SHALE HILL ISOLATED POOL	6.8	7500	5
S35	WATER TOWER PYRITE OUTCROP	2.6	600	-
S36	WATER TOWER PYRITE OUTCROP 46 M DOWNSTREAM	3.4	600	-
S37	WATER TOWER PYRITE OUTCROP 63 M DOWNSTREAM	5.2	-	-
S42	WATER TOWER COLLECTION POOL	3.5	600	-

Table 3: pH, Conductivity and Temperature of surveyed areas

From the values of pH and electrical conductivity, as well as from the temperatures, the following observations can be made. The running water in all locations is neutral to alkaline, with a few interesting exceptions. In locations **S16** (watershed of West Twin Lake), and in location **S35** (around the water tower), (**Map 4a**), the water is acidic. These creeks were followed downstream some **60** to **90** m, where the water is neutralized after running over dolomitic gravel. This acidic water does not have higher conductivities, as is expected in more temperate climate. The water leaving the waste-rock pile (S27) with pH of 7.9, has a conductivity of 1,200 umhos/cm, compared to sampling locations **S35** and **S36,** where the pH's are **2.6** and **3.4** respectively, with conductivity 600 umhos/cm. All waters investigated which have been in contact with mining activities have generally higher conductivities, but are not necessarily acidic **(S24** to **S31).** Calcium chloride ($CaCl_2$) used during drilling, together with remnants from the blasting, are likely the cause of these elevated electrical conductivities. The observations presented in **Table** 3 indicate that acidification does occur despite the very low temperatures measured, ranging from 1 to 8°C. However, given the presence of the country rock shale and dolomite, the water is neutralized by coming in contact with the rocks.

In **Table 4,** water samples **1** to **4** (**Maps 4a** and **4b**), represent creeks and water bodies which are not associated directly with mining activity. In the Shale Hill area (Location 1, **Map 4b**), exploration activities are evident, hence the conductivity of **3,000** umhos/cm of the water. The samples from locations **5** to 8 were associated with mineralization and the presence of pyrite. The metals **As**, Cd, Cu, Hg, Pb and Zn have been selected for evaluation, as they are identified for monitoring as part of the water licence for Nanisivik. These elements show similar concentration ranges in the samples 1 to 4 of the non-mining locations, as in samples 5 to 8, collected in the disturbed locations. Indeed, the concentrations of As are slightly higher in non-mining locations, with an average of 0.028 mg/l for the 4 "clean" samples, and an average of 0.006 mg/l for the 4 mining-area water samples. For lead, the two groups of samples do not show any differences, as for both groupings the average value is around 0.45 mg/l.

Distinct differences are evident as expected between the groups of water samples for the concentrations of Zn, S, Ca, Mg. These elements are higher by at least an order of magnitude in the areas with mining activities, excepting the water from Shale Hill.

The samples 9 and 10 (Map la) are waters collected from two acid creek systems (A.C. #1 and A.C. #2) in the West Twin Lakeswater shed, both originating from pyrite outcrops. The concentrations immediately below the outcrop and those in the water collected 85 to 90 m downstream, are presented for both creeks. Acid creek #1 had been neutralized over this distance, indicated by a pH increase from 2.5 to 6.3, and Acid creek #2 had increased from 4.3 to 6.1. All elemental concentrations have either decreased significantly or not changed due to neutralization by country rock.

MAP:	48	4A	4A	4A	4B	48	48	4B		4A	4A
LOCATION:	1 SHALE HILL POND SUPPORTING ALGAE	2 STREAM FEEEDING E.TWIN L. ALGAE	3 DRAINAGE OVER DOLOMITE SUBSTRATE	4 EAST TWIN LAKE	5 EAST WASTE ROCK PILE: SEEPAGE	6 AREA 14: POOL BELOW ADIT	7 AREA 14: SEEPAGE ABOVE RED	a TREATMENT PLANT: NON-FE STAIN	STREAM	9/10 IMMEDIATE DRAINAGE WATER FROM	9/10 DRAINAGE WATER FROM PYRITE 85/90 M
ANALYTICAL SAMPLE NO.	102	90	a9	97	93	95	99	96		92 98	91 94
pH	7.4	6.5	6.5	6.2	6.9	6.5	6.4	7.9	A.C.#1	2.56	6.3
									A.C.#2	4.3	6.1
CONDUCTIVITY	3000	20	55	20	2400	4500	1500	1500	A.C.#1	6000	1500
(umhos/cm)									A.C.#2	3100	-
TEMP (°C)	4	5	3.1	6	4	4	4	4	A.C.#1	3	
									A.C.#2	4	
ELEMENTS (mg/L):											
ARSENIC	**0.01**	0.006	0.09	0.006	**0.01**	**(0.01**	**0.001**	0.004	A.C.#1	0.005	0.01
									A.C.#2	0.005	<0.01
CADMIUM	**0.01**	(0.005	(0.005	**0.01**	<0.005	0.08	<0.005	0.01	A.C.#1	0.02	0.06
									A.C.#2	(0.005	<0.005
COPPER	(0.005	(0.005	<0.005	(0.005	<0.005	(0.005	<0.005	<0.005	A.C.#1	(0.005	(0.005
									A.C.#2	(0.005	(0.005
MERCURY	**(0.01**	<0.01	**(0.01**	<0.01	0.04	(0.01	<0.01	(0.01	A.C.#1	<0.01	0.01
									A.C.#2	(0.01	(0.01
LEAD	0.9	0.02	0.1	0.8	(0.01	0.8	0.3	0.8	A.C.#1	1	0.5
									A.C.#2	0.6	0.05
ZINC	(0.005	(0.005	(0.005	(0.005	40	7.6	0.08	0.4	A.C.#1	1	0.001
									A.C.#2	0.8	<0.005
IRON	32	33	32	33	33	33	31	33	A.C.#1	(0.01	33
									A.C.#2	(0.01	26
SULPHUR	692	7	21	7 1	1254	3799	1232	957	A.C.#1	3941	1277
									A.C.#2	3565	899
CALCIUM	282	4	9.2	4 1	189	332	284	221	A.C.#1	332	224
									A.C.#2	333	215
MAGNESIUM	**101**	0.7	3.7	0.7,	305	813	179	138	A.C.#1	302	199
									A.C.#2	572	165
SODIUM	22	2	3.2	2	30	23	11	16	A.C.#1	a	11
									A.C.#2	5	4

These elemental compositions of the water suggest two main aspects. The nature of the country rock (dolomite and shale) is very beneficial in neutralizing the acidic conditions which do occur naturally and in association with the mining activities. The concentrations of Pb are generally around 0.5 mg/l in the area and do not appear to be associated with mining activities, nor the acidic conditions.

In **Table** 5, the elemental characteristics of the solid samples are presented. The metal concentrations in tailings (sample Locations 11, 12 and 13, **Map 4a**), can be compared with those of an undisturbed mineralized pyritic outcrop in the Oceanview area (sample Location 14, **Map 4b**), with those of an undisturbed non-mineralized pyritic outcrop. Further elemental concentrations of weathered material originating from shale and dolomite piles (sample Locations 15 and 16, **Map 4b**), and East Twin Lake sediment (sample Location 4, **Map 4a**), are given. With the exception of the sediment samples, all materials are weathered and assumed to be representative of long term conditions.

The concentrations of *As*, Cd, Pb and Zn are highest, as expected, in the mineralized material from Oceanview. The tailings have a copper concentration of 300 - 500 mg/kg, compared with <10 mg/kg in all other samples. Copper sulphate is used as a flotation modifying agent, at a rate of about 600 g/ton during milling. This is the likely source of copper in the tailings. The concentration of Pb, on the other hand, is lower in the tailings (2,000 to 3,000 mg/kg) than in the mineralized material from Oceanview (44,000 to 90,000 mg/kg), and only slightly higher than the concentrations in mineralized pyritic outcrops (700 - 1,000 mg/kg).

Table 5: Chemical composition of tailings and substrates

MAP:	4A	4A	4A	4B	4B	4A	4A	4A	4B	4B	4A
LOCATION:	11	12	13	14	14	9	9	9	15	16	4
	NEW TAILINGS	TEST POND TAILINGS	WEST TWIN AT DECANT, SEDIMENT	OCEAN VIEW PRECIPITATE FORMED FROM PYRITE(ORE) OUTCROP	OCEAN VIEW: LAYER BENEATH PRECIPITATE	SULPHIDE OUTCROP	WEATHERED SULPHIDE OUTCROP (SLUMPED)	PRECIPITATE FORMED FROM PYRITE OUTCROP DRAINAGE	SHALE HILL SHALE SAND	AREA 14: DOLOMITE SAND	EAST TWIN LAKE, SEDIMENT
ANALYTICAL SAMPLE NO.	109	108	106	113	111	**110**	112	107	**104**	103	105
pH	9.94	9.87	11.8	DRY	DRY	DRY	DRY		DRY	DRY	6.7
CONDUCTIVITY (umhos/cm)	900	1000	170	DRY	DRY	DRY	DRY	6000	DRY	DRY	20
TEMP (°C)	6	6	6	DRY	DRY	DRY	DRY	3	DRY	DRY	N.R.
ELEMENTS (mg/kg):											
ARSENIC	<10	<10	<10	70	100	<10	100	<10	<10	**100**	100
CADMIUM	**10**	30	<10	80	40	<10	30	10	<10	<10	
COPPER	300	500	<10	**<10**	<10	<10	<10	10	<10	<10	20
MERCURY	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
LEAD	2000	3000	600	90000	44000	700	800	1000	300	500	500
ZINC	7000	14000	1000	36000	8000	**1000**	800	2000	1000	2000	1000
IRON	283300	269150	70830	288280	262070	254990	339980	358400	31170	43210	87830
SULPHUR	426000	48000	18000	458000	52000	47000	425000	39000	6000	16000	**15000**
CALCIUM	110140	92980	15020	720	2150	4290	2150	2860	112290	193820	5720
MAGNESIUM	57900	54280	3620	600	4220	7840	2410	6030	104340	118810	13270
SODIUM	7420	10390	1480	740	7420	7420	1480	5190	6680	5940	8160

Shale, dolomite and the sediments in East Twin Lake do contain some lead, one order of magnitude lower than the tailings, i.e. 500 mg/kg as compared with 3,000 mg/kg. The concentrations of Zn, comparing the different materials, display a similar distribution, but the differences are less distinct.

The Comparison of the concentrations of Fe, S, Ca, Mg and Na in tailings and in the other weathered materials indicate some interesting aspects. Shale and dolomite contain concentration ranges of Ca which are similar to those in the tailings (11% and 19%, and 11% and 9%, respectively), whereas the sulphur concentration is considerably lower than in the tailings. Also, in shale and dolomite, the concentrations of Mg are high. As these elements are probably present as carbonates, the neutralization ability of the material observed in the acid creeks is expected. The sediments in East and West Twin Lakes are very similar in composition to shale and dolomite, with lower concentrations of calcium. These comparisons of compositions of tailings and weathered material suggest that the tailings material will not pose any long-term environmental conditions which are significantly different from those of the area at large.

Given the low temperatures in this region of permafrost, the question of microbially-mediated acid generation arises. *Thiobacilli* generally have temperature requirements considerably higher than those attained in this environment. Samples of the old tailings and material below the pyrite outcrop (sample Location 9) were tested for the presence of bacteria. In all materials *Thiobacilli* were obtained from an initial culture at 12°C.

However; a second generation could not be developed, with the exception of the sample taken at the source of Acid creek #l. The cultures exhibit very slow growth rates even at this elevated temperature. This suggests that although the microbes are present, they require low temperatures and work at slow rates. After evaluating the water characteristics **(Table 4)**, and the solid weathered material **(Table 5)**, one is lead to the conclusion that tailings and the general area are not significantly different. The tailings water should, in principle, not differ drastically from the water characteristics found in other locations in the area. The water quality in the tailings pond is summarized, differentiating **3** locations within West Twin Lake **(Table 6)**. Water was collected in the area where tailings are being discharged, in the contained section of the pond, (representing a long term test section), and at the decant of West Twin Lake. Monitoring data from the company's annual report (Nanisivik) are presented for comparison with these water analyses. Monitoring data are derived from unfiltered samples. The concentrations determined by our method are within the range of values found in the monitoring data. This indicates that our analyses are in general agreement, and do not represent unusual conditions. The concentrations of As, Cd, Cu, Hg, Pb and Zn are well within the ranges noted for natural or mineralized areas **(Table 4)**. Indeed, it could be argued that the tailings water is of slightly better quality than, for example, that of the acid creeks.

Although it appeared unlikely that Biological Polishing processes are feasible in this environment, a potential for their application does exist. The most significant observations were those made at the outflow of the creek close to the concentrate loading dock. This creek receives the tailings overflow and all other discharges from the site, including the effluent from the sewage treatment plant. A dense mat of attached filamentous algae, identified as *Ulothix* sp. in association with *Monoraphidium* spp. and other small green unicellular algae, was found. The algal filaments occur as dense mats attached to rocks in the fast flowing creek.

MAP: / LOCATION:	4A / 11	4A / 12	4A / 13	MONITORING DATA STATION 159-2: JAN 14/86 TO DEC 23/86	
	NEW TAILINGS, SUPER-NATANT	TEST POND, SUPER-NATANT	WEST TWIN LAKE, DECANT	MIN	MAX
ANALYTICAL SAMPLE NO.	100	88	101		
pH	11.2	6.7	11.5	10.65	11.95
CONDUCTIVITY (umhos/cm)	2200	1000	2200	300	1800
TEMP (°C)	7.5	6	7	0.2	6
ELEMENTS (mg/L):					
ARSENIC	0.01	0.001	0.01	-	-
CADMIUM	0.004	<0.005	0.009	<D.L.	0.04
COPPER	<0.005	<0.005	<0.005	-	-
MERCURY	<0.01	0.01	<0.01	-	-
LEAD	1	0.03	1	<D.L.	0.8
ZINC	0.2	0.09	0.2	<D.L.	0.52
IRON	32	32	32	-	-
SULPHUR	5291	681	4624	-	-
CALCIUM	332	304	332	-	-
MAGNESIUM	0.2	10	0.7	-	-
SODIUM	43	18	41	-	-

Table 6: Tailings Solution Composition: Current Report and Monitoring Data

Algal material was collected and analyzed for elemental concentrations. The results are given in **Table 7**, together with the water characteristics extracted from the annual report for sampling station 159.6. The concentration factors, the ratio between the concentrations in the biomass *(dry* weight) and the minimum and maximum concentrations in the water, are remarkably high for lead and zinc. This is not too surprising, as *Ulothrix* spp. are the main species suitable for biological polishing processes. The algal Occurrence in the outflow of the creek to Strathcona Sound is probably due to the addition of the effluent from the sewage-treatment plant upstream. The concentrations in this algal mat of Pb and Zn (0.08 and 0.6% *dry)* represent an improvement of the water quality.

A second group of algae with biological polishing potential was identified in pools of water with low flow-through rates in the areas of East Twin Lake and Shale Hill. Algal mats, either composed of blue greens with the mat-forming Oscillatoria spp. or nitrogen fixing algae *Nostoc* spp., were present. Other species associated with these algal mats are given in the appendix. Mats of these blue green algae were found to have colonized slow flowing water, where they filter suspended particulates or are covered with iron precipitate. The utilization of these algal mats, in conjunction with sewage, fertilizer and permafrost stabilizing measures, could lead to a self-sustaining remedial process functional in the long-term.

MAP:	4		
LOCATION:	17=159.6		
	ALGAE	WATER (FROM MONI-TORING DATA)	C.F.
ANALYTICAL SAMPLE NO.	116		
pH	-	7.48-9.77	-
CONDUCTIVITY (umhos/cm)	-	53-320	-
TEMP (°C)	-	1.5-5.1	-
ELEMENTS (mg/L):			
ARSENIC	<10	N.R.	-
CADMIUM.	<10	<0.001-0.001	<10000
COPPER	<10	N.R.	-
MERCURY	<10	N.R.	-
LEAD	800	<0.001-0.077	800000-10390
ZINC	6000	0.052-0.996	115384-6020
IRON	33998	N.R.	-
SULPHUR	34000	N.R.	-
CALCIUM	86539	N.R.	-
MAGNESIUM	57294	N.R.	-
SODIUM	5193	N.R.	-

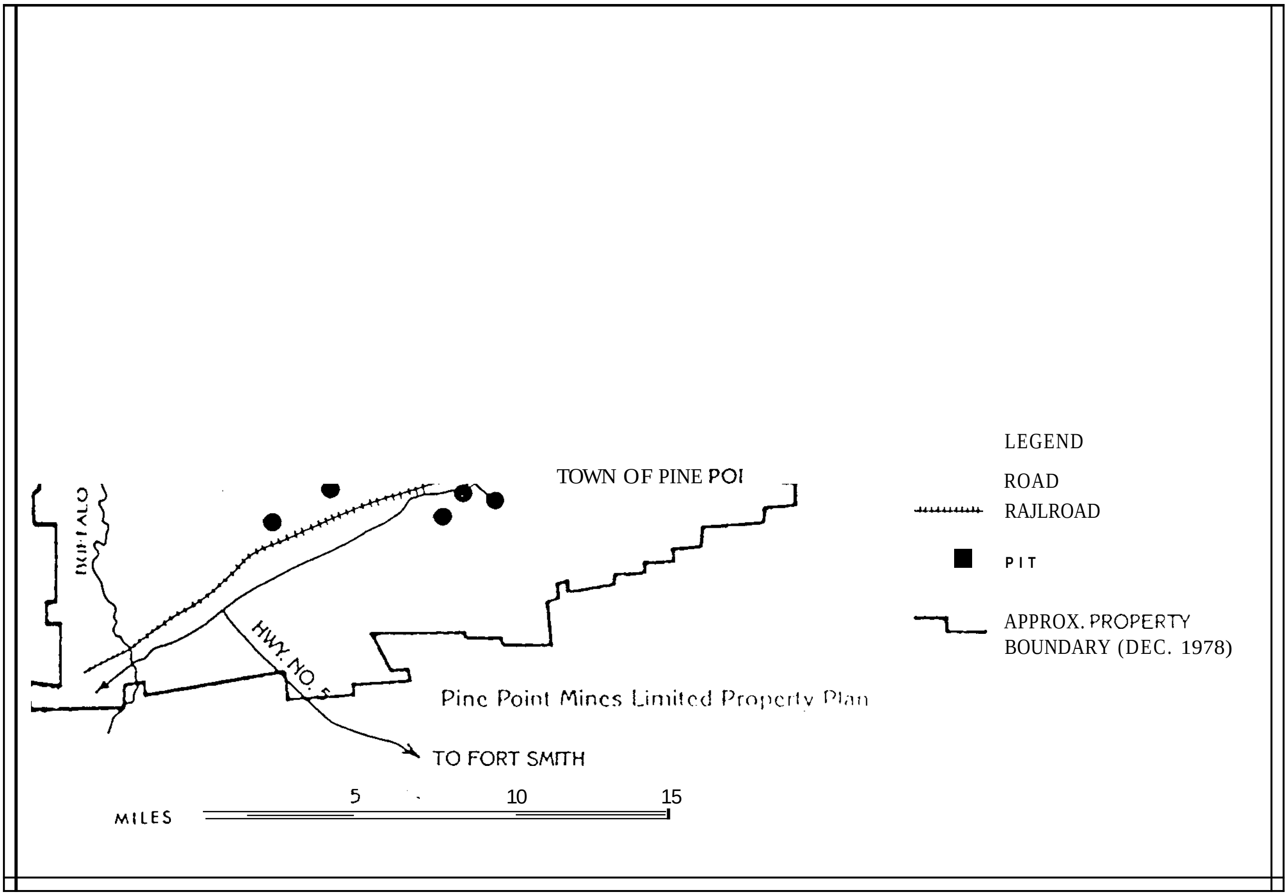
Table 7: Algae Composition, Water Quality and estimated Concentration Factors

3.6 Desk assessment:' Pine Point and Salmita

Both these operations are farther south than the sites visited for field investigations and their vegetation region has been discussed previously. The mining area of **Pine Point** is outlined in **Map** *5.* This large mining camp where 40 ore bodies occur in an area about 32 **km** miles long and 8 km wide, has sustained open-pit mining activities since 1964. Details of this base-metal operation extracting Pb and Zn, are given in the appendix.

The waste-management area at the time of close-out will consist of waste-rock piles, open pits and the tailings. 54,400,000 tonness of tailings are contained in an area of 445 ha confined by earthen dikes on three sides, and a natural ridge of the .land on the fourth. The tailings have no acid-generating potential, as the ore was contained in dolomite and calcite, with low sulphur content. This will also be the case for approximately 208,700,000 tonness of overburden and waste rock, estimated to have accumulated by 1985.

From the mineralogy of the area, it does not appear that water quality concerns are relevant in the long term. The hydrological conditions of the area will reach a new equilibrium after pumping from the open pits has ceased. Although some pit walls were grouted in 1985, an effective seal was not achieved, and the grouting was discontinued. It can be expected that the open pits will fill **up** with water, forming man-made lakes. The electrical conductivity of the water·might initially be. somewhat higher than background, due to solubilization of drilling and blasting reagents. Once the water levels in the region have reached equilibrium, natural background characteristics of the water are expected in the long term.



Map 5: Overview of Pine Point property plan from Pine Point Mines Annual Report, 1978

In the absence of details on the condition of the concentrate shipping facilities, metal contamination of the environment, either by wind transport or precipitation, could be anticipated from this component of the mining operations. This area probably requires some remedial action to prevent distribution of concentrate dust.

The long-term implications for the waste-rock piles and the open pits are, in essence, changes in the environment which are permanent and of a physical nature. Thus, severe long-term consequences of the same magnitude that can be expected from acid-generating waste material are non-existent in this area.

Conventional reclamation efforts, such as establishing vegetation covers, are unlikely to produce a significant improvement of the environmental conditions of the tailings. Tailings-erosion control measures, making use of waste rock as a cover, would probably produce conditions considerably more stable in the long term than those conventional methods requiring the establishment of a vegetation cover. Introduced vegetation covers do require a considerable amount of maintenance for some time. The tailings rarely provide a substrate with sufficient nutrients to sustain a non-indigenous cover in the long term. For example, some old gold tailings sites in the Timmins area which are alkaline, were reclaimed by conventional methods in the mid-sixties. In 1987, they exhibit an extremely sparse vegetation cover. Erosion of the tailings by wind and precipitation is reoccurring. It does appear that, from an environmental point of view, the close-out conditions for the Pine Point operation should address physical stabilization of the area.

The Salmita mine, a gold property, owned by Giant Yellowknife Mines Ltd., is, strictly speaking from a waste-management point of view, a mine site with a small open pit. It can be anticipated that waste-rock piles exist on the surface. Waste rock might have been used for construction of roads and as foundations for mine buildings.

The ore from the Salmita operation was milled in the Tundra Mill and thus the tailings were discharged in the same location as those of the old Tundra operation. Those were discharged into a lake, forming a beach with exposed tailings. One berm was built to contain the tailings, and had to be raised during of the tailings area. Milling of Salmita ore started at the Tundra mill in 1983 and ceased in 1987. Details of the Salmita operation are given in the Appendix.

At the time of shutdown of the Tundra operation, the total tailings tonnage discharged to the lake was estimated at 171,500 tonnes **(Kalin, 1985).** The total tailings tonnage in the lake is 215,295 tonnes (p.c., K. Morton). The milling process of the Tundra operation used amalgamation and cyanidation, however the process was converted to the (Zn precipitation) for the Salmita ore. The tailings might therefore contain both Hg and Zn.

The gold mineralization is reported to be associated with minor amounts of sulphides, consisting of pyrite, traces of pyrrhotite and some galena. Thus the potential for acid generation from the waste material does exist. **As** the neutralization potential of the country rock is unknown, detrimental effects on the water characteristics in the long term should be considered in a close-out scenario for the site.

From an environmental point of view, the long-term concerns are clearly directed towards water In an evaluation of monitoring data on abandoned hard rock mines in the Northwest Territories and the Yukon, the Tundra operation was classified as a site with no environmental concerns, based on the fact that it was, at that time, within an operating waste-management area, controlled by a water licence. In the same report, an evaluation of sites with a potential. for acid generation, the site was regarded as a property with low probability of acid generation **(Kalin, 1985).** This was mainly due to the fact that reports on mineralogy indicated only minor amounts of pyritic minerals and further, that the tailings were disposed to a large extent under water, thus curtailing acid generation. Based on acid generation tests carried out by Giant Yellowknife Mines Ltd., the tailings have an acid consuming capacity (58.6 exceeding the acid generating potential (29.4 The long-term environmental scenario of this site can therefore be anticipated to produce no environmental degredation if the site is abandoned considering the hydrological conditions of waste placement.

4.0 CONCLUSIONS; CLOSE-OUT SCENARIOS

Environmental disturbance which has been evaluated in detail for two mines in the high Arctic, with particular emphasis on environmental changes which might be expected in the long term, should not be considered in isolation of the larger context of the Northern environment. A broader view should be taken to give a perspective to the location, i.e. the environment at large, in which the anticipated changes might be of concern, should be considered.

Many ecological studies, often motivated by environmental concerns, have led to a respectable understanding of this vast precious northern resource. Conservation efforts have led to the identification of different areas in the Northwest Territories which deserve particular attention. Ecological sites were identified within the International Biological Program by the Canadian committee under the direction of N. Nettelship and P. Smith in 1975. Three of these sites could be considered to be located in the greater vicinity of the mine sites, taking an extremely broad geographical view.

Further sites have been identified and documented by D. **Beckel** in the same year and declared as valuable IBP Ecological sites. Of these sites, six were considered within the context of this report. For ease of reference and to provide as an information base as possible, the information for all sites which might be considered "close" to the mining operations are provided verbatim in the Appendix.

The main factor which led to the selection of these sites appeared to be their uniqueness as special habitats and/or breeding grounds for wildlife. The environmental implication of the mine sites for the nature of these habitats is difficult if not impossible to perceive. The rationale used in the selection criteria, from an environmental point of view, leads to the inclusion of an abandoned mine site, namely Discovery IBP Site 38 (SEE **Appendix).** These considerations lead to the conclusion that a site-specific assessment of the close-out scenarios, carried out on a site-specific basis, is justified within the larger context of conservation and environmental protection in the Northwest Territories.

4.1 Field site assessments, Lupin and Nanisivik

Lupin:

The utilization of the waste-rock and/or Esker material as a cover for the tailings area is considered a realistic long-term stabilization method. Esker material used on site for road construction has already been colonized by indigenous vegetation in 3 to 5 years, and thus additional stabilization by colonization of indigenous, self-maintaining vegetation, could be promoted by the use of this material.

The results of the long-term static leach experiment suggest that further thought should be given to an evaluation of the boundaries of the tailings and the environment. The planned sloping of the tailings areas with the waste-rock and/or Esker material cover will prevent ponding of water on the tailings which, together with the low temperatures of the region, is a beneficial combination of conditions. The dams containing the tailings are constructed of earth material. The dam material is frozen and therefore no fluid flow is possible **and Judge, 1987).** Acidification of the tailings, although anticipated to be extremely slow, can be associated with heat production, which could gradually affect the freezing behaviour of the tailings **(Kalin and van Everdingen. 1987).**

A reasonable assumption is that reduced biological activity in cold climates will result in reduced acid-generation rates. However, in principle, the oxidation process in the tailings mass is associated with the generation of some heat which would tend to delay or even prevent freezing of the tailings. In addition, freezing-point depressions can be expected, due to the generally high dissolved solids content of the pore water in the tailings. Whether the heat production of the tailings is significant in the long term cannot be assessed at the present time for regions with continuous or discontinuous permafrost. This might be of importance however, particularly for the **Lupin** operation. Some consideration should be given to the temperature behaviour of the waste-management area in the close-out scenario.

The presence of biological polishing agents (attached algae) and the natural colonization by grasses noted on the Esker material indicates that Ecological Engineering methods are applicable to this operation. These measures will be particularly useful in maintaining the water quality behind Dam 1A, and providing effective long-term protection between the tailings and the environment.

Nanisivik:

On close-out of the mining operations, the tailings in West Twin Lake will be covered with water which, in addition to the low temperatures experienced at the site, will retard acid generation, despite the presence of The occurrence of these acid-generating bacteria was not anticipated under the prevailing climatic conditions.

The temperature behaviour of the tailings at **Nanisivik** is less important as the tailings are not contained by frozen dams. The water cover will freeze during the winter and equilibrate potential heat produced seasonally. The anticipated water cover on the tailings appears to be an environmentally sound close-out scenario.

The disturbance of permafrost on surfaces where mining activities have taken place, has resulted in point sources of metals in surface seeps. This has led to the installation of a water-treatment facility for which shut-down procedures should be established. The curtailment of these point sources of metals emerges as a more significant environmental aspect of the close-out scenario than the tailings area. The long-term environmental implications of the mine site are not focused on the tailings deposit, but rather dictated, for. Nanisivik, by effects of changes induced by the mining activity in permafrost on the surface.

The neutralization ability of the country rock can be utilized to ameliorate and curtail these environmental changes. The point sources of acidified or metal-loaded surface seepages could be directed through a series of terraces made of country rock which would neutralize the water, as was observed in the field investigation. The water quality could be further improved through biological polishing, initiated with the assistance of fertilizers. This would be particularly beneficial for areas where the surface water is ponded in the summer season or in seeps with low flows. A third measure to be considered for a close-out scenario might be to promote freezing of those areas which are below the waste rock piles and the concentrate loading area. The beneficial properties of the shale and dolomite, together with careful consideration of the drainage basins and the topography of the area, all lend themselves to the implementation of an environmentally sound close-out scenario.

Pine Point and **Salmita:**

The interesting aspect of these operating mines and their close-out is that during the course of the contract, both operations have closed down. The close-out scenarios are, therefore, not a potential future event, but a reality of today. Ecological Engineering methods in the vegetation regions of these two mine sites are realistic and, particularly for the Salmita operation, essential to a curtailment of the potential long-term effects of acid generation. The close-out of the **Pine Point** mining operations does not appear to pose any long-term problems with water quality. Therefore, Ecological Engineering methods and Biological Polishing processes are not required for this site. By careful consideration of the physical stabilization of the waste-rock piles and drainage collector ditches, natural colonization by indigenous species will take place on these surfaces within a reasonable time.

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6.0 APPENDIX

6.1 Results of Examination of Periphyton Samples

* indicates most common taxa

Samples from Nanisivik (August, 1987)

1) Outflow to Strathcona Sound (Station #159.6) (Aug.

taxa present: spp.
small flagellates
small greens
Ulothrix sp. **

- considerable amount of bacteria and numerous protozoa.

2) East Twin Lake (*Nostoc* sample) (Aug.

taxa present: *Eunotia* spp.
spp.
spp. (mucilaginous bluegreen colony) **
Oscillatoria sp.

3) East Twin Lake sample) (Aug.

taxa present: *Ceratoneis arcus* *
Cosmarium sp.
spp.
spp.
Navicula spp.
Nitzschia spp.
Oscillatoria spp.
Zygnema spp.

4) East Twin Lake sample) (Aug. 3/1987)

taxa present: *arcus* *
Cosmarium sp.
spp.
Oscillatoria sp.
Zygnema spp.

5) East Twin Lake ***(Nostoc*** sample) (Aug. 3/1987)

taxa present: ***arcus***
Cosmarium sp.
Navicula spp.
Nostoc spp. *
sp.

- sample dominated by moss species which was coated with precipitate (dried sample of moss of identification by Christine Manville).

6) Shale Hill (Aug. 2/1987)

taxa present: *Euglena* spp. *
Navicula spp. *
Nitzschia spp. *
sp.
small flagellates
Tabelaria spp.

- sample contained moss protonemata which were coated with precipitate.

7) Shale Hill (Aug. 6/1987)

taxa present: ***arcus***
Euglena spp. *
spp.
Navicula spp. *
Nitzschia spp. *
sp.
Synedra spp.

- sample contained moss protonemata which were coated with precipitate.

8) Sample from Volcano Area

taxa present: ***Navicula*** spp.
Nitzschia spp.
spp. *

6.2 Operations.Background

PINE POINT MINES LIMITED

Location

Lat. 60° 50' 50"
Long 114° 27' 12"

Some 40 orebodies occur in an area approximately 32 km long by 8 km wide along the south shore of Great Slave Lake.

Metals Recovered

Lead and zinc concentrates are recovered.

History

1898 - was originally staked.

1920's Renewed exploration activity, and in 1928, Consolidated Mining and Smelting Co. (now Cominco) joined in the work through the Northern Lead Zinc Co.

1940's In mid 40's, Cominco and Ventures Ltd. acquired a 500 square mile concession from the Federal and explored the property.

1951-54 Pine Point Mines Ltd. was incorporated to develop the properties and 4.5 million tonnes of ore was outlined, grading 4% lead and 7% zinc.

1962 Exploration resumed.

1964-68 High grade ore was shipped to smelters.

1965 A 4,500 tonnes per day concentrator went into operation late in the year.

1966 Pine Point Mines purchased the property of Pyramid Mining Co.

1969 Milling capacity increased to 9,000 tonnes per day.

1972 Installed acid leaching circuit to reduce magnesia content of zinc concentrate.

1976 With increasing depth of pits, dewatering becoming a problem. A program of reclamation instituted at completed open pit sites and studies on these and other matters continued.

1978 Seeding of the waste dump at one pit was completed and in these reclamation activities were continued.

1981 Tailings dyke raised and extended.

1985 High strip ratio and cost of dewatering making Pine Point Mines a high-cost producer. Semi-commercial underground mining commenced in a high grade zone. Five-year property dewatering licence renewed by NWT Water Board. Renewal of the property's tailing disposal permit was approved by the Water Board for a further 5-year period.

1985 Spent **$8.2** million grouting on pit. **N-85.** A project abandoned after contractor went bankrupt.

1986 Commercial production began on underground mine on a limited scale.

1987 In January, Pine Point Mines announced that mining operations will cease by July, and milling operations by the end of the year.

The board of directors approved **$2** million expenditure toward exploring remaining areas of the property having reasonable potential for ore discovery.

Geology

Pine Point's lead-zinc deposits are Mississippi Valley type. The ore is found in an extensive .middle Devonian barrier complex trending in a southwest direction and plunging gently west into northern Alberta. The area is covered with approximately 12m of glacial till. Barrier sediments occupy a stratigraphic interval of **122** to **165** m and are known as Pine Point group.

Fine sandy textured dolomite occurs in the lower part of the barrier. Above the sandy dolomite lie vuggy, coarse, crystalline Presqu'ile dolomite and lateral time equivalent limestone beds. Both Presqu'ile and sandy dolomites are host rock for the Pine Point The ore bodies occur as large prismatic lenses of mineralized breccia - many of which are exposed at the outcrop surface - or as flat-lying sheets, discontinuous lenses, and runs, which occur at various depths. Orebodies vary in size from a few hundred thousand to several million tons.

Ore minerals consist of sphalerite and galena, and gangue minerals consist of marcasite, grey and white vein dolomite, calcite with minor sulphur, and bitumen. Reserves now total about **34** million tonnes grading **2.3%** lead and **5.7%** zinc.

Mill Feed

Mill feed has come from some **30** open pits, with several pits in operation at one time.

Mill feed from **1964** to **mid-1985** amounted to **64.6** million tons. **In** addition, **1.4** million tons of direct-shipping ore was produced between **1964** and **1968.**

Mill feed averaged 6.7% zinc and 3.0% lead to 1984.

Milling Process

The ore is finely ground and separate lead and zinc concentrates are recovered by flotation. In 1972, an acid leaching circuit was added to reduce the magnesia content of the zinc concentrate. Concentrates are dried and shipped to a smelter.

A small amount of cyanide is used to depress iron sulphides. The leaching plant operates intermittently as required. In 1974 the process involved the addition of sulphuric acid to unthickened zinc concentrate to lower the pH to 1.0, followed by neutralization of the leached slurry with anhydrous ammonia to raise the pH to 6.5 ; neutralizing agent may have changed since that time). This process might have changed since then.

Milling Reagents (1974)

	Lb/Ton
Lime	2.43
Sodium isopropyl xanthate	0.205
Copper sulphate	0.49
Methyl isobutyl carbinol	0.15
Sodium cyanide	0.088
Sodium sulphite	0.058

Mill Concentrates

To mid-1986, the production of lead concentrate amounting to 1.77 million tonnes, and zinc concentrate totalling 5.85 million tonnes.

Mill Tailings

Calculated mill tailings produced to mid-1986 amount to 56.2 million tons. By the time operations are suspended in 1987, tailings produced could amount to 54 million tonnes.

Mill tailings contain approximately 0.6% zinc and 0.4% lead as sulphides. During the operation of the acid leach plant, the tailings contain some chlorides of calcium and magnesium.

The tailings pond comprises an area of 445 ha, enclosed by an earth-dyke on three sides and a natural ridge of land on the fourth. Due to the high content of dolomite and calcite in the ore, and the low content of sulphides not recovered in concentrates. The tailings will have no acid generating potential. Tailings solids are approximately 55% finer than 200 mesh (74 microns), thus representing a relatively coarse tailings material.

Waste rock

In addition to the mill tailings, approximately **230** million tonnes of overburden and waste rock was excavated by year-end **1985.**

SALMITA MINE

Location

The mine is located on the shore of Matthews Lake, **150** miles northeast **of** Yellowknike, N.W.T. The ore is treated in the former Tundra Mill, some **6** km. southeast of the mine.

Ownership

Salmita is a division of Giant Yellowknife Mines Ltd.

Economic Metals

Gold, with minor amount of silver.

Ore Reserves

Proven and probable reserves at year-end **1984** were **80,000** tonnes containing **0.85** oz/ton gold, down to the 6th level **(950** ft.).

Operating Costs

Operating costs in **1984** were **$211.10** per ton and **$288.51** (U.S. 222.81) per ounce.

History

Gold was discovered on the property in **1939** and the property staked in **1945.** Giant optioned the property in **1975.** **An** underground exploration program and feasibility study in **1981** led to a production decision. Milling commenced in August, **1983.** The ore is processed in the Tundra mill which was extensively rehabilitated in **1983** prior to production. Operations have continued steadily since **1983.**

Geology and Mineralogy

Salmita is one of several gold showings associated regionally with the contact zone between younger, finely laminated metasediments in the east and older intermediate to felsic volcanics in the west. Locally, the Salmita deposit is contained within a persistent **1.7** m. wide zone of intense epithermal silicification with free milling gold associated with some scheelite and minor sulphides (arsenopyrite, pyrite and trace amounts of pyrrhotite, galena and sphalerite).

Shrinkage stoping is used, due to the narrow veins, averaging 1.5 m. wide. Ore is hauled up a 13% decline in the footwall of the

Annual Tonnage Grade

Salmita output in **1984** totalled 55,000 tonnes at a grade of **0.764** ounces gold per ton. Grade from **0.63** ounce in the first quarter to 0.93 ounce per ton in the final quarter.

Gold Recovery, %

Recovery improved to more than **97%** in the latter months of **1984.**

Gold Production

In the full year **1984,** gold production was **44,414** ounces.

Milling Process

Crushing to 3/8 inch in jaw and cone crushers.
Grinding to **70% - 200** mesh.
Straight cyanidation leach (36h).
Gold recovery by Merrill-Crowe process.
Precipitate smelted at Giant

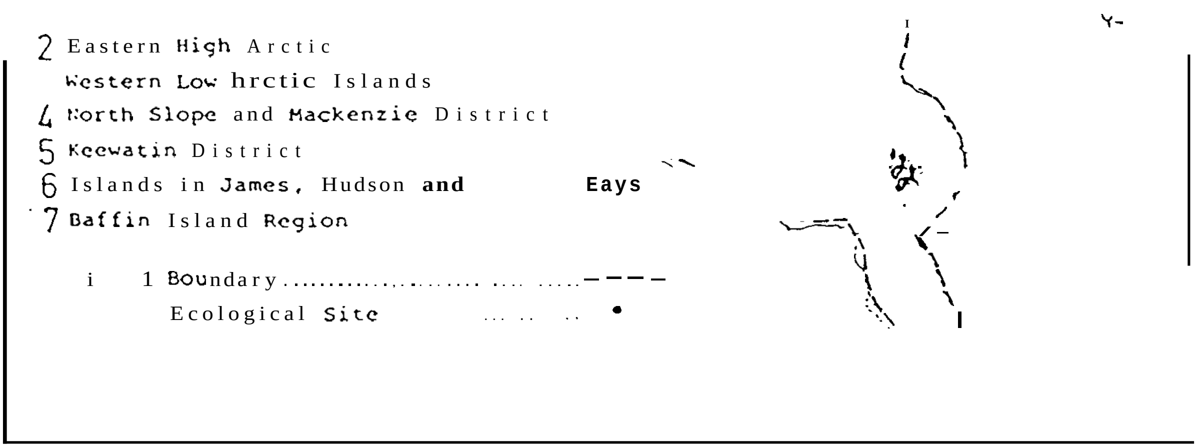
Due to the unusual hardness of the Salmita ore, mill throughput was initially restricted to **125** TPD. With the installation of an 8ft x **8** ft. ball mill in June **1984,** mill throughput was increased by **50** TPD.

Tailings

About **215,291** tonnes of tailings are impounded in the original Tundra tailings area, which has had the berms raised.

6.3 Selected Ecological Sites and IBP Sites.

REGIONS AND PROPOSED ECOLOGICAL SITES



6.3 Selected Ecological Sites and IBP sites.

A. Ecological Sites in Northern Canada ed: David N. Nettleship and Pauline A. Smith (1975) Ottawa: Cdn Committee for Int'l Biological

SITE 7.7 BAILLARGE BAY, BAFFIN ISLAND

A major Northern Fulmar colony (at least 25,000 breeding pairs) extends continuously from Baillarge Bay northeast to Elwin Inlet, a linear distance of slightly more than 10 miles (16 km). They nest on bare and grassy-turfed rock ledges and in crevices in the cliff face from about 325 feet (100 m) above the sea right up to the uppermost edge of the cliffs (2,000 feet or 610 m). The highest density of breeding birds is found from the northeast tip of Baillarge Bay east to the mid-point of the promontory, totalling about 5.6 miles (9 km) of coast.

Observations of the general area (Admiralty Inlet-Lancaster Sound) indicate that it is an area critical to the reproduction and survival of many marine bird (Northern Fulmar, Glaucous Gull, Thayer's Gull, Black-legged Kittiwake, Thick-billed Murre, Black Guillemot, Snow Goose, Oldsquaw, eider) and marine mammal (white whale, ringed seal, walrus, polar bear) populations. All these species breed and/or feed in the area, and fulmars, gulls, white whales, narwhals, ringed seals, walrus and polar bears are known to be abundant. This suggests that the waters around this area have an unusually high productivity.

SITE 7.5 BYLOT ISLAND

There are two major Thick-billed Murre and Black-legged Kittiwake colonies on Bylot Island, one of pairs of murres and ±50,000 pairs of kittiwakes on steep m) cliffs about 5 miles (8 km) west of Cape Hay extending for 2.2 miles (3.5 km) and another of ±20,000 pairs of murres and 3,000 pairs of kittiwakes at Cape Graham Moore (72° 56 76° 02'W) on vertical cliffs covering approximately 0.5 miles (0.8 km).

In the southwest region there is a low-lying region of some 500 square miles (1,295 km^2) with a dense cover of vegetation which supports a unique number and diversity of shorebirds and land-birds, including a major part of the world population of Greater Snow Goose (7,500 pairs) and large numbers of Red-throated Loons, Oldsquaw and King Eider.

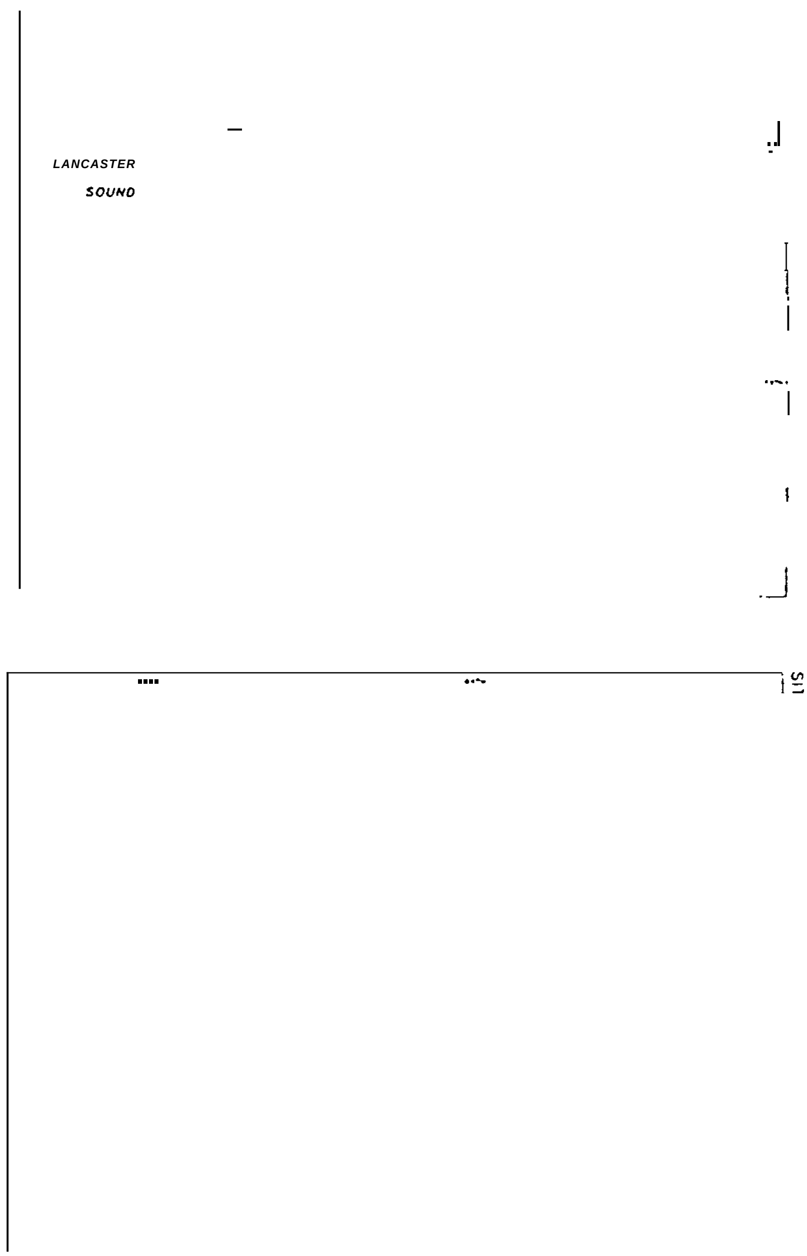
The island is also important to marine mammals. Polar bear denning occurs on the east and north coasts and pregnant females use the northwest tip of the island as a summer sanctuary. Ringed seal, bearded seal, hooded seal, narwhale and polar bear congregate in the waters off Button Point where there is a semi-permanent ice floe.

Many archaeological sites occur along the coast, including a possible Viking site about midway north along Navy Board Inlet.

SITE 4.5 BATHURST INLET

The scenic variation within so small an area is uncommon on the Canadian Shield. The vegetation, although relatively rich, is representative of a mainland low arctic site. Shrub willow up to 7 feet (2 m) high is found in sheltered valleys and on lower slopes of the inlet. Dwarf-shrub heath dominates the better drained lowlands, while sedge tussocks are common in the poorly drained areas. In upland areas and at low elevations on the coast a rock desert prevails.

Part of the calving grounds of the Bathurst caribou (an estimated population of 160,000 animals) falls within the site. The main calving area is located between the Ellice River and the eastern side of Bathurst Inlet. Some small caribou herds over-winter in the area. Muskoxen, wolves and barren-ground grizzly bears are relatively common.


LANCASTER
SOUND

B. IBP Sites in Subarctic Canada ed: Dorothy B. Beckel (1975) Lethbridge: The University of Lethbridge Prodn. Services.

SITE NAME: **WHOOPING CRANE NESTING**

SITE NUMBER: 13

LOCATION: District of Mackenzie, Northwest Territories: eastern part of Wood Buffalo National Park.

SIZE: 1400 square miles approximately.

ECOSYSTEM: Grass-sedge meadows, black spruce-tamarack woods and small areas of muskeg related to European Oxycocco-Sphagnetum. Part of Upper Mackenzie section of boreal forest ecological zone. Whooping crane nesting area.

DESCRIPTION: Generally a marshy area with numerous shallow ponds and potholes separated by thin strips of land on which grow black spruce, tamarack, aspen, willows. Brules common. Shallow overburden of till over limestone rock. Major soils: Rego Gleysols, Terric Fibrisols, Eutric Brunisols.

ECONOMIC POTENTIAL: Mineral - poor: Hydrocarbon - low: Timber - low: Agriculture - along southwest generally unsuitable or with extremely severe limitations for agriculture (O & D): remainder with very severe limitations (C); Recreation - recognized canoe route along Little Buffalo River: Wayside Park adjacent to mile 135 of Highway 5.

EXCEPTIONAL INTEREST: Only known nesting area of the Whooping Crane.

SITE NAME: **PLAINS SOUTHWEST OF GRAND**

SITE NUMBER: 3

LOCATION: District of Mackenzie, N.W.T. between Grand Detour on Slave River on the east and Little Buffalo River on the west.

SIZE: 62 square miles approximately

ECOSYSTEM: Grass-sedge meadows and prairie with forest margin; wolf and bison habitat.

DESCRIPTION: Extensive grass and sedge meadows and prairie interspersed with willow copses: spruce forests bordered by poplars: flat with little relief. Major soils are Regosols and Gleysols. Some areas near the west may be seasonally inundated by the Little Buffalo River.

ECONOMIC
POTENTIAL: Mineral - Poor; Hydrocarbon - Poor; Timber - Low; Agriculture - very severe limitations (c); Recreation - Medium, situated on recognized canoe route (Little Buffalo River).

EXCEPTIONAL
INTEREST: This area is found near the northern limit of the Occurrence of these extensive prairie-like grass- sedge meadows. The prairies constitute important summer range for bison and it is here that these large ungulates and wolves are still abundant in a relatively undisturbed state. The area may also be of interest from a forest succession point of view, for the "prairie-patches" are being invaded by aspen which in turn may be replaced by white spruce.

SITE NAME: **SALT RIVER ALKALI FLATS**

SITE NUMBER: 12

LOCATION: Spanning border between District of Mackenzie, Northwest Territories and Alberta about ten miles west of Slave River.

SIZE: 100 square miles approximately.

ECOSYSTEM: Major plant community (*rubrae*) with saline affinity; second community is a northern variant of a prairie community Part of Upper Mackenzie section of the boreal forest.

DESCRIPTION: Area flat, much of it bare of vegetation or sparsely vegetated. Thin deposits of sale left in many depressions by outwash from brine springs in Brine Creek drainage. Plants with saline affinities such as *rubra, Suaeda depressa*, and *patula* found here. Area frequented by wolves and bison, particularly in the winter. Major soils Saline Orthic Regosols and Rego Gleysols.

ECONOMIC
POTENTIAL: Mineral - poor; Hydrocarbon - low; Timber - low; Agriculture - very severe limitations (c); Recreation - includes Salt Mountain Territorial wayside park (adjacent to highway 5)

EXCEPTIONAL
INTEREST: Saline habitats are .utilized as salt licks by ungulates. Area supports a number of for the region and probably near their northern range limit.

SITE: BRULE 'POINT

SITE NUMBER: 52

LOCATION: District of Mackenzie, Northwest Territories; area on the Slave River about 40 miles north west of Fort Smith.

SIZE: 26 square miles approximately.

ECOSYSTEM: Boreal Forest Zone (Upper Mackenzie Section); typical white spruce association.

DESCRIPTION: Flat alluvial delta of a former arm of Great Slave Lake: the Slave River, which constitutes one border of the area inundates portions of the site frequently. Special physical features include abandoned stream meanders some containing lakes and meadows; modem flood plain being colonized. Major plant communities are the dominant forests of white spruce-poplar-birch, and wet sedge meadows. Major soils: Gleysols, Regosols.

ECONOMIC POTENTIAL: Mineral - low; Hydrocarbon - very low; Timber - high to very high; Agriculture - very severe limitations (C); Recreation - low.

EXCEPTIONAL INTEREST: The site is part of a typical white spruce stand, including the pioneer stage in development. Wet sedge meadows and a typical riparian sequence of willow-alder brush are represented as well. The frequently inundated modem flood plain is being colonized in a fashion typical of such flood plains.

SITE NAME: BENIAH LAKE

SITE NUMBER: 36

LOCATION: District of Mackenzie, Northwest Territories; about 100 miles northwest of Yellowknife.

SIZE: 350 square miles approximately.

ECOSYSTEM: Northern Boreal Forest Zone (Forest-Tundra Section); treeline ecotone.

DESCRIPTION: This area is a representative sample of the spruce lichen habitat at the edge of the open tundra.

ECONOMIC POTENTIAL: Mineral - moderate: Hydrocarbon - negligible: Timber - low; Agriculture - extremely severe limitations (d); Recreation - low.

EXCEPTIONAL INTEREST: With its stunted and widely spaced trees, this is a representative sample of the treeline ecotone between the open black spruce forests and tundra.

SITE NAME: DISCOVERY MINE

SITE NUMBER: **38**

LOCATION: District of Mackenzie, Northwest Territories; about 54 miles north of

SIZE: **3** square miles approximately.

ECOSYSTEM: Boreal Forest Zone (Northwestern Transition Section); jack pine and black spruce woodlands; willow-alder-fireweed-horsetail regeneration on mine tailings.

DESCRIPTION: Typical glaciated Canadian Shield landscape, thin soils overlying granite bedrock; many rock outcrops, ponds and **bogs.** Environmental disturbance at the mine site from building construction, storage and tailings disposal; also disturbance from woodcutting, prospecting, winter roads and fire. Mining operation from **1950** to **1968** when ore **body** ran out. In many locations possible to trace the age by stage of plant succession. Major soils: Lithosols, Podzols, Organic soils.

ECONOMIC POTENTIAL: Mineral - moderate; Hydrocarbon - negligible; Timber - low; Agriculture - extremely severe limitations; Recreation - low.

EXCEPTIONAL INTEREST: Site typifies degree and extent of ecological modification that mining activities in the transition forest portion of the Shield. **An** area where studies have been carried on to learn how plant succession after disturbance reoccupies this type of northern mine site.

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