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Design and Monitoring of Earth Embankments over Permafrost

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SYNOPSIS: As the northern regions of Canada are developed, there is an increasing need to protect the fragile ecology as well as to maximize usage of local construction materials. The construction of earth dykes to retain liquid wastes is a common requirement in municipal and industrial developments. Frozen core earthfill dykes provide an effective technique to cut off seepage in cold permafrost areas (Sayles, 1984). The seepage of water through an unfrozen overburden or fractured bedrock foundation can occur and accelerate the thermal deterioration of an earth embankment. The development of the active layer during the summer reduces the dam's ability to retain water if the freeboard is inadequate.

Several earthfill dams were built at the Lupin mine near Contwoyto Lake in the Canadian Arctic to form a mine tailings pond. Even though design forecasts indicated 9 m high structures would remain frozen after impoundment of the reservoir, very few case histories were found to support the design. Several earth dams have been monitored since 1982. Initially, ground temperature measurements were taken with thermistor strings in short boreholes. More recently, deep boreholes were instrumented with thermistor strings and the ground probing radar has been used to confirm and locate unfrozen zones within the dams.

Specifically, the performance of three dams is reviewed here. The first dam, the base case, was built over virgin cold permafrost. The complete dam section froze during the first winter after construction. Part of the second dam was built over a 5 m deep talik associated with a seasonal creek and possibly a fault zone. The talik is apparently mostly refrozen and continuing to cool, however, geophysical surveys indicate a possible unfrozen remnant. The third dam was built across the reservoir after impoundment and during the winter. The internal nature of that dam and its thermal behaviour are quite different from the above two.

The thermal regime of the dams and underlying foundation has changed considerably over the five years following construction. The results of the ground temperature and radar profiles are compared for various seasons to reconstruct the transient thermal regime at uninstrumented sections. The findings are significant for the design and monitoring of future water retaining structures in the North.

INTRODUCTION

In today's developing North, there is a recognized need to protect the fragile ecology. As mine and industrial sites are developed and communities grow, the construction of earth dams and dykes to retain liquid wastes is a common requirement. In design of such structures there are economic pressures to maximize use of local construction materials. Frozen core earthfill dams are an effective retainment technique in cold permafrost.

However, before a dam is built the foundation conditions and the ground thermal regime must be sufficiently understood. The development of the active layer during the summer reduces the dam's ability to retain water if the freeboard is inadequate. The seepage of water through an unfrozen overburden or fractured bedrock foundation can occur and induce the thermal deterioration of the frozen earth embankment.

Several earthfill dams were built at the Lupin mine to enclose a small watershed and to form a mine tailings pond. The dams were instrumented with thermistor strings and frequently surveyed with a prototype ground radar. This paper reviews the design and performance of three of these dams. The results of the ground temperature and radar profiles are compared for various seasons to reconstruct the transient thermal regime at uninstrumented sections. This paper also discusses the significance of the findings for design and monitoring of future earthfill structures in the North.

BACKGROUND INFORMATION

Location

The Lupin mine is situated on the shores of Contwoyto Lake, some 380 km northeast of Yellowknife, N.W.T. (Figure 1). The area is characterized by low relief (less than 15 m), a poorly developed drainage pattern, numerous shallow lakes and cold permafrost. The mine is only accessible by aircraft during the summer or by a 400 km ice road during the winter.

The mean annual air temperature is -12.1°C with freezing and thawing indices of 5100 and 680°C-days respectively. Total yearly precipitation is 275 mm. Lake ice reaches a thickness of 2m.

A 614 ha watershed was formed by damming a seasonal creek and five saddles which connected at various elevations with adjoining watersheds (Figure 1). The dams were built during the summer of 1981. Prior to impoundment, the tailings pond area contained 15 lakes up to 15 ha in area and with water 1 to 6 m deep. Since 1985, the tailings area has been divided in two ponds: an upper pond (1) which receives the mill water and allows the solids to settle, and a lower pond (2) which stores the clarified and partially treated water (treatment is carried out while decanting water from the upper to the lower pond) prior to discharge into the natural environment.

The three dams which are the subject of this paper are: Dams 1A, 2 and J shown on Figure 1. Dam 1A was built across the valley of an intermittent creek, the outlet of the enclosed basin. At the time of construction, the talik beneath the bed of the intermittent outlet could not be completely subexcavated because of its saturated state and of the lack of time for completion during the same construction season. Temperature measurements have since shown the talik to extend 5 m below the original ground surface. Dam 2 was built over undisturbed permafrost between two lakes. Finally, Internal Dam J was built across the impounded reservoir. Internal Dam J was built where a shallow lake (up to 3 m deep) used to be and is about 13 m high from toe to crest. The water depth in the tailings basin at the time of construction was about 7 m. The dam has water on both sides.

Subsurface Conditions

The detailed geology and geomorphology at the dams are discussed in Holubec et al. (1982) and Dufour and Holubec (1988). One or two test holes were drilled at each dam site during the winter of 1980-81 for preliminary planning purposes. A go-ahead decision was taken shortly after completion of the preliminary engineering study and further field investigations were not carried out. The site of Internal Dam J was never investigated as it was not part of the initial tailings management plan. The following observations were made at seven test holes within the tailings area. Their results concur with those of nearly 30 holes drilled for the airstrip and the mine facility nearly 3 km.

The overburden is thin and consists of silty sand till 0 to 7 m. The surface is covered by a thin organic layer up to 45 cm thick in wet depressions. The till has from 12 to 42% fine-grained silt and up to 20% cobbles and boulders by weight.

The bedrock is generally competent phyllite with a weathered zone extending 1.5 to 3 m deep. The bedrock is generally highly fractured within the weathered zone. Frost-thrusted blocks (felsenmeer) are common on rock outcrops.

The soil and rock are permanently frozen. The thickness of the active layer varies from 0.6 m in thickly vegetated areas with overburden cover to about 2.5 m in general and up to 7 m occasionally in barren exposed bedrock areas. Ice lensing was observed to be of rare occurrence. The largest ice layer observed was 80 mm thick. Other lenses observed were smaller than 25 mm. The average moisture content is 14%. The undisturbed mean annual ground temperature was measured to be about -9°C. Based upon observations in the mine, the regional permafrost base extends to over 400 m deep.

The silty sand dam foundation and the thin overburden cover on fractured bedrock could pose substantial seepage and stability problems for a water retaining dam on an unfrozen foundation. In view of the cold permafrost regime, it was deemed that seepage could be prevented with a frozen dam core.

Dam Cross-Section

Dams 1A and 2 consist of a summer compacted, sorted silty-sand till (with no cobbles or boulders) core built over the surface stripped of organics. An impermeable membrane was provided on the upstream face and keyed into the permafrost at the upstream toe (Figures 2 and 3). The minimum soil cover on the membrane is 2 m.

Allowing for the thawing of the upper 2 m of overburden, it was predicted that the 6 m high stage I dam would freeze back in three winters at most. The prediction was based upon the review of other case histories and upon one-dimensional heat transfer analysis (Holubec et al., 1982).

Construction and Post-Construction Performance

Dams 1A and 2 were built during the summer of 1981. The construction sequence consisted of first placing the drainage blanket which also served as the access road. This was followed by building the part of the dam downstream of the impermeable liner, excavating the key trench, placing the liner and finally covering the impermeable liner to the crest.

Prior to placing fill the dam base areas were stripped of organics and hummocky soil down to frozen till. Stripping was immediately followed by fill placement to minimize frost degradation of the in-situ till. Construction of the dams was completed to elevation 485 m in early October 1981.

During construction, significant unfrozen soils were encountered at the location of the intermittent basin outlet (north end of Dam 1A). The saturated soils could not all be removed (for lack of adequate equipment and time) and the area was identified for post-construction monitoring. Mill tailings and effluent production began in May 1982 and shortly after thaw in July 1982, seepage was observed at the downstream toe of Dam 1A. A downstream blanket was placed to ballast the dam toe and an upstream silty sand blanket was also built to reduce the seepage. None of the other dams experienced water seepage.

During the winters of 1983-84 and 1984-85, the snow was kept clear of both the upstream and downstream toes of Dam 1A. Snow usually drifted to about 2 m deep on the toes of the dam, thus providing significant insulation.

During the summer of 1984, the pond water level was near minimum freeboard at Dams 1A and 2. The water elevation was higher than the elevation of the base of the active layer on the bedrock hill between the dams. The hydraulic gradient thus created caused escape of water through a heavily fractured area just beyond the south abutment of Dam 2. The seepage stopped upon freezing in the fall.

In August 1984, Dam 1A and 2 were raised to crest elevation 486.5 m by end-dumping unsorted overburden materials on the downstream side of the crest.

The tailings pond was drawn down during the summers of 1985 and 1986 because it had reached minimum freeboard and the water quality was acceptable for discharge into the natural environment.

Internal Dam J (Figure 4) was built in 1985 to divide the existing pond in two basins for water treatment purposes as mentioned earlier. Dam J was built with 150 mm minus mine waste rock (run-of-mill fill) dumped through the ice in the winter. It is estimated, based upon bathymetric soundings taken in 1980, that internal Dam J was built in 7 m of water. The dam was built with few controls and is rather irregular in cross-section due to several failures which resulted from the thawing of ice entrapped in the fill during construction. The waste rock material is relatively permeable and is unable to support a fluid head across the dam. Hence during the summer, dry tailings were borrowed from the existing tailings delta and placed against the upstream side in a thin layer. The following years Internal Dam J was widened on the downstream side in an attempt to take advantage of the cold winter temperatures in building up a frozen core which could further seal the dam.

It is interesting to note that the contaminated water has its freezing point depressed and that the growth of a watertight frozen core cannot be judged on the progress of the 0°C isotherm. In other words, to be watertight, the ground needs to be colder than 0°C. The actual freezing point depression remains undetermined at this time.

THERMAL REGIME

Instrumentation

The first set of thermistor strings was installed by Echo Bay Mines Ltd. in May 1982 to obtain preliminary ground temperature data to a maximum depth of 8 m. In April 1983, new and permanent thermistor strings were installed to formally monitor the dams' thermal regime but again limited to 8 m. Two 15 m deep strings were installed in October 1983. Most instruments were lost while the dams were raised in August 1984. Thermistors were replaced in April 1985 to depths varying between 15 m and 25 m at one section through each of Dams 1A and 2. One thermistor string was installed at Internal Dam J just before this paper was written in August 1987.

Dam 1A

Based on preliminary thermistor readings and seepage observations during the summer of 1982, it is believed that the fill and subjacent active layer froze during the first winter. Only the foundation talik beneath the old creek bed remained unfrozen. The 1983 ground temperature readings on Figure 5 show that the foundation is just below 0°C at the fill/foundation interface and just above 0°C at bedrock. The talik was defined to extend down to elevation 473 m, or 3 m into a bedrock.

All thermistors below the crest of Dam 1A at the creek section (along string D1A-12) show a cooling trend. There is also a net drop in ground temperature after the pond level was drawn down in 1985 and the seepage consequently reduced. The pond level fluctuations are shown in Figure 5. For example, at 18 m deep, the temperature dropped from -1.5°C to -2.2°C.

It is interesting to note that after 1985 the amplitude of seasonal variations increased. This is most likely due to better heat transfer and deepening of the depth of zero seasonal fluctuations following the freeze-back of the underlying soils.

The talik froze back at the instrumented section during the winter of 1984-85, four years after construction. There is little doubt that snow clearing at the dam toes played a large role in the talik freeze-back.

The isotherms in Figure 6 show the thermal regime as at August 1987. The dam section is comfortably below 0°C and well within the depth of large seasonal variations. A bulb colder than -5°C extends from the downstream area into the central core. Readings discussed above show this core is still expanding (cooling).

Dam 2

The fill and thawed part of the foundation soils froze completely during the first winter. This section is representative of all of Dam 2 and of the part of Dam 1A outside the talik area. At mid-summer 1982, thermistors showed a dam core temperature of -1°C (Holubec et al., 1982). By the summer of 1987, the ground temperature at the same location was down to -3°C (Figure 7).

The evolution of the ground temperature is shown on Figure 8. All curves for the deep sensors beneath the dam core show a cooling trend. It is conceivable that the temperatures will eventually approach the mean annual ground temperature of the area. Figure 8 also shows that the depth of zero seasonal variations is about 18 m.

The 1986 pond drawdown appears to have been followed by a 0.4°C temperature drop at 20 m beneath the dam crest (elevation 466 m).

Figure 7 illustrates the isotherms as at August 1987. The foundation beneath the core is colder than -5°C and the dam core itself is clearly within the depth of great seasonal temperature variations. A natural lake some 100 m downstream of the dam probably influences the position of the -4°C isotherm.

Internal Dam J

Ground temperature data collection at internal Dam J commenced at the time of writing and is not yet available. It can be inferred that the complete dam section was probably unfrozen during construction and until the dam was widened.

It is likely that a significant talik existed beneath the former lakes over which part of the dam is built. As for former dry land, it is estimated that there could be up to 5 m of thaw. Hence the thermal regime beneath Internal Dam J is quite complex and varies significantly along its length.

GROUND PROBING RADAR SURVEYS

Ground probing radar (GPR) surveys were undertaken during late June and September of 1986 and April of 1987 along Dams 1A, 2 and J. The purpose of the GPR surveys was to establish if a high resolution geophysical technique, such as ground probing radar, could detect unfrozen zones (taliks) within or below the dams and so reveal a picture of the dam and overburden conditions.

Ground probing radar is a fairly new geophysical tool, the first models being commercially available in the mid nineteen-seventies. GPR is similar in principle to the reflection seismic method in that a pulse of energy is directed into the ground and the arrival times of reflections from subsurface interfaces are recorded. Seismic and ground radar records are very similiar, the most visible difference being in the magnitudes of the vertical time scales. The main difference between the techniques is that radar uses an electromagnetic as opposed to an acoustic energy source. Radar possesses a much more limited depth of penetration than seismic, typically of the order of 50 m or less, but provides a significant increase in resolution. Subsurface resolution is dependant upon the pulse length and, as such, can be as low as 0.5 m. This high spatial resolution can be important in the solution of complex near surface problems.

The depths to specific reflectors are calculated from a knowledge of the subsurface radar velocity distribution. In air, the radar pulse, typically in the MHz or GHz frequency range, travels with the speed of light (0.3 m/ns). In the ground the pulse travels with a velocity which is dependent upon the electrical properties of the material traversed. This velocity will be some appreciable fraction of the speed of light, usually between 10% and 50%. The radar velocity distribution in the ground can be determined, as in the case of seismic surveys, by a common depth point sounding (CDP) (Annan and Davis, 1976). Subsurface velocities to different interfaces are calculated from a plot of antenna separation versus travel time.

Dam surveys

Dams 2 and J were initially surveyed in June of 1986. Internal Dam J was resurveyed in April of 1987. A third site, Dam 1A (Figure 1) was surveyed in late September of 1986 and resurveyed in April of 1987.

The dams were profiled using an A-Cubed Pulse-EKKO III ground probing radar equipped with 50 and 100 MHz antennas. The horizontal axis on the radar profiles represents the distance along the dam, while the vertical axis represents travel time (nanoseconds) to a particular reflection event.

Dam 1A

Dam 1A was surveyed with the object of mapping one or more large unfrozen zones (taliks) which were thought to exist in the dam's foundation. This dam was surveyed using the 100 MHz antennas in September of 1986 in order to provide the best subsurface resolution. The April 1987 survey employed the 50 MHz antennas to achieve maximum penetration in the absence of an active layer. The station interval was 2 m.

Two radar profiles were obtained at this site, one along the crest of the dam and one at a lower elevation along the downstream toe road. The latter profile is shown in Figure 10. Common depth point soundings were taken in both cases. The ground wave velocities at the top of the dam and on the access road are 0.094 and 0.081 m/ns respectively. These are approximately equal to the velocity estimates for Dam 2 discussed later.

The profile along the crest of the dam shows strong reflections from the interface between the original silty-sand fill and the gravelly-sand material used in raising the dams. The interface between the dam fill and the original overburden is also evident. The bedrock/overburden interface is not obvious on this profile. The holes drilled from the top of the dam, D1A-11 and D1A-12, indicate that bedrock is at least 10 m. This corresponds to a minimum of 220 ns in radar travel time.

The 300 m profile along the downstream toe road (Figure 9) shows three strong reflectors (Figure 10). Reflector R1 represents the interface between the gravelly-sand dam fill and the original silty-sand dam fill. Reflector R2 represents the interface between the silty-sand dam fill and the natural overburden. Reflector R3 represents the bedrock interface. Drillhole D1A-10 intersects the bedrock at 5.2m deep. The depth to bedrock at D1A-10 as calculated from the radar profile is 5.1 m. The radar profile shows a pronounced dip in the bedrock topography between locations 130 m and 210 m along the profile. This agrees with the drillhole data which indicates that the bedrock interface is substantially deeper (more than 10 m) at station 166 m.

Generally, returns are recorded to depth along the length of the profile. Two zones showing an absence of deeper reflections are marked on the profile. These are areas of high electromagnetic attenuation which are probably partially to substantially unfrozen. The absorption of electromagnetic energy in the central unfrozen zone has resulted in an extremely weak reflection from the bedrock interface between 170 m and 195 m (as indicated by the dashed line). Furthermore the lower radar pulse velocity associated with this zone has depressed that portion of the bedrock reflector which is visible. The bedrock interface thus appears slightly deeper than it actually is in this region.

The thaw zone between stations 60 and 90 m corresponds with the stream bed leading out of the original watershed, confirming that a talik existed prior to dam construction. The top of the zone lies at a depth of about 5 m. Thawing of the overlying overburden and dam fill has occurred under locations 180 m to 190 m.

Thermistors D1A-10, -12 and -13 are located on the southern edge of this talik which has reduced in extent since the construction of the dam. The talik starts at the top of bedrock beneath frozen overburden. The depth extent of this talik is not indicated by the radar profile.

Dam 2

Dam 2 was surveyed with the object of mapping the sub-dam bedrock and overburden competency. The 1984 seepage was observed to occur around the south abutment of the dam, near station 310 m on the radar profile (Figure 11). The core extracted from a drillhole at location 356 m, beyond the end of the radar profile, showed substantial fracturing through the first 5 m of bedrock.

Dam 2 was profiled from north to south using the 50 MHz antennas. The transmitting and receiving antennas were separated by 4 m and the station spacing was 4 m.

The interpretated stratigraphy is shown on the radar profile in Figure 11. The velocity (0.11 m/ns), determined from CDP soundings, can be used to calculate the depths to reflectors 1, 2 and 3 indicated on Fig. 11 (LaFleche et al., 1987b).

Reflector 1 is at a depth of about 2.0 m appearing to combine the boundary between the new and old dam material and the depth of the active layer. Temperature data from thermistors D2-5 and D2-6 indicate that the latter should reside between 2 and 3 m. Since both interfaces could be roughly coincident at this time of year it would be difficult to resolve them as separate events. It can however be observed that in many places reflector 1 is represented by a broad double pulse indicative of a complex boundary. The new dam fill is coarser sand which should retain much less moisture than the original silty-sand till. Such an interface should provide a good electrical contrast as indicated by reflector 1.

Reflector 2 is at a depth of about 4.2 m and represents the interface of the silty-sand fill with the natural silty sand overburden. The natural overburden should contain considerably more frozen water than the dam fill resulting in a strong electrical contrast. The dam fill material was obtained by drying excavated natural overburden material to substantially reduce its water content.

Reflector 3 varies considerably in depth along the profile. It represents the top of the bedrock. A substantial (5 m) dip in the bedrock topography is observed near the middle of the dam (at distance along the profile of 110 to 222 m). Drillholes D2-6 and D2-7 (Figure 11) indicate bedrock depths of 4.1 and 10.4 m respectively. The depths calculated at D2-6 and D2-7 from the radar profile are 5.9 and 9.5 m respectively. The discrepency arises from an uncertainty of the true velocity profile. Each layer of dam fill possesses its own radar velocity and thickness and these should be taken into account when calculating the true depth to bedrock.

Strong reflections are observed within the bedrock. These most likely represent included ice within the phyllite; the ice could be present either along cleavage planes or in fractures and joints. The bedrock material should possess a higher radar velocity than the natural silty sand overburden; the addition of an increased thickness of lower velocity material stretches out the traces in this area yielding a distorted image of the deep structure.

Internal Dam J

Internal Dam J was surveyed with the object of confirming the prescence of seepage zones and channels through either the dam itself or its foundation. The dam was profiled using the 50 MHz antennas in June 1986 and April 1987. The transmitter-receiver separation and the station spacing were 4 m for the June 1986 survey and 2 m for the 1987 survey respectively. A CDP sounding was taken near the north end of the dam. The radar profiles over the dam are shown in Figures 13 and 14. CDP soundings taken in September 1986 and April 1987 indicate that the top layer velocity is 0.14 m/ns.

In the initial survey (Figure 12) the depth of penetration of the radar is quite limited over the dam itself. This is evidenced by the lack of returns at mid to late times at locations 40 m to 200 m along the profile. The high water content and unfrozen nature of the overburden under Internal Dam J limits the penetration of the radar pulse. Note that the rather clean radar traces directly under Dam J are in direct contrast to the profile presented for Dam 2 (Figure 10) where strong reflections are indicated to depth. The traces at either end of Internal Dam J, that is in the areas not originally submerged, exhibit the latter character.

These initial survey results confirm that several possible seepage paths from Pond 1 to Pond 2 are:

- Through the thin tailings sand liner.
- Through channels left by the melting of lake ice entrapped with the waste mine rock during dam construction.
- Through the unfrozen lake-bottom foundation.

The results of the April 1987 survey (Figure 13), conducted along the newly widened and raised dam, show that radar penetration has increased significantly under the dam itself, suggesting that the dam fill has frozen considerably over the winter of 1986/87. Figure 14 shows, for comparison, the interpreted stratigraphic section for the April 1987 survey. The interface between the old rock fill and the new fill is clearly visible in the radar profile. The base of the dam can now be traced across the old lake bed.

CONCLUSIONS

The experience at the Lupin mine shows that water-tight frozen core dams can be economically constructed. The performance of the dams from both an engineering and an environmental point of view has been highly satisfactory. The seepage at Dam 1A was always minor and no significant trace of contaminants was ever detected downstream. The freeze-back effectively occured during the first freezing season and has been monitored using a combination of ground instrumentation and geophysical techniques. The ground beneath the former intermittent creek was initially thawed to a depth of 5 m below original ground and has been freezing back since the end of construction.

The case of Internal Dam J will provide in time an interesting study of freezeback of a large water retaining structure constructed over frozen ground and under operating conditions.

The ability of GPR to image the ground allows not only resolution of the dam structures, sub-dam overburden conditions, bedrock topography and depth of thaw, but also unfrozen zones (taliks) within the overburden.

The ground probing radar surveys were able to yield considerable information on the dam thermal (and hence hydrological) performance. This information corresponded well to the known subsurface conditions. The radar was also useful in extending our knowledge of the subsurface to areas where little was previously known. Radar surveys should be a powerful technique for pre-construction site investigation and for monitoring both before and after dam construction. Poor quality of bedrock, such as on the ridge between Dams 1A and 2, can be detected in advance and integrated into the design when necessary. Two probable thaw zones under Dam 1A were identified on the radar profile. These corresponded well with the existing ground temperature data. Likewise the radar was able to detect the unfrozen initial state of Internal Dam J and follow its cooling with time. The major advantage of the radar is that it is able to map the total extent of the thaw zones between drillholes.

Given seasonal ground temperature variations, it would be advantageous to monitor the dam conditions with the radar at several times during the year. This, in conjunction with the on-going temperature monitoring program, would allow determination of any long term changes. A combined geophysical and thermal history of these sites will be an important case study in the consideration of similar developments on this type of permafrost.

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REFERENCES

Annan, A.P., and Davis, J.L. (1976). Impulse radar sounding in permafrost. Radio Science, 11, pp. 383-394.

Dufour, S. and I. Holubec (1988), "The Performance of an Earthfill Tailings Dam in the High Arctic", Proc. V. Int. Conf. on Perm., Trondheim, Norway (in press).

Environment Canada, Atmospheric Environment (1975). Canadian Normals, Temperature. Volume 1-SI, 198pp. No. U.S.C. 551-582 (71), Downsview, Ontario.

Futwilder, C.W. (1973). Thermal regime in an Arctic earthfill dam. Proc. 2nd Int. Conf. on Perm., Yakutsk, U.S.S.R., North Am. Cont., U.S. National Academy of Sciences, 622-628.

Holubec, I., Zehir, T., Dufour, S. (1982). Earthfill Dam Design and Construction in Cold Permafrost at Contwoyto Lake, N.W.T. 35th Can. Geot. Conf., Montreal, Quebec, Canada.

LaFleche, P.T., Judge, A.S., and Taylor, A.E. (1987a). Applications of geophysical methods to resource development in northern Canada. CIM Bulletin, 80, p.78-87.

LaFleche, P.T., Judge, A.S., and Pilon, J.A. (1987b). Ground probing radar in the investigation of the competancy of frozen tailings pond dams. Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p.191-197.

Morey, R.M., 1974. Continuous subsurface profiling by impulse radar: Proceedings of the Engineering Foundation Conference on Subsurface Exploration for Underground Excavation and Heavy Construction, American Society of Civil Engineers.

Sayles, F.H. (1984). Design and performance of water-retaining embankments in permafrost. Final Proceedings of the Fourth International Conference on Permafrost, Fairbanks, Alaska, pp. 31-42.

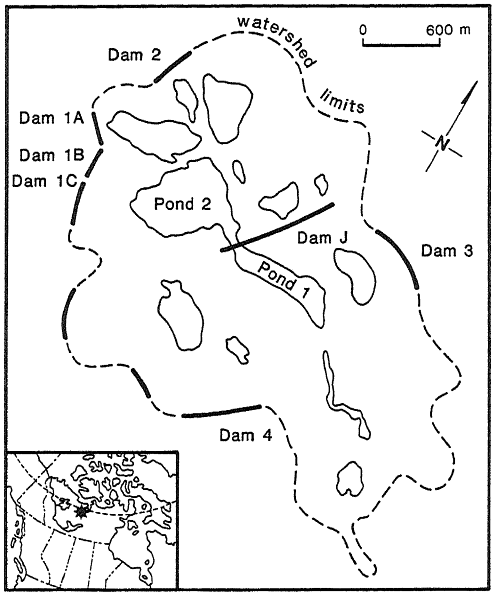

Figure 1. Location map for the Lupin mine and outline of the tailings facility.

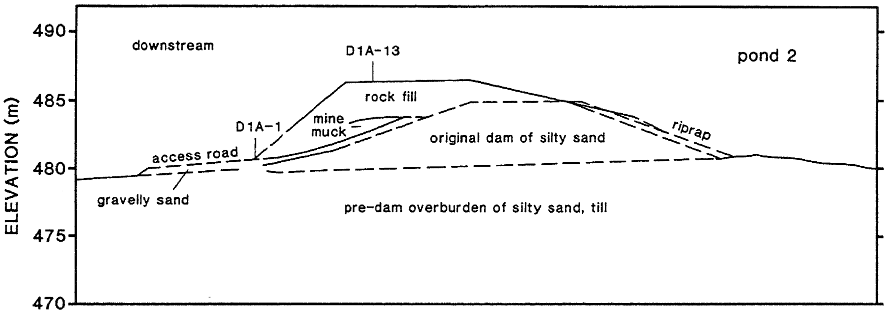

Figure 2. Cross-section of Dam 1A.

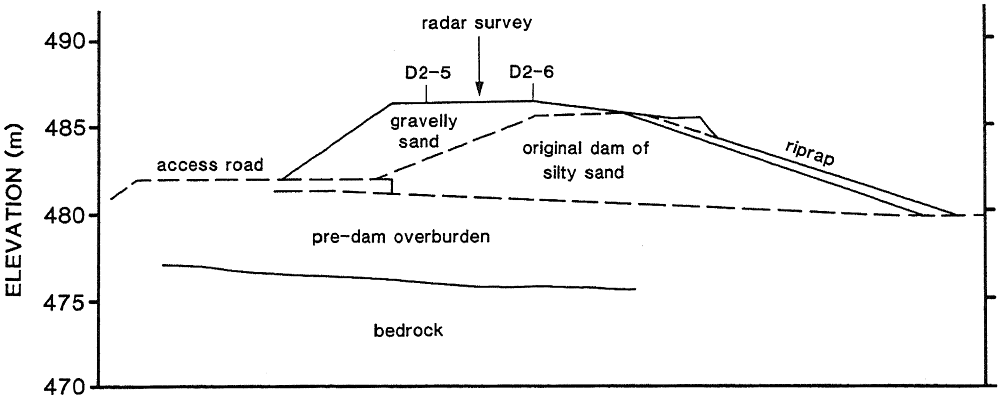

Figure 3. Cross-section of Dam 2.

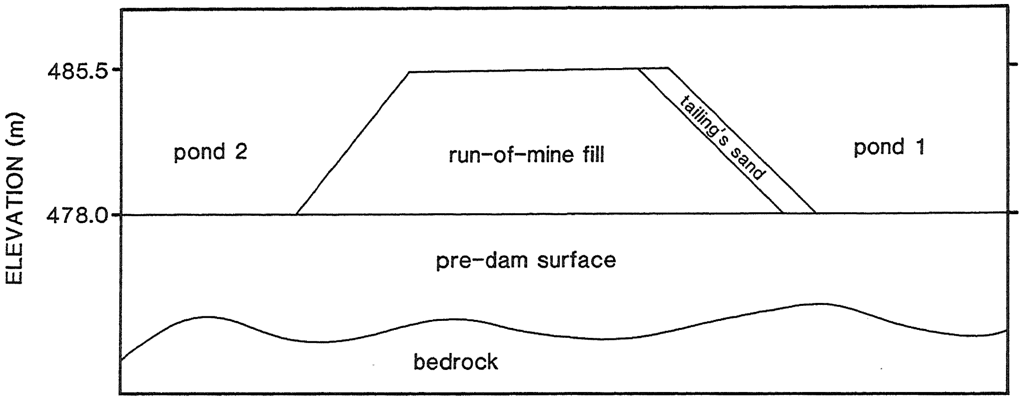

Figure 4. Design cross-section of Dam J.

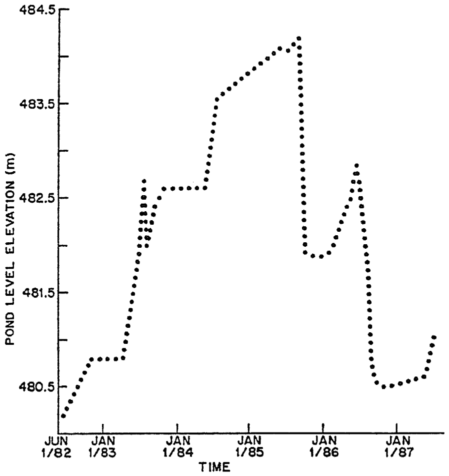

Figure 5. Tailings pond water levels.

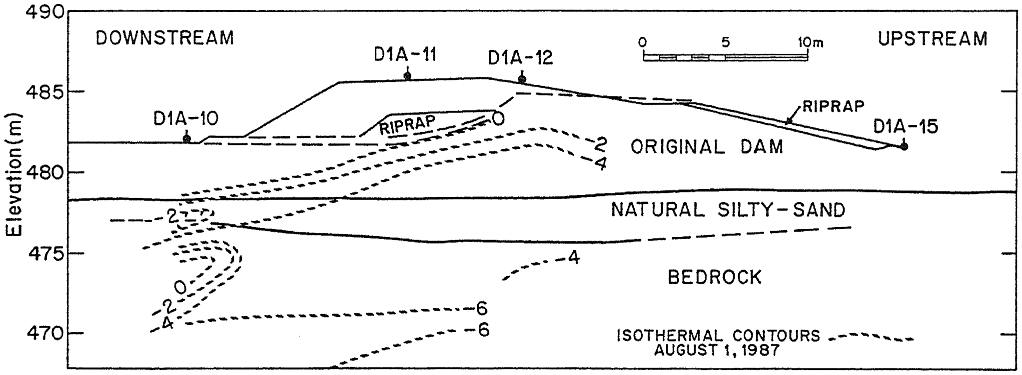

Figure 6. Isotherms for Dam 1A, August, 1987.

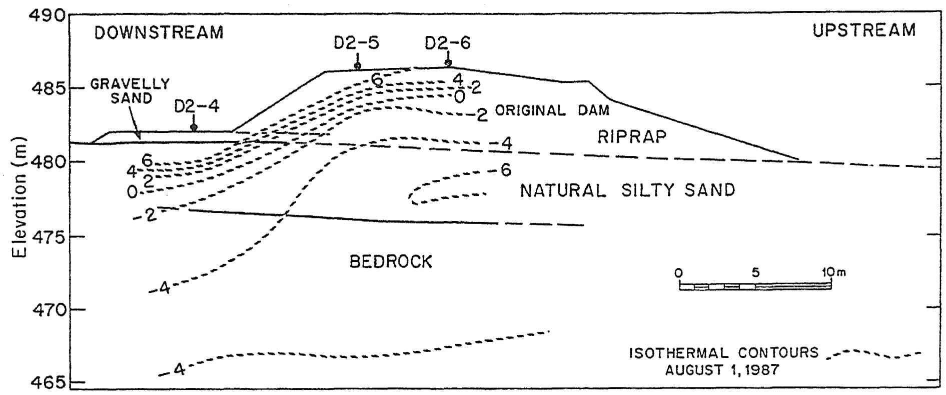

Figure 7. Isotherms for Dam 2, August, 1987.

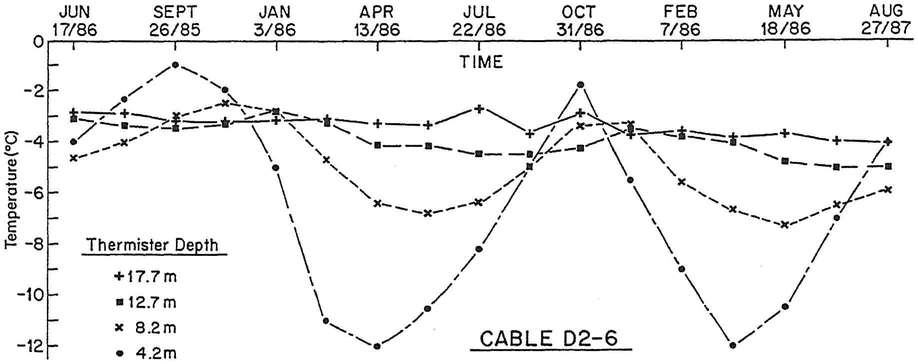

Figure 8. Borehole thermister temperatures for Dam 2.

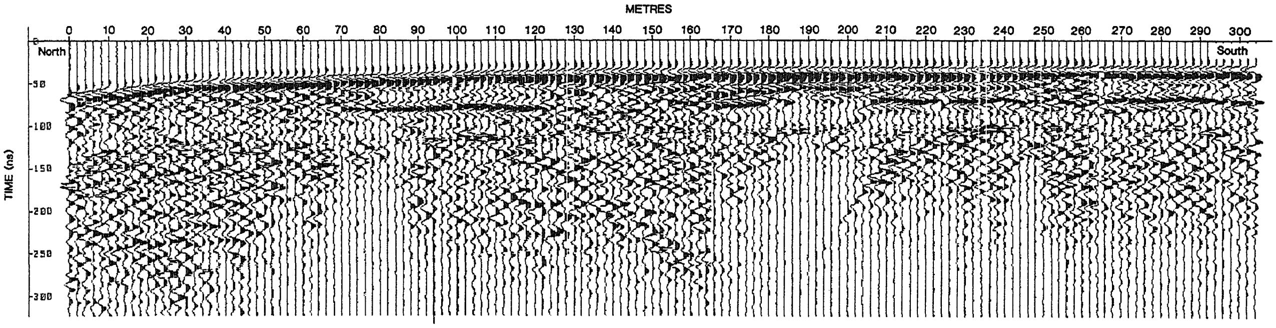

Figure 9. A 100 MHz radar profile along the Dam 1A access road in September of 1986.

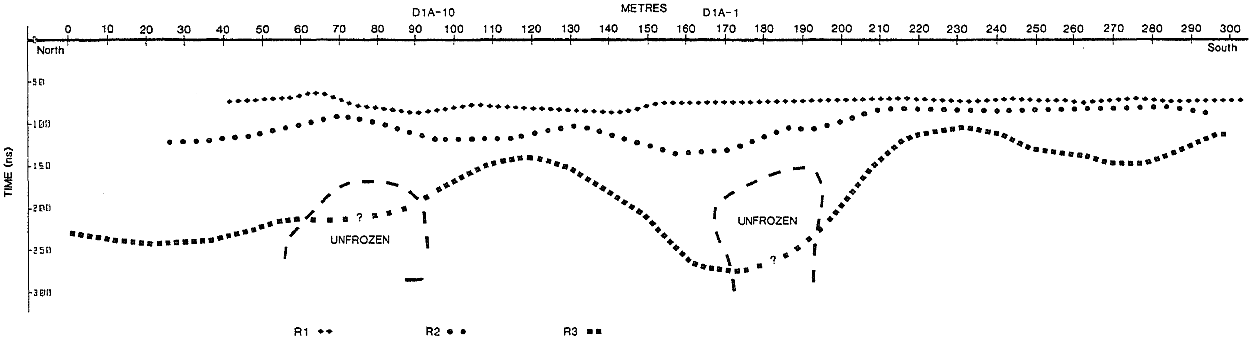

Figure 10. Interpreted section for the ground radar profile along the Dam 1A access road.

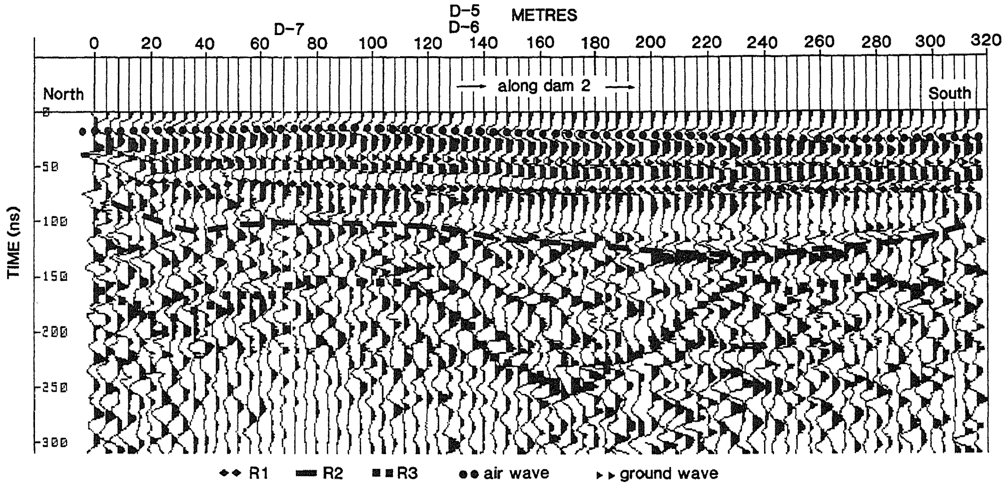

Figure 11. A 50 MHz radar profile along Dam 2 in June of 1986. The interpretation is overlain on the radar profile.

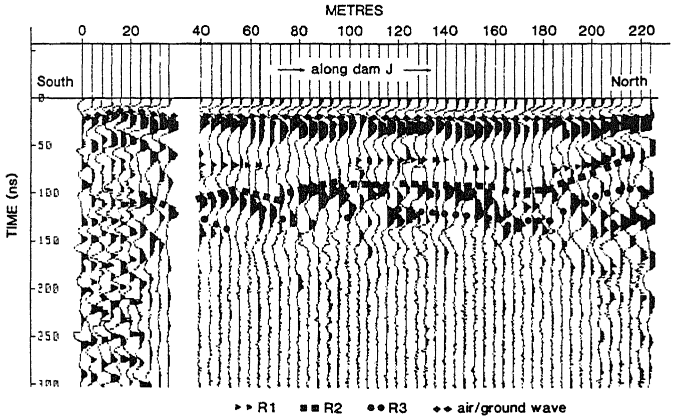

Figure 12. A 50 MHz radar profile along Dam J in June of 1986.

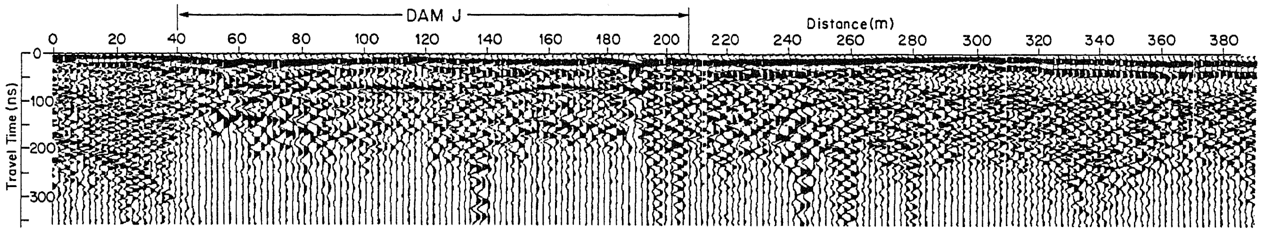

Figure 13. A 50 MHz radar profile along Dam J in April of 1987.

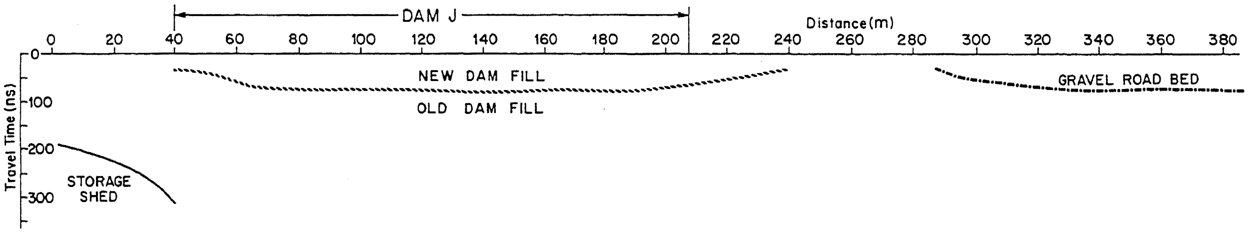

Figure 14. Interpreted section for the ground radar profile along Dam J.