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PROPOSED TAILINGS FACILITY

Submission to the Water Technical Session
BHP Diamond Mine Environmental Assessment Panel

Yellowknife, NT

Prepared by

Government of the Northwest Territories

Department of Renewable Resources
Department of Safety and Public Services

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EXECUTIVE SUMMARY

The Departments of Renewable Resources and Safety and Public Services have reviewed the NVVT Diamonds Project Environmental Impact Statement (EIS) and supporting documents as they apply to two specific areas, construction and stability of the frozen core dams and long term stability of the tailings facility after closure.

Based upon this review and experience gained from the nearby Lupin Mine, it is concluded that the frozen core dam is an acceptable concept for use in cold Arctic regions and this type of dam will perform satisfactorily at this location. Conservative attention must be paid however, during design to water level fluctuations with respect to the top of the frozen core and the construction must be performed under strict control.

The placement of tailings in the valley of a relatively large watershed challenges the capability to provide long term erosion control after mine closure. There are no known North American case studies for successfully managing such large volumes of high clay content tailings in this manner. [t is our opinion that the Proponent should consider concentrating the tailings in a smaller area in the upper reaches of the local watershed. This will provide for reduced erosion susceptibility and allow more conservative final erosion control because of a smaller footprint. Locating the tailings in smaller zoned cells in the upper reaches of the watershed would reduce the erosion mechanism and its rate, and would be more conducive for more substantial erosion protection.

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1.0 INTRODUCTION

The Departments of Renewable Resources and Safety and Public Services have reviewed the Environmental Impact Statement (EIS) and supporting documents, particularly the "Tailings Management Plan and Preliminary Design of Retention Structures" (EBA, December 1995). We are pleased to provide this submission and would like to commend both the Environmental Assessment Panel and BHP Diamonds Inc. (the Proponent) for developing such a comprehensive document package.

1.1 Departmental Mandate

The mandate of the Department of Renewable Resources, as it relates to this submission, is to **provide environmental management, assessment, and protection measures and to plan** for land and water use. The mandate of the Department of Safety and Public Services is for the administration of public safety in the Northwest Territories including promoting and enforcing public and worker safety, and protecting the interests of the worker and consumer. This includes the promotion and monitoring of compliance with safety standards in the mining industry.

The following principles have guided the review and preparation of this submission to the Panel:

- The environment should be protected.

- The Northwest Territories' economy and cultures are deeply rooted in the environment and the Government of the Northwest Territories shall ensure that environmental quality is maintained to support the long term stability of northern society.

- Workplaces are safe and workers are trained in safe work practises.

The primary regulatory instruments for the departments are the *Environments/ Protection Act* and *Mine Health and Safety Act* and their regulations.

In addition to the departments' own expertise, a technical expert was engaged in order to assist in our review by providing advice and recommendations. Dr. Igor Holubec has over 30 years experience in geotechnical/civil engineering that includes 8 years of research and teaching and 25 years consulting. Since 1974 he has worked on projects in permafrost across Canada and Russia. This started with being a senior reviewer of the Alaska Oil

Pipeline leading to extensive involvement in numerous oil/gas projects planned for the arctic islands, the Norman Wells refinery, long and short range radar stations, and several mining projects. His most relevant experience to this review is extensive work on Lupin Mine's tailings facilities that extended from design to construction and thermal monitoring. Dr. Holubec's curriculum vitae is attached.

The departments also consulted on the permafrost issue with the federal Department of Natural Resources Canada and their experts.

1.2 Statement of Issues

The two issues addressed in this submission refer to EIS Guideline requirements 602 and 603 and were initially identified in the GNWT Conformity Report.

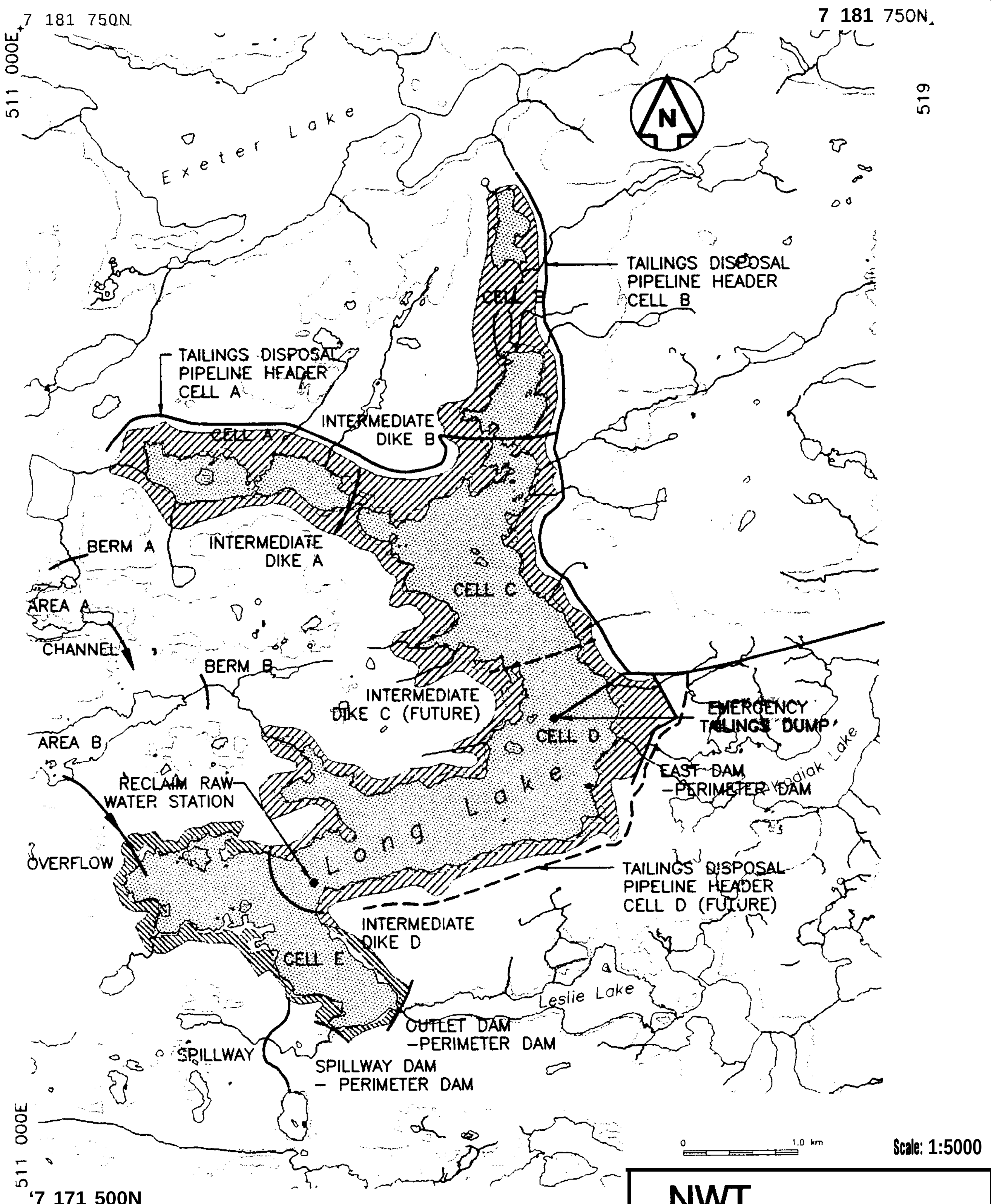
The first issue relates to Guideline 602, the use of frozen core tailings dams and the sole reliance on permafrost for the impermeability of the structure. The concern was whether this technology would be successful at this latitude and under both current and global warming climate conditions. It was also seen that the review and subsequent approval of the use of frozen core dam technology for this project would set a standard for the use of frozen core dams in the Northwest Territories. Therefore, it would be in all parties best interests that a thorough assessment of this technology be undertaken to assist the Panel when assessing the use of this technology.

The second issue relates to Guideline 603 (a), the long term stability of the tailings facility after closure. Two concerns were identified, the substantial surface area used for tailings deposition and the potential long term problems associated with tailings management and closure given the relatively large amount of clay material in the tailings.

1.3 General Background

The project will produce about 133 million tonnes of tailings that will be deposited into the Long Lake basin. The tailings storage area will be created by construction of permanently frozen perimeter dams and intermediate seepage dykes that will form five cells (Figure 1). The tailings will be deposited in four cells with a fifth cell to be used to clarify the effluent water before discharging the water into the downstream course.

The tailings are the product of milling Kimberlite ore that produces a fine grained material composed of about 75% sand sized particles and 25% silt and smectite clay. By volume the silt and clay represents about 33% of the tailings. The smectite clay has undesirable properties that cause it to remain in suspension for a long period, consolidate poorly and readily erode.



Technical Submission
FIGURE 1

NWT
DIAMONDS
PROJECT

Figure 2.6-1
Tailings Impoundment

Source: EBA Engineering

The proposed tailings plan places the tailings along a longitudinal low area within a 45 km^2 watershed. The tailings in Long Lake will raise the lake's surface elevation by as much as 14 m and enlarge the water surface footprint from about 620 hectares (ha) to about 1200 ha of tailings surface. The tailings will remain in the low area of the watershed where the runoff from adjacent slopes will concentrate.

The deposition of tailings will segregate the sands into beach areas near the tailings discharge point with the fines settling out further down slope in ponded water. The excess water in the cells will seep through the separator dykes into the downstream cells. Based on simple tailings volumes, it is estimated that the fines, with ponded water, may occupy about ⅓ of the area of the tailings cells.

2.0 USE OF FROZEN CORE TAILINGS DAMS

2.1 Background

The proposed tailings facility has three perimeter dams and four interior separator dykes that will contain water, settled tailings and suspended clay. The perimeter dams will contain water by using dams with a frozen foundation and internal frozen cores.

The proposal to use frozen core dams is enhanced by the proponent's design, construction method and scheduling. It is proposed to lower the water level in Long Lake before starting construction of the dams. This will provide additional time before water starts impounding against the dams. The dams will be constructed during the winter to promote quick freeze of the fill. Thermosyphons will be installed at one dam which has a zone of unfrozen foundation (talik). The lowering of the water level in Long Lake will stop the discharge at the outlet of the watershed where this dam is located which will be beneficial in freezing the talik.

It is the position of the departments that the frozen dam concept is an acceptable design for this project location. The validity of the frozen dam concept is supported by the Proponent's thermal analyses and published performance case histories of two existing frozen dams with practically identical climatic and foundation conditions. The project site's mean annual air temperature is -1 1.8°C which is similar to Lupin Mine at -12.1°C and Thule, Greenland at -1 1.1°C.

The first frozen dam similar to the proposed project dams reported in literature is from Thule, Greenland (Fulwider, 1973). Published temperatures from within the dam show that the frozen dam performed successfully over the warm summer months.

Considerable information on frozen core dam performance is available from the nearby Lupin Mine (Holubec et al 1982, 1986, 1988 and 1991). These dams were constructed in 1981 and monitored ever since. The information provides detailed temperature data from immediately after construction to long term performance under different reservoir conditions.

The tailings dams at Lupin Mine were constructed during the summer in 1981 from thawed silty sand till. The dams were designed with a plastic liner that was extended from the foundation to the crest to prevent seepage during the first one or two years before the internal core of the dam froze. This was also to ensure no seepage occurred through the upper portion of the dam during high reservoir water levels. One dam at Lupin Mine was constructed over continuous frozen ground which was about 1 m above the lake water level. The dam froze in one year and performed successfully as designed. However, a dam constructed over the outlet of the watershed experienced seepage in the foundation, just below the dam, as water started to impound behind the dam in the spring following construction.

It was concluded that the seepage was caused by excessive thaw in foundation below the dam during construction. This thaw was produced by a combination of excessive warming when the organic layer under the dam imprint was cleared during summer construction and the presence of a talik. Upon discovery of the seepage, a low permeability berm was constructed on the upstream toe of the dam that reduced the seepage to a 'trickle' and the dam foundation froze completely during the following winter.

Another observation made at the Lupin Mine was that reservoir levels should not be allowed to rise above the crest of the frozen core. About four years into the tailings pond operation, the reservoir was allowed to rise to about 1.5 m below the dam crest. The dam fill performed as designed even though the thaw depth below the crest was about 4 m because the dams were designed with a plastic liner. However, seepage occurred in the abutments. This seepage occurred because the fill over the abutments was not sufficiently thick to keep them frozen. The seepage was stopped by lowering the reservoir water level.

Frozen dams have been constructed in North America and Russia with other mean annual air temperatures and designs. One of the more interesting dams presently under construction is the Raglan Project in northern Quebec. The Raglan Project has a similar mean annual temperature and foundation condition as the Proponent's. This dam design also uses the same winter construction method proposed by the Proponent. It would be informative for the proponent's consultant, EBA Engineering Consultants Ltd. (who are also the designers for the Raglan Project), to comment on the winter construction success and incorporate this experience into the Proponent's project.

2.2 **Review of Proposed Design**

The project will have three perimeter frozen dams, namely East Dam, Spillway Dam and Outlet Dam. The first two dams will be constructed over ‘dry’ land underlain by continuous permafrost while the Outlet Dam is located at the outflow end of Long Lake. This location currently experiences continuous water outflow with the flow varying through the year. The continuous flow has produced an unfrozen section, talik, in the soil/bedrock foundation. The Outlet Dam is the most critical of the three dams because it has a talik in the valley bottom, is the highest(17 m) and is located upstream of the proposed Leslie pit.

Two aspects critical to the stability of the perimeter dams are:

a) freezing of the foundation and the development of a frozen core within the dam, and

b) having an adequate freeboard for the maximum reservoir level.

a) **Freezing the foundation and developing a frozen core**

The departments are confident that an ice core dam can be successfully developed and maintained at this location. The Proponent has used all the necessary steps to create the frozen condition as early as possible. The measures are as follow:

- lower the Long Lake water level to stop water flow at the Outlet Dam depression and provide about 2 years water reservoir storage before water starts damming up against the dam

- use winter construction to freeze the dam section quickly during construction

- use thermosyphons at the Outlet Dam to speed up the freezing of the talik (Thermosyphons are not required at the other two dams because of continuous permafrost in their foundations)

- quality control and monitoring programs as outlined in EBA Engineering Consultants Ltd. December 1995 Report titled “Tailings Dams Preliminary Design Report” Sections 9.7 and 10, and

- employ mitigative measures including those described in Section 4.4 of the above listed EBA report.

It is noted that lowering the Long Lake water surface to El 446.0 m will reverse the seepage through the talik between Long Lake and Leslie Lake as the current elevation of Leslie Lake is EL 447.5 m.

b) Freeboard during maximum reservoir level

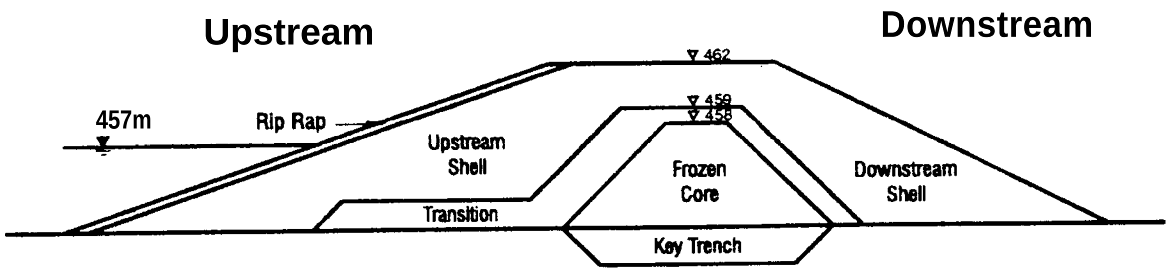
It is important to provide a conservative freeboard between the highest predicted reservoir water level and the crest of the impermeable zone. The proposed frozen dams at the project are constructed from cohesionless material (ie. silty sand and blasted rock) and the frozen core represents the impermeable barrier. Therefore the freeboard is the difference between the maximum reservoir water level and the top of the frozen core during the maximum summer thaw. The proponent is considering freeboard as the difference between maximum reservoir level and the top of the dam structure. It has to be noted that the upper portion of the dam structure, above the frozen core, is permeable.

The proposed design for the perimeter dam has the crest at El 462.0 m and the top of the frozen core at El 458.0 m as shown in Figure 2. During the maximum thaw depth, the effective crest of the dam that retains the water is the top of the frozen core. Thermal analyses of active layers presented in EIS Volume II - Environmental Setting (Page 2.23) shows the active depth to range from about 1 m in a stratigraphy of 0.4 m organics over 1.5 m till over rock to nearly 5.0 m where bedrock is exposed at the ground surface (Figure 3). However, the Proponent's Tailings Management Plan and Preliminary Design of Retention Structures document indicates active depths of about 2.5 to 3 m under the crest of the dams. These two documents provide a considerable spread in the active layer depth for relative similar conditions of exposed rock and blasted rock under the dam crest.

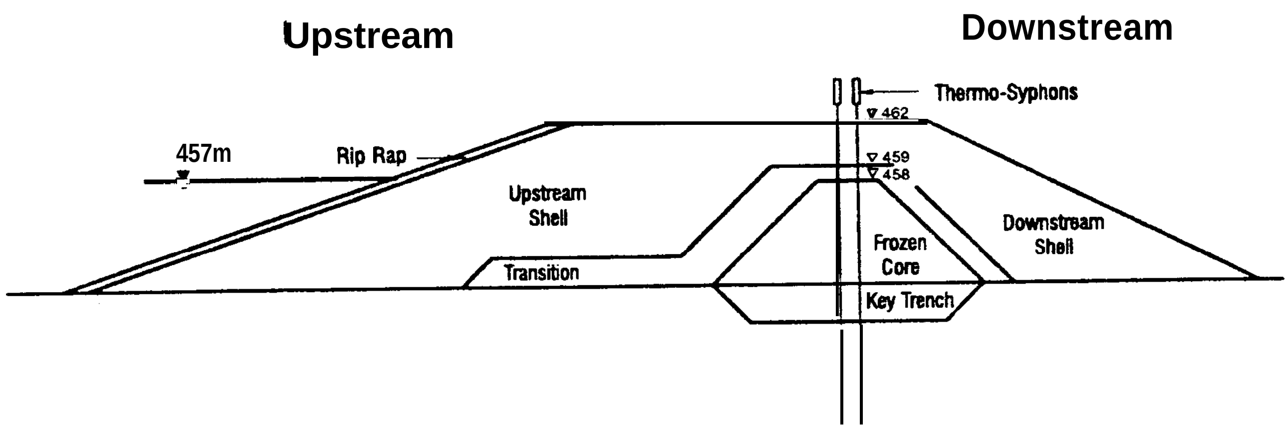
Thermal monitoring of the active zone in the dam crest at the Lupin Mine showed that the active zone depth is about 4.0 m (Holubec 1991). This depth is reasonable for granular material with an absence of vegetation and high exposure to sunlight. However, this does not provide any factor of safety for extra thaw under unusual warming conditions.

The Project design shows the normal full reservoir level to be at El 457.0 m that is governed by a 15 m wide emergency spillway with invert at El 457.0 m (EIS Volume I - Project Description, Section 2.6.1.1 Perimeter Containment Dams). The designer also assumes that the reservoir level may rise 0.6 m due to heavy runoff to EL 457.6 m. Section 4.2.2 of the EBA document considers fetch and wave action which, when combined with the maximum reservoir elevation, could exceed the crest of the frozen core.

The conclusion is that the active zone could likely be 4 m or more which results in the frozen core crest being at or below El 458.0 m. The maximum water level in the reservoir could be at or above El 458.0 m. This does not provide any effective freeboard. Under these potential conditions, tailings effluent could begin to seep over top the frozen core resulting in progressive deterioration of the core.



Perimeter Dam - Typical Cross Section
(Applicable to all Dams)



Perimeter Dam Founded on **Talik** – Typical Cross Section
(Applicable to Segment of Outlet Dam Only)

0 10 20
SCALE (metres)

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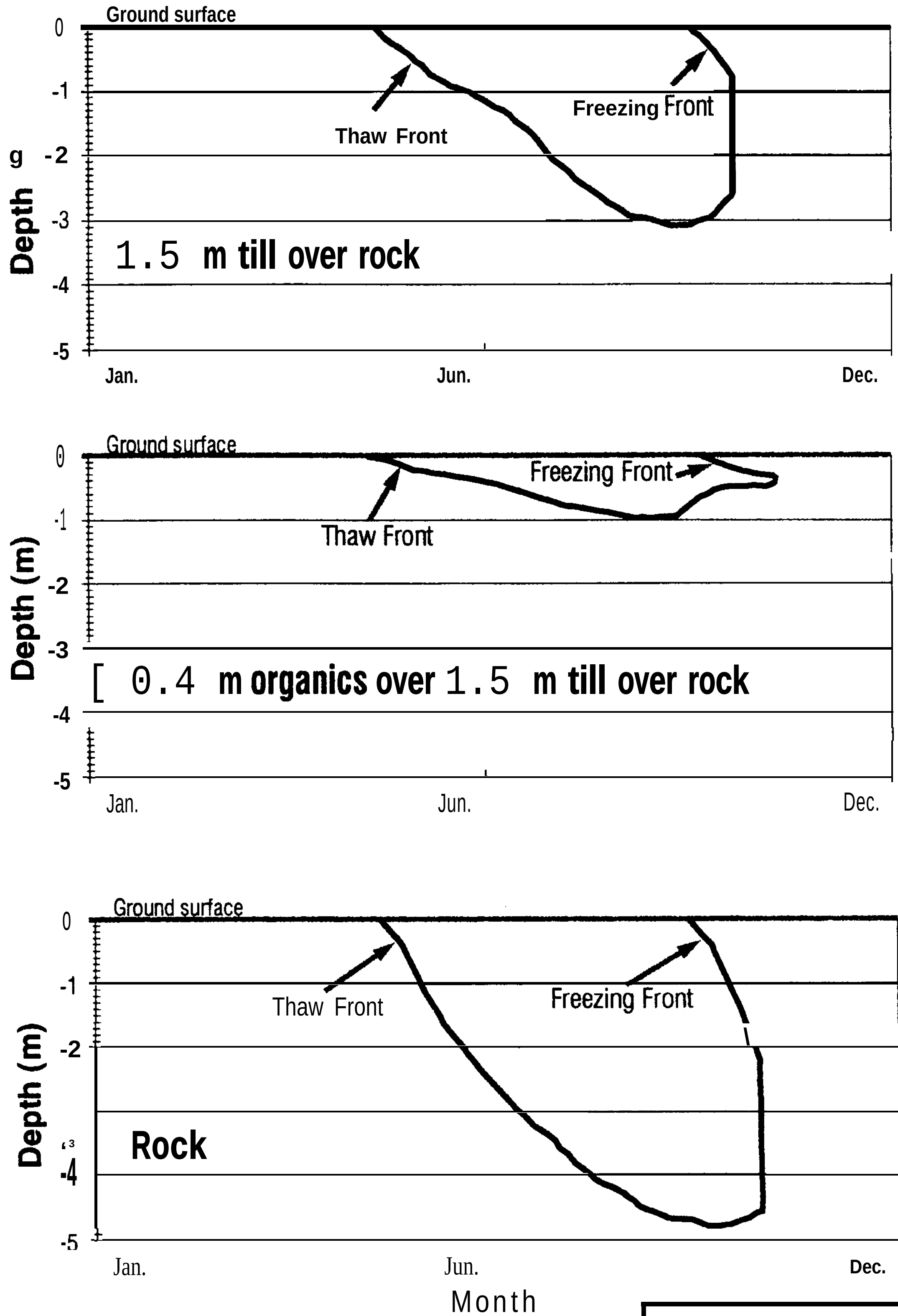
FIGURE 2

NWT DIAMONDS PROJECT

Figure 5.2-3
Perimeter Dam
Typical Cross Section

Source: EBA Engineering



Technical Submission
FIGURE 3

(Note the region above the thaw front and below the freezing front is above O°C, hence the active layer)

NWT DIAMONDS PROJECT

Figure 2.1-8
Predicted Position of the Phase Boundary

Source: BGC

2.3 Recommendations

The construction of frozen core dams by the Proponent is feasible as long as proper construction procedures are followed and the design provides adequate freeboard below the active depth for maximum high water levels. To ensure that these are obtained, we recommend the following:

1. The Proponent should obtain more detailed foundation condition information at the Outflow Dam talik (stratigraphy, particle sizes and hydraulic conductivity). This information should be incorporated into the detailed dam design.

2. The Proponent should review the available freeboard below the frozen core during the conditions of maximum thaw and reservoir level. These worst case factors should be assessed and incorporated into the detailed dam design.

3. The quality control and monitoring programs as outlined in EBA Engineering Consultants Ltd. December 1995 Report titled “Tailings Dams Preliminary Design Report”, Sections 9.7 and 10, should be instituted and maintained.

4. Construction of the Outlet Dam should be scheduled and completed as early as possible during the winter construction period to obtain the maximum freezing of the talik. It is noted that the thermosyphons will not be effective until the following season if installed at the end of the winter season.

3.0 LONG TERM STABILITY OF THE TAILINGS FACILITY

3.1 Background

The Proponent proposes to deposit all tailings in the Long Lake depression in four cells through the construction of four separator dykes as shown in Figure 1. The proposed tailings facility will contain a total of 133 million tonnes of tailings that will be produced during the planned 25 year mine production. This weight of tailings translates to a total volume of tailings of about 90 million m^3.

The tailings will consist of about 75°A sand and 25% fines (silt and clay) by weight. This translates to about 67°A sand and 33% fines by volume. Occasionally, the silt and clay fraction may be as high as 50% by weight, depending on the ore being milled. During the deposition of tailings in the cells, the sand will settle out either on beaches or in ponded water. However, the fines will form a slurry that will consolidate very slowly. It is estimated that the initial solid content of the slurry will be about 20°/0 which will increase to about 40°/0 solids after 30 years of consolidation (estimated from EBA Tailings Management Plan, Section 2.0 Tailings Properties and Behavior). Furthermore, the smectite clay will readily re-suspend if disturbed, resulting in turbid water.

Long Lake currently is about 8,400 m long and 730 m wide with an average water depth of 7.4 m and a maximum depth of 32 m. The water surface with an area of about 620 ha is located within a 4,560 ha watershed. Long Lake will be used for tailings by constructing four cells using separator dykes. The proposed final tailings level will be raised between 14 m at Cell A and 7 m at Cell D above the existing Long Lake water level. Information regarding the geometries of the proposed watersheds and cells is given in Table 1.

The description of the tailings deposition provided by the Proponent indicate that the tailings will be discharged at the far end of the cells, as viewed from the separator dykes. This will form sand beaches away from the separator dykes and create ponded water against the separator dykes. The separator dykes are designed to allow seepage into the downstream unused cells. This seepage may be hindered by the slurry settling against the upstream slope of the separator dykes. If sufficient water does not seep through the cells, water will have to be decanted by some means.

The slurry will collect, settle and consolidate in the area against the dams producing slurry ponds. These ponds may represent as much as 30°A or more of the cell surface. It is these areas that will be difficult to reclaim.

The cells will be filled progressively from upstream Cells A and B to the downstream Cells C and D. This will allow the downstream cells to be used for clarification of the water. Areas of watershed, existing water surfaces and final tailings areas estimated from Figure 4 are given in Table 1.

Table 1. Surface Area Characteristics

Item	Cells					Total
	A	B	C	D	E	
Watershed, ha	490	780	1050	770	1470	4,560
Existing Water-Surface, ha	50	40	150	260	120	620
Final Tailing Area, ha	140	130	300	445		1,015
Tailings as Percent of Watershed, %	30	17	30	58		
Tailings Surface Above Existing Water Surface, m	14	10	10	7		

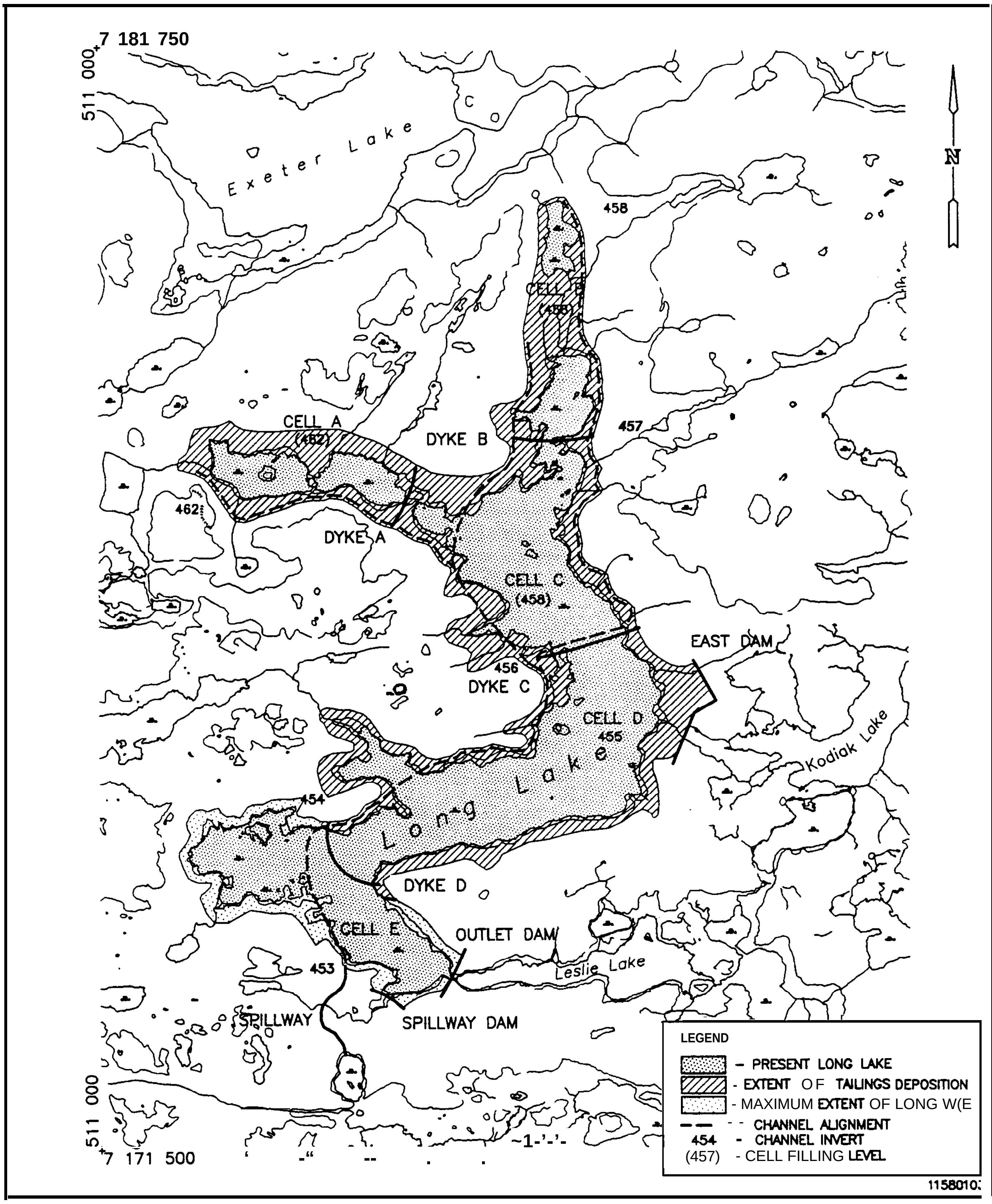


FIGURE 17 LAYOUT OF DRAINAGE CHANNELS AFTER RECLAMATION

Technical Submission
FIGURE 4

3.2 Comments

The closure plan for the tailings facility will leave a tailings surface area of about 1,015 ha in the low spot of the watershed area. The tailings surface will consist of areas that are either beached and settled sand tailings or ponded slurry. The relative magnitude of these areas may be about 70% settled sand and 30% slurry ponds underlain by silt and clay sediments. The slurry ponds will have both beaches and standing water.

The slurry ponds will likely be located adjacent to and in the central portion of the separator dyke in each tailings cell. Upon closure of the tailings facility, the slurry ponds may eventually become connected by drainage channels becoming part of the tailings area drainage system.

Based on the surface area estimates given in Table 1, the proposed tailings storage plan will make the least use of the upper most cell to store tailings, Cell B. The greatest coverage of the watershed areas with tailings is Cell D, the lowest cell.

a) Erosion cover over slurry ponds

The Proponent proposes, upon abandonment, to cover the beached tailings and partially cover the consolidated slurry with a layered sequence of coarse tailings, waste rock and reclaimed lake bed soil. It is also proposed to progressively place an erosion cover over the slurry ponds by working over the ice/frozen surface during the winter (EIS Volume Ill, Section 9.3.2.2).

Construction of a durable cover over the slurry ponds will be difficult for the following reasons:

- slurry pond areas may be rather large, could be as much as 300 ha,
- slurry will be composed of a highly plastic clay with poor success in consolidating in warm climates,
- freezing of the slurry is complex because of the consolidation process and possible inclusion of silt/sand layers, and
- there are no case histories available where such an undertaking has been performed with high clay content tailings in permafrost.

It is noted that the maximum depth of Long Lake is 32 m and it is proposed to place the tailings about 10 and 7 m above the existing lake surface at Cells C and D respectively. This means that at some location the slurry may as much as 40 m thick.

The departments are concerned that a permanent cover over the slurry ponds may not be achievable. The slurry will subsequently be exposed and eroded which may lead to increased downstream suspended solids loading.

b) Watershed drainage after closure

It is proposed to grade the tailings cover to direct the surface water in a new channel constructed along the side of the basin. The location of the proposed channels is shown in Figure 4.

There is concern that the surface water drainage from the watershed will revert with time into the existing lake location and start eroding the exposed smectite clay. The concern is based on the following observations.

1) The proposed tailings area will remain a low area within the surrounding watershed and therefore water flow will be directed into it.

2) Constructed rock lined channels, even in frozen tailings will change with time through erosion, and blockage by slope sloughing and sedimentation.

3) The provision of graded surface to control runoff from the tailings surfaces may be more complex than the Proponent envisions because of the size of the proposed tailings surfaces, uneven tailings surface produced by tailings discharge and the consolidation of areas of thick slurry. Furthermore, the end result of consolidation and freezing of slurry is unknown.

3.3 Recommendations

The large size of the proposed tailings area, with the presence of the slurry ponds, will make it difficult to provide the protective cover required to prevent erosion of the smectite clay. Therefore the following recommendations are made:

1) The Proponent should review the concept of concentrating the tailings in the upper watershed cells, especially Cell B, by constructing higher perimeter and separator dykes in this area. The large volumes of mined rock and coarse tailings could be used for the construction of these higher dams. The project may save on tailings surface reclamation costs in the long term because of the smaller tailings surfaces.

2) The Proponent should consider pumping slurry, concentrated in pond areas, into excavated open pits when the pits become available.

3) The Proponent should prepare a more detailed tailings deposition and reclamation plan with the intent to ensure minimum erosion of the tailings surface after closure of the tailings facility.

These recommendations should be assessed and incorporated into the final design and operational plans for the tailings management facility.

4.0 CONCLUSIONS

This review addresses two aspects of the proposed project, construction and stability of the frozen core dams and long term stability of the tailings facility after closure.

4.1 Frozen Core Dams

Our opinion is that the frozen core dam design is an acceptable concept for cold arctic regions and this type of dam will perform satisfactorily at this location. Conservative attention must be paid during design to water level fluctuations with respect to the top of the frozen core and the construction must be performed under strict control.

Any modifications to the frozen core dam design required to accommodate the concerns in this submission will be minor and can be handled during final design. Further, the ongoing monitoring program should identify any problem areas in a timely manner and sufficient resources are available at the mine site to rectify any problem during the operational period.

4.2 Tailings Facility

The placement of tailings in the valley of a relatively large watershed challenges the capability to provide long term erosion control after mine closure. It is our opinion that the Proponent should consider concentrating the tailings in a smaller area in the upper reaches of the local watershed. This will provide for reduced erosion susceptibility and allow more conservative final erosion control because of a smaller footprint. Locating the tailings in smaller zoned cells in the upper reaches of the watershed would reduce the erosion mechanism and its rate, and would be more conducive for the application of more substantial erosion protection.

5.0 REFERENCES

BHP-Diamet NWT Diamonds Project, Environmental Impact Statement Vol. 1, II and Ill, 1995.

Dufour, S. and Holubec, 1.1988. Performance of Two Earthfill Dams at Lupin, N.W.T. Proceedings of the 5th International Conference on Permafrost, Norway, Vol. 2, pp 1217-1222.

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Fulwilder, C. W., 1973. Thermal Regime in an Arctic Earthfill Dam. Proceedings of the 2nd International Conference on Permafrost, Yakutsk, USSR, North American Contribution, U.S. National Academy of Sciences, pp 622-628.

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Holubec, 1. and Dufour, S. 1986. Performance of Frozen Tailings Dams. Presented at Geotechnical Stability in Surface Mining Symposium, University of Calgary.

Holubec, 1. 1991. Temperature Monitoring of Frozen Dams and Tailings at Lupin Mine, DRAFT, Geocon Inc. report to Lupin Mine.

APPENDIX

IGOR HOLUBEC, P. Eng., Ph.D.

Education

B.A.Sc., Civil Engineering, University of Toronto, Ontario, Canada, 1959
M.A.Sc., Soil Mechanics and Highway Engineering, University of Toronto, Ontario, Canada, 1961
Ph. D., Soil Mechanics, University of Waterloo, Ontario, Canada, 1966

Professional Affiliations

Professional Engineers of Ontario, (Consulting Engineer)
Canadian Geotechnical Society
Canadian Institute of Mining and Metallurgy
Canadian Dam Safety
Tunneling Association of Canada
American Society of Civil Engineers

Experience

Over 30 years of diversified consulting gee-environmental engineering experience across Canada and internationally covering most climatic and geological conditions. Assignments varied from initial site selection and environmental assessments to surface water management, design of water supply, geotechnical design of plant sites and earthworks and final decommissioning of sites. Projects included: heavy plants, pipelines, marine structures, mines and transportation projects.

Magnola Project, Noranda Metallurgy Inc. Evaluated the J.M. Asbestos Mine site for locating the proposed magnesium plant This involved locating the plant, conceptual design of residue storage area and determination of the availability of water, electricity and natural gas.

Magnola Project, Noranda Metallurgy Inc. Assessed options for storing plant residue in constructed ponds, an existing open pit and filter cake mounds. This included conceptual designs to prevent groundwater contamination and estimating order-of-magnitude capital and operating costs.

Kudu Project. Provided the geotechnical due diligence assessment of three mines in Brazil, Indonesia and Canada and an aluminium smelter in Brazil.

QIT-Fer et Titane Inc. Identified sources for fresh water supply for a heavy mineral plant. Directed seepage and contaminant transport analyses to minimize water requirements for dredge mining and developed fresh water supply for the mine and plant by proposing a combination of well pumping and a river supply to be stored in above and inground water reservoirs

Sidbec-Dosco (ISPAT) Inc., Etobicoke Works. Performed Phase II environmental evaluation, prepared a clean-up plan and contract documents, obtained government permits, and managed the clean-up.

Stelco, Lake Erie Works. Designed leachate pumping systems for two slag storage areas and prepared technical specifications. The work included runoff and seepage water estimation, design of one pond, pumphouses and pipelines to existing water treatment plant.

Ocelot Oil Industries. Manager for geotechnical design and construction for a methanol plant located in Kitimat, British Columbia. Responsibilities included: site selection; site preparation in an estuary area; foundation design for a furnace, storage tanks and a wharf. Design for liquefaction and rapid construction were some of the design challenges.

Esso Resources. Geotechnical reviewer for the design and construction of a refinery at Norman Wells, Northwest Territories. The 'warm' permafrost created unstable ground conditions for the construction of pile foundations and collection ponds.

Strait of Canso Port Facilities. Senior geotechnical engineer for the design of wharf facilities to handle very large oil tankers in the Strait of Canso, Nova Scotia. The design involved caisson piles and concrete cell foundations for the main and transshipment wharves, and land site preparation.

Department of National Defence. Manager for geotechnical design and construction monitoring of 10 short range radar stations along the Arctic coast in western Northwest Territories. Developed, tested and employed a high capacity grouted pile to support the elevated structures in permafrost

Saskatchewan Power. Lead geotechnical engineer in the design and monitoring of Rafferty dam that was constructed over very soft clay. The dam had to be built on top of a wick drain foundation to prevent instability of the earth embankment.

Kenya Petroleum Ministry. Manager for the geotechnical design and construction of a large petroleum storage facility at the Port of Mombasa. Work included: site stabilization which had experienced slope failures; foundation design for 65 m diameter floating roof tanks located on unstable ground; surface water management and water intake structure.

Echo Bay Mines Ltd., Lupin Project. Manager for geotechnical engineering. Designed the airstrip and tailings facility, managed the construction of the earth dams and monitored the performance of the frozen dams and tailings for eight years.

Arctic Pilot Project. Geotechnical manager for site investigation and the geotechnical design of a wharf and support facilities for a LNG plant on Melville Island, NWT.

Bell Mine, British Columbia. Project Manager and Geotechnical Specialist in the development of closure design of a copper mine with acid drainage problem.

Saskatchewan Power. Lead geotechnical engineer for the design and construction of the Alameda Dam. The dam was underlain by highly plastic shale that required careful construction control based on 2D and 3D stability and finite element deformation analyses.

Ankara Subway, Turkey. Reviewed the stratigraphic and groundwater conditions along the line and provided comments on excavation procedure, drainage system and earth pressures.

Yukon Territory Water Board. Technical advisor to the Water Board in their review and permitting of mines in the Yukon.

Syncrude Ltd., Oil sand mine in Alberta. Technical advisor for the design of 40 m high dykes on soft dragline spoil.

Caroline Gas Plant, Alberta. Manager for site preparation.

Syncrude Canada Ltd. Geotechnical consultant on various assignments and manager for mine highwall monitoring team for four years. The low stability of the dragline cut into oil sand and soft sedimentary rocks resulted in the need for continuous monitoring of the mine cut by means of visual, survey and geotechnical instrumentation.

Aleyaska Oil Pipeline. Senior geotechnical reviewer of the oil pipeline design for the U.S. Dept of Interior. Reviewed the geotechnical design of access roads, pipeline pad, foundations, tanker terminal and pump stations.

Nuclear Power Plants. Senior geotechnical engineer for the design and construction monitoring of two nuclear power plants, one in North Carolina, U.S.A. and the other in northern Italy.

Coal Mines. Contributed the geotechnical expertise to a State-of-the-Ah Study for the U.S. Dept of the Interior and provided tailings pond designs for several coal mines in eastern U.S.A.

Designed earth dams in eastern U.S.A

Publications

Published 26 papers and gave lectures across Canada and internationally.

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EXPERIENCE RELATED TO ARCTIC ENGINEERING

Since 1974, Dr. Holubec has worked on a large number of diversified projects in permafrost across Canada and Alaska. The projects ranged from site selection and conceptual design to detailed design, representations before regulatory agencies, construction control and management and performance monitoring. Major projects which illustrate his achievements in permafrost are:

Senior geotechnical reviewer of the design of the Alaska Oil Pipeline in 1974 to 1975.
Site studies and geotechnical design of a proposed LNG wharf and gas liquification facilities for the Arctic pilot Project on Melville Island, N.W.T., 1978 to 1980.

Design, construction and temperature monitoring of frozen dams at the Lupin mine, Echo Bay Mines Ltd., N.W.T. 1980 to 1989.

Site evaluations, foundations and earthworks design, and pile installation for Long and Short Range Radar Stations across Canada. Developed Arctic grout pile design for soil permafrost conditions. The design was based on extensive experience with cold room grout testing, field pile installation and pile load testing, N.W.T., 1985-1988.

Other projects in permafrost

Proposed Izok Project, Winter Haul Road
Provided an extensive review of gravel pads performance on permafrost from case histories and personal experience to develop design recommendations for thin gravel cover for winter haul road. It was concluded that thin gravel pads will produce a low permafrost disturbance and will revegetate most readily upon road abandonment. Design and construction recommendations were provided. Metall Mining Corporation, 1993.

Preventing AMD by disposing of Reactive Tailings in Permafrost
Conducted a review of permafrost across northern Canada and discussed the relevant factors that have to be considered in disposing reactive tailings in permafrost. Based on case history data, guidelines were proposed for storage of tailings in permafrost and designs of tailings impoundments for closure condition. prepared for New Ideas Projects, MEND, 1993.

Guidelines for Arctic Foundation Design
He co-authored the above guidelines writing the chapters of pile foundations and road and embankments and contributing to the other chapters. These guidelines were prepared by HBT AGRA Limited for Public Works of Canada (May 1992).

Short Range Radar Stations, Western Arctic
Provided geotechnical recommendations for roads, airstrips, helipads and building pads. Designed pile foundations for saline, non-saline and bedrock conditions for nine sites in the Canadian western Arctic. Also provided consultations on earthwork construction, methodology and scheduling and finally interpreted pile load test results to ensure that the installed piles met the design specifications (for UMA Engineering Ltd/1 CEU, 1987 to 1991).

Khariaga Oil Field, Arkhangelsk Region, U.S.S.R.
Visited the proposed Khariaga oil field located on the Arctic Circle east of Arkhangelsk, U.S.S.R. and reviewed the U.S.S.R. Ministry of Oil site data to develop conceptual designs for foundations and earthworks and geotechnical components of pipelines and drill pads. The site area, about 8 km by 30 km, is located in a sensitive discontinuous permafrost zone covered by muskeg and underlain by unstable ice-rich soils (3 months, 1987).

Long Range Radar Station
Provided consultation in the development of design and construction specifications for anchor piles for the modification of three existing radar domes in central Arctic. Followed by over-viewing three geotechnical engineers supervising the construction (Metcalf& Eddy Inc., 1986). Arctic Ports Handbook, N.W.T.

Headed the geotechnical contribution for an Arctic Ports Handbook prepared for the design of port structures in the Canadian Arctic waters. The contribution included geology, permafrost and seismicity and discussion of site studies; foundation and earthwork design; soil improvement methods, and performance monitoring. Handbook was prepared by Lavalin for Transportation Development Centre, Canada (3 months, 1984).

Proposed Tungsten Mine, Yukon Territory
Developed conceptual geotechnical design of on-site facilities for a proposed tungsten mine located at MacMillan Pass on the border of the Yukon and Northwest Territories for Amex of Canada Ltd. Work encompassed location and geotechnical design for plant, tailings pond, fresh water sources, airstrip, roads and availability of construction materials (4 months, 1982).

Lupin Mine, Contwoyto Lake, N.W.T.
Supervised field surveys and geotechnical design of a new mine, including airstrip, plant foundations, tailings disposal area, and fresh water intake, for Echo Bay Mines Ltd., Contwoyto Lake, N.W.T. Subsequently represented the client at hearings and supervised the construction management and control of the tailings dam (2 years, 1980-82);

Camlaren Mine Reclamation Developed potential schemes for reclaiming an abandoned tailings pond which was polluting adjacent Gordon Lake. In this work the reclamation design was developed and the capital cost of the work with potential annual maintenance costs was established. Following this work a scheme was selected and executed. Department of Northern Affairs, Canada, 1985.

Frozen Dam Thermal Monitoring
Having designed and overviewed construction of frozen earthdams for Echo Bay Mines Ltd. at Contwoyto Lake, N.W.T., subsequently monitored and evaluated the thermal regime of these dams for Department of Supply and Services (on going since 1982).

Salmita Gold Mine
Designed an earth tailings dam on permafrost at Salmita Gold Mine on Bulldog Lake, N.W.T. for Giant Yellowknife Mines Limited (2 months, 1982).

Foothills Gas Pipeline, Yukon
Conducted stability and thermal analyses of a large-diameter (1200 mm) bermed gas pipeline. Developed a design for insulating above-ground pipelines in granular embankments to reduce either thawing or freezing of the foundation soils; provided block foundation design for a frost heave test facility, and conducted an overview of a mile-by-mile terrain evaluation (Foothills Pipeline Ltd., 1977-81).

Sea Bed Production Pipeline, Melville Island, N.W.T.
Conducted the geotechnical evaluation of the construction procedure and stability of a buried gas production pipeline within a frozen protective envelope to resist ice scour. Work also included evaluation of the seabed soils, trench plow capability and trench stability (Panarctic Oils Ltd., 1980).

Proposed LNG Wharf and Terminal, N.W.T.
Supervised selection of site for a potential LNG terminal; organized preliminary site survey, and provided preliminary layout and geotechnical design comments for a wharf; barge containment areas, and site services, for Arctic Pilot Project Group, Ellef Ringnes Island, Northwest Territories (4 months, 1979).

Arctic Pilot Project, Melville Island, N.W.T.
Responsible for field work and geotechnical design, and attended hearings for a proposed LNG terminal for Petro Canada in Bridport Inlet, Melville Island, Northwest Territories. The assignment included developing detailed bathymetry and geotechnical data; providing geotechnical design recommendations for a marine terminal; on-site services, such as: airstrip; camp; granular resources; as well as earthquake evaluation; liquefaction, and dynamic slope stability and thermal analyses of barge containment areas (3 years, 1978-80).

Elsa Mine, Yukon
Provided design for winter construction of a 5 m high by 450 m long water retention dam over muskeg and permafrost, and subsequently monitored the construction, for United Keno Hill Mines Ltd., Elsa, Yukon (5 months, 1979).

Alaska Gas Pipeline, Alaska, U.S.A.
Developed representative soil conditions for the critical area of the proposed Alaska gas pipeline andmodelled soil/pipe load/deformation behaviourforpipe stress studyofalarge-diameter gas pipe. Testified before regulatory agencies in Washington D.C. (Northwest Pipeline Co., 1977).

Artificial Island, Beaufort Sea, N.W.T.
Participated in the evaluation of sea bottom conditions for a feasibility study of a production platform, for Petro Canada, Beaufort Sea, Northwest Territories. Also responsible for ice scour and permafrost distribution (2 months, 1976).

LNG Facilities, King Christian Island, N.W.T.
Responsible for all logistics and site investigations for a proposed LNG marine terminal, and prepared preliminary geotechnical design parameters for the construction of a dock; causeway; dredging, and onshore foundations, for Dome Petroleum Limited, King Christian Island, Northwest Territories (3 months, 1977).

Alyeska Oil Pipeline, Alaska, U.S.A.
Reviewed the geotechnical design criteria and "mile-by-mile" design of the Alyeska Oil Pipeline and several pump stations, including design of above- and below-ground pipe modes and associated erosion control procedures, for Mechanics Research Incorporated, Alaska. Special attention was given to slopes in frozen ice-rich soils and potential creep of vertical support members in frozen soils (U.S. Dept. of the Interior, 1974-75).