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Investigation of geological constraints on granular resource extraction in the Tuktoyaktuk coastlands area, N.W.T. Source 155 North

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INVESTIGATION OF GEOLOGICAL CONSTRAINTS ON GRANULAR RESOURCE EXTRACTION IN THE TUKTOYAKTUK COASTLANDS AREA, NORTHWEST TERRITORIES SOURCE 155 NORTH

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INTRODUCTION

Indian and Northern Affairs Canada has, since 1972, commissioned at least 10 studies to identify potential sources of granular materials in the Tuktoyaktuk coastlands area. The objective of these studies was to outline and evaluate sources of aggregate in response to increased demand by the local communities due to increased oil and gas exploration activities.

Problems have been associated with exploitation of some of these deposits. Melting of buried ice exposed by extraction activities has resulted in surface disturbances which have limited further access to the deposit and left an irregular, unsightly landscape. Vegetation has been slow to recover at these sites due to the lack of organic cover. Some deposits recommended for development were not fully exploited because of thick overburden cover or unsuitable aggregate.

In the spring of 1991 a joint Indian and Northern Affairs Canada/Inuvialuit Land Administration/Geological Survey of Canada project was initiated to provide the scientific basis to better define the geothermal and geomorphological effects of granular extraction in perennially frozen ground and to address some of the geological limitations on borrow pit operations. Source 155N, an active borrow pit, was selected as the study area. During the course of this study a separate project was initiated to provide a preliminary evaluation of the environmental problems posed by the abandoned borrow pits at Source 160/161 and the extent of aggregate remaining.

This project is a part of the Inuvialuit Final Agreement Implementation Program: Task 7-Sand and Gravel Inventories. The work is directed by the Terrain Sciences Division of the Geological Survey of Canada (TSD/GSC). Field investigations were conducted by Northwood Geoscience and TSD/GSC.

Previous Work

Studies undertaken to determine the volumes and types of granular material required in the Tuktoyaktuk region and to evaluate potential sources include: Ripley Klohn and Leonoff International Ltd. 1973; R. M. Hardy and Associates Ltd, 1977; Hardy Associates [1978] Ltd, 1980; EBA Engineering Consultants Ltd. 1983; Hardy BBT Limited, 1986; EBA Engineering Consultants Ltd. 1987; Hardy BBT Limited, 1987-1; Hardy BBT Limited, 1987-2; Hardy BBT Limited, 1988; Hardy BBT Limited, 1989.

The 20 year Government of the Northwest Territories requirement for the community of Tuktoyaktuk has been defined as 400,000 cubic metres of embankment fill and 100,000 cubic metres of surface material (Hardy, 1987). The 20 year requirements for local capital projects and maintenance of community facilities is 200,000 and 116, 000 cubic metres respectively (EBA, 1987. Demand for granular material for speculative projects such as a road link to Inuvik and large scale onshore petroleum production could be as much as 9 million cubic metres (EBA, 1987).

Sources 155 North (155N) and South (155S) were identified by Ripley et al (1973) but not recommended for development because of expected variable quality of the granular materials, medium to high ice content and environmental problems related to potential siltation of Kittigazuit Creek. Hardy (1986) indicated large volumes of potentially good quality material at 155N and recommended a drilling program to prove out reserves at this site and to test neighboring deposits. The resultant drilling programs delineated 388,000 cubic metres of granular materials at 155N (Hardy, 1987-2] and 632,000 cubic metres of granular materials at 155S (Hardy, 1990]. Source 155N was expected to provide 288,000 cubic metres of embankment fill and 100,000 cubic metres of surface material.

The north deposit was selected as the prime source for the Tuktoyaktuk community and has provided aggregate since 1988. The south deposit contains superior quality material but requires a longer overland haul road and it was recommended as a reserve for future needs (Hardy, 1987-2).

In 1991 the pit operator indicated that reserves at Source 155N may be less than initially expected due to poor quality of the aggregate and the need for environmental protection measures (R. Newmark pers. comm.).

Scope of the Present Study

The main objectives of this project are twofold, to monitor geothermal and geomorphological changes in an active borrow pit and to address some of the geological constraints on borrow pit activities in perennially frozen ground. This work is expected to provide the scientific basis for an improved understanding of borrow pit operations that can be applied to maximize recoveries and limit environmental damage in borrow pits in the Richards Island/Tuktoyaktuk Peninsula area.

The study has several components:

1. Drilling and geophysical logging of boreholes to determine stratigraphy and identify areas of massive ice and ice rich sediments.

2. Surface Ground Probing Radar surveys to determine the extent of buried ice and evaluate near surface stratigraphy.

3. Installation and monitoring of thermistor cables and data loggers in the boreholes to determine annual variations in subsurface ground temperatures in disturbed and undisturbed areas.

4. Geomorphological monitoring of the borrow pit to observe the extent of any surface disturbances due to melting of buried ice during the thaw season.

5. Measuring the depth to frozen ground to determine the thickness of the active layer in disturbed and undisturbed areas.

6. Evaluation of the effectiveness of the berms in containing runoff and limiting siltation of adjacent water bodies.

7. Reevaluation of remaining recoverable reserves at 155N

8. Evaluation of present exploration, development and restoration practices.

Acknowledgments

Field work conducted as part of this study would not have been possible without the assistance and support provided by the Polar Continental Shelf Project, the Inuvialuit Land Adminstration, Indian and Northern Affairs Canada, and the Geological Survey of Canada.

In particular the author would like to acknowledge the direction and assistance provided by R. Gowan, S. Dallimore and A. Judge. Thanks are also due J. Bicknell and S. Kerr who generously provided input with respect to land use concerns and R. Newmark and several others at E. Gruben Transport who provided information on the history of development at the site and first hand experience of working in the area. Field assistance for the project was ably provided by J. Kasper and J. Shimeld. Technical assistance was provided by J. Bisson and V. Allen.

SITE DESCRIPTION

Source 155N is located 32 km southwest of Tuktoyaktuk at approximately 133 37'W, 69 15'N (Figure 1). The deposit comprises two broad flat plateaus, areas A and B, separated by a dry channel that runs from a lake (herein called Lake 155) on the west to Kittigazuit Creek on the east (Figure 2). A small pond, which drains into Kittigazuit Creek, occupies the eastern part of the channel. Deposits 155N A and B are approximately 200,00 and 70,000 square metres in size respectively. The plateaus are steep sided and stand 10-12 metres above Lake 155 and 25-35 metres above Kittigazuit Creek. The southwest margin of Area A is bounded by a highland.

Deposit 155N is described in detail by Hardy (1987-2 and 1989). The source of aggregate is a 0.5-2 meter thick sequence of interbedded sand and gravel which overlies in excess of 3 metres of uniform fine grained sand. In Area B and on the northeast side of Area A the coarse granular sequence is generally capped by <0.5 metres of organics and, locally, silt. In the southwest and central part of area A it underlies 0.5-1.5 metres of silt and organics. Massive ice of unknown thickness was intersected at depths of 2-4 metres in 5 of the 40 exploration boreholes.

The geological setting of the region is described by Rampton (1988). Sands and gravels of 155N and 155S were deposited in a glaciofluvial channel which, for part of its length, occupied Kittigazuit Creek Valley. These sediments are considered to be early Wisconsonin in age, associated with the Toker Point Stade. Deposits, such as 155N, with a flat topped profile are considered to be glacial outwash. Hardy (1987-2) suggests that the underlying sands are preglacial Mackenzie Delta deposits.

Work at 155N started, on a speculative basis, in 1986 at the small pit on the east side of Area A and aggregate is still stockpiled here. No further work was attempted in this area because it is close to the edge of the slope and there was concern that drainage into Kittigazuit Creek from the borrow pit could occur. Work started at the main borrow pit in 1988 subsequent to the Hardy (1987-2) drill results.

The main borrow pit centres on the channel which separates Areas A and B and is about 180 by 300 metres [Figures 2 and 3]. Aggregate was extracted from the slopes and shoulders of both plateaus and loose fill was pushed into the base of the channel. Organics are stockpiled on the north side of the pit and along the length of the channel. On the northeast side of the borrow pit organics were dumped over the edge of the slope. Organics have been partially stripped back on the south side of the borrow pit and on the west slope of Area A.. Berms were constructed between Lake 155 and the pit to contain drainage.

The haul route from Tuktoyaktuk to 155N is by ice road along the coast, up Kittigazuit Creek and overland to approach the deposit from Lake 155. The road is 40-45 kilometres long, approximately 2 kilometres of which is overland. Access to the pit is along the channel between deposits A and B.

FIELD PROGRAM

Summary of Activities

In March of 1991 six test boreholes were drilled to depths of 31-36 metres. Plastic casing was installed to preserve the holes for further studies. Borehole geophysical surveys, natural gamma and inductive conductivity, were carried out by J. Hunter (TSD/GSC). Ground probing radar surveys were conducted from borehole 16 to 19 and from borehole 20 to 21 by A. Judge (TSD/GSC). Borehole and survey locations were selected during the on-site visit by R. Gowan of Indian and Northern Affairs Canada (INAC), S. Dallimore and A. Judge (TSD/GSC). Results from the geophysical and ground probing radar surveys will be presented in a later paper and are not discussed in this report

In late June, on-site visual evaluations of Sources 155N, 155S and 160/161 [Figure 1] were undertaken [Sites at 160/161 were worked in the late 1970's/early 1980's and provide examples of post extraction thaw settlement]. These preliminary investigations were conducted by F. Thompson of Northwood Geoscience, R. Gowan (INAC) and S. Kerr of the Inuvialuit Land Administration (ILA). Discussions with the pit operator were initiated at this time.

At Source 155N survey lines were laid out between boreholes and to Lake 155 (Figure 3). A total of 1405 metres of level survey and 1000 metres of active layer survey were conducted along these lines to provide baseline data of early thaw conditions. The surveys were conducted by Thompson and Gowan. Silicon liquid was poured into four of the boreholes to provide a stable temperature environment for the thermistor cables through the winter period when cold surface temperatures could induce air circulation in the casing.

Thirty meter long thermistor cables were installed in boreholes 16/18/19/20/21 and a 15 meter cable in borehole 17. Temperature beads on the 30 meter cables are at 0.5 metres above ground level, ground level and 1/4/6.5/9/14/19/24/29 metres below ground level. Temperature beads on the 15 meter cables are at 0.5 metres above ground level, ground level and .5/1/1.5/4/6.5/9/11.5/14 metres below ground level. Temperature readings were taken manually on July 4. Data loggers programmed to provide twice daily readings (5:00 and 17:00 hr) were installed on boreholes 16, 19, 20 and 21. The data loggers read the top eight temperature beads. Cables and loggers were installed by Thompson and J. Schmeld (TSD/GSC). Manual temperature readings were taken by P. Egginton and J. Schmeld (TSD/GSC). Water samples were collected from Lake 155 and the pond to determine sediment content.

In early September source 155N was resurveyed to establish depth of thaw penetration during the summer and determine the extent of any thaw settlement. Manual temperature readings were taken September 1, 3 and 5 and the data logger records "downloaded" to a portable computer. The data loggers were set in a rigid plastic cover for protection from the elements and curious animals. The September surveys were conducted by F. Thompson of Northwood Geoscience and J. Kasper (TSD/GSC). Ground probing radar surveys were conducted between borehole 17 and 21 and across area A by A. Judge (TSD/GSC). Lake 155 and the pond were resampled.

The drill hole casing did not provide a water tight seal and only 6 to 9 metres of silicon liquid was left in the boreholes by early September. The upper 1.5 metres of the casing was packed with insulation, as an alternative method, to restrict air circulation.

Logistics

During the June field surveys accommodation was provided at the Polar Continental Shelf base in Tuktoyaktuk. Transportation to and from the field site was by 206B and 206L helicopter from the Polar Shelf base. The September field work was conducted from a temporary on-site tent camp. The camp was mobilized from the Polar Shelf base by Cessna 185.

SPRING AND FALL FIELD SURVEYS

Thermal Conditions

The objective of the thermal studies was to determine the differences in thermal regime between areas with an intact organic cover and areas disturbed by extraction activities. These studies are preliminary at this stage and long term monitoring of the thermistor cables will provide more complete information on annual and interannual variations in ground temperature.

Thermal data from manual reading of the thermistor cables is presented in Appendix A and graphically represented in Figs.4 to 9. The annual thermal data provided by the data loggers will be presented in future studies and is not discussed in this report.

Test boreholes 17, 18, 19 and 21 were located in undisturbed terrain. Borehole 20 is at the edge of the borrow pit where the organics have been disturbed during extraction activities leaving a discontinuous mat of organics less than 0.1 metres thick. Borehole 16 is located in sandy gravel in the borrow pit. Borehole 21 is 16 metres from the edge of the borrow pit.

Near surface temperatures varied considerably from spring to fall and from disturbed to undisturbed terrain. One meter below ground surface in undisturbed terrain (boreholes 17/18/21) temperatures remained below freezing throughout the year, -3.0 to -2.5 C in the spring and -1.1 to -1.4 C in the fall. Temperatures at this depth in the borrow pit (borehole 16) were above freezing and relatively stable, +2.3 to +2.5 C from spring to fall. Under disturbed organic cover (borehole 20) temperatures were -0.8 C in the spring and +0.8 C in the fall. Four metres below ground surface in undisturbed terrain temperatures were -6.8 to -7.3 C in the spring and -4.3 to -4.9 C in the fall. Temperatures at this depth in the borrow pit were 1 to 2 C degrees warmer, -5.8 in the spring and -3.1 to -3.5 C in the fall. Under disturbed organic cover temperatures at a depth of four metres were -6.8 in the spring and -3.4 to -3.8 in the fall. Near surface temperatures in borehole 19 were generally 1 C warmer than at other undisturbed sites. The more closely spaced temperature beads on the 15 meter cable in borehole 17 permitted a more detailed evaluation of near surface temperatures in undisturbed terrain. At 0.5 metres below ground surface temperatures were -1.7 and -0.4 C in spring and fall respectively.

Deeper in the boreholes temperatures were less variable. From 14-29 metres below ground surface, temperatures in all boreholes were stable at -6.1 to -7.5 C from spring to fall. The warmest temperatures at this depth were recorded in boreholes 16 and 19. This may reflect their locations near the southern and western edge of the plateau. The coldest temperatures, -7.2 to -8.7 C, were recorded in the spring at depths of 6.5 to 9 metres below ground surface. Temperatures at this depth warmed to -5.4 to -7.3 by September. Cold spring temperatures from 6.5 to 9 metres below ground surface reflect preservation of deep winter freezing. The warmest temperatures at this depth were recorded in boreholes 16 and 19.

Active Layer Survey

The active layer is the zone between permafrost and ground surface that thaws each summer. The natural organic cover provides thermal insulation. Where this cover is removed or disturbed, ground temperature will rise, the active layer will become thicker and previously permanently frozen ground will be exposed to thaw. Where buried massive ice or ice rich sediments are captured by this deeper active layer, thermokarst depressions or thaw ponds are formed due to the melting of ice and resulting collapse of the ground surface. The depth of these depressions will be dependent on the thickness of ice exposed to thaw.

The objective of the active layer survey was to determine the depth of thaw penetration in disturbed and undisturbed areas. To measure the depth to frozen ground a 1.2 metre steel probe was manually forced into the ground until resistance was encountered. At the base of the active layer, frozen sediments will stop further penetration Where there is insufficient water content to provide bonding the probe could penetrate frozen sediments. In undisturbed areas the organics and underlying sediments generally contain sufficient water to provide bonding. In the lower parts of the borrow pit the surface is saturated. In the well drained higher parts of the borrow pit there is some potential that water content could, locally, be insufficient to bond the sediments. Test pits indicate that the water table is generally above the depth of thaw in both spring and fall.

Where there was any possibility that the probe may have "hung up" in compact or stony but unfrozen ground, several attempts were made to confirm depth to frozen material. In areas where the depth to frozen ground exceeded 1.2 metres shovel pits were excavated and the active layer probed from the base of the pit.

Along survey lines 1 and 2 active layer probe readings were taken at 5 or 10 metre centres. The more detailed readings were taken where it was easy to get accurate readings and here the data was considered to be more critical. In September, where it was necessary to excavate shovel pits in the borrow pit, readings were taken at 20 to 50 metre centres. Readings were taken at 30-50 metre centres along lines 3 and 4 in September. The results of the active layer survey are presented in Appendix B and graphically represented in Figures 10 to 12.

In undisturbed terrain, depth to frozen ground in the spring was 0.1-0.4 metres and averaged 0.2 metres. By September depth of thaw had penetrated to 0.2-0.9 averaging 0.4 metres. This is consistent with the thermal data which indicates that at one meter below ground surface in undisturbed terrain temperatures remain below freezing throughout the year. There was positive correlation between the spring and fall readings. Areas with relatively shallow or deep spring depth of thaw also had relatively shallow or deep fall depth of thaw respectively. The thickest active layer and warmest near surface temperatures are recorded on the narrow strip of plateau along the north east side of area A (borehole 19).

In the borrow pit, depth to frozen ground in the spring was 0.8-1.2 metres and averaged 0.9 metres. By September depth of thaw had penetrated to 1.2-1.7 metres averaging 1.5 metres. This is consistent with the thermal data which indicates that the freezing point isotherm in the borrow pit is between one and four metres below ground surface in both spring and fall.

Where organics are still on surface but have been disturbed by pit traffic or snow clearing operations depth to frozen ground was 0.3-0.7 metres in June. There were not enough September readings in these areas to establish the fall active layer because the surface deposits were pebble rich and difficult to penetrate. Thermal data indicates that the active layer would be above one meter in the spring and below one meter in the fall.

Depth to frozen ground in other types of disturbed terrain was generally intermediate between that of the exposed surface of the borrow pit and that under an undisturbed organic mat. In areas where gravel/organic fill covers the natural organic surface depth to frozen ground was 0.4 and 0.6-0.8 metres in June and September respectively. In storage piles of organics mixed with gravel depth to frozen ground was 0.2-0.5 and 0.3-1.0 metres in June and September respectively.

Level Survey

The objective of the level survey was to determine if the borrow pit had undergone settlement during the thaw season.

The casing of the GSC boreholes provided stable base elevation sites and borehole 17 was defined as 100 metres above datum. Stakes were placed at 50 meter centers on the survey lines to provide control points and level readings were taken at 5 or 10 meter centres. The more detailed readings were taken where settling was expected. The survey was completed to a known point on Lake 155 to provide geographic control. The results of this survey are presented in Appendix B and graphically represented in Figures 10 to 12.

Field checks indicate that individual level readings are accurate within 2 to 3 centimetres. However it was not possible to relocate, for the fall survey, exact sites of the spring survey. Therefore level reading can vary by 5 to 10 centimetres dependent on the position of the stadia rod. In areas of irregular topography, level reading can vary by as much as 15 centimetres for the same grid location. The objective of the level survey was to identify areas with substantial subsidence and this degree of accuracy was considered suitable. To provide greater accuracy it would be necessary to accurately mark each level reading site to guide subsequent surveys.

The plateaus of deposits A and B are generally flat with a gentle slope down to the north. Elevations vary from 100 metres above datum in the north of area B to 102 metres above datum in the central part of area A. The exploration level survey [Hardy 1988] indicates that the gentle slope continues to the south end of area A. The continuous slope between the two separated areas suggests that they were originally one connected deposit that has been cut by a fluvial channel. The slope could reflect the original depositional environment or postglacial isostatic changes in elevation. The channel between areas A and B is about 95 metres above datum near the small lake in the eastern end, rises to a saddle near the central part and drops off to 90 metres at Lake 155.

Throughout undisturbed terrain and most of the borrow pit there is no consistent change in elevation and the fall elevation is generally within 10 centimetres of the spring elevation. The foregoing would indicate that there has been no substantial thaw settlement. The organic storage piles in the channel are generally 10 to 20 centimetres lower in the fall. This likely reflects melt of snow and ice incorporated in the dump. Similarly, the 1991 berm has settled as much as 30 centimetres metres. The lower parts of the borrow pit above the berm on lines 3 and 4 are generally 5 to 10 centimetres lower in the fall. Part of this is fill and the settling could reflect compaction of loose materials dumped in the low or melting of ice and snow incorporated with the fill. The area between the berm and Lake 155 appears to be stable suggesting that the fill is well compacted and does not contain buried snow and ice.

Discussion

Depth of Thaw

The active layer survey and thermal data demonstrate that depth of seasonal thaw is generally less than 0.6 metres in undisturbed terrain but can be as much as 1.7 metres where the natural organic cover has been removed. Similar depth of thaw was measured by the author in disturbed terrain at Source 160/161. It should be noted that this is considered to be a minimal figure. Depth of thaw could be deeper in other parts of the pit or in other years. The foregoing would suggest that melting of buried ice and thermokarst collapse can occur in any borrow pit in the Tuktoyaktuk region that has massive ice or ice rich sediments within 2 metres of the base of extraction. Once thermokarst collapse has been initiated deeper buried ice can be exposed to thaw.

On the margins of the pit at 155N, where the organic cover has been disturbed by borrow pit activities, ground temperatures in the fall are 2 C warmer at a depth of 1 meter and 1 C warmer at a depth of 4 metres than in undisturbed terrain [Figures 13 and 14]. The foregoing demonstrates that any disruption to the organic cover can increase depth of thaw. Conversely, even this thin discontinuous cover of organics provides some thermal protection. At the end of the thaw season, ground temperatures at a depth of 1 meter are nearly 2 C colder than in the borrow pit. The foregoing would suggest that it may be possible to significantly limit depth of thaw with an incomplete organic cover.

Buried Ice and Thaw Settlement

The exploration boreholes [Hardy 1987-2], as well as the GSC boreholes and ground probing radar surveys completed by the TSD/GSC as a part of this study, indicate that there is very little massive ice or ice rich sediments underlying the present workings at Source 155N. This is consistent with the absence of any large scale thaw settlement in the pit.

In undisturbed areas there is no visual or measured evidence of surface settling. Where the organic cover has been disturbed, buried or removed there are a few linear depressions and ponds that appear to reflect melt-out of buried ice. These are commonly 0.5-2.0 metres wide, up to 1 meter deep and can exceed 10 metres in length. On the north and west facing slopes of area A, these depressions suggest an ice wedge system that rings the crest of the plateau with radial ice wedges down the slope. Excavation of some of these depressions indicates that they are underlain by ice buried by less than 1 meter of aggregate.

An active ice polygon network was observed in undisturbed areas along the channel separating Areas A and B, but no ice wedge cracks were noted in undisturbed terrain on the plateaus during field studies or in pre-extraction aerial photographs. The thaw settlement cracks in disturbed areas along the channel may reflect this active ice polygon network that was buried under fill. The thaw settlement cracks on disturbed parts of the plateau may reflect melt of a fossilized ice polygon network that was exposed by removal of the organic cover and aggregate.

Drainage Control

Drainage from the borrow pit has been moderate. No water flow was observed in late June but a breach in the 1991 berm, channeling and silt filled lows all indicated some early spring runoff. In the fall there was a slow steady flow along the channel and this seeped into the stony beach at Lake 155. Visual estimates are that water flow was less than two litres per minute.

Thaw settlement and drainage at Source 155N has, to date, been limited because very little ice was exposed under the borrow pit. As a result it was relatively simple to control drainage. Low areas ponded by the berms served as small settling ponds. Furthermore the material extracted does not contain large volumes of silt and, as a result, drainage from the pit contains very little sediment. There was no evidence of siltation of Lake 155 during the spring or fall site visits. There was some minor drainage from organics dumped along the slope at the east side of the pit but the water seeped into the ground and there was no flow observed to the pond on the east side of the channel. There may be greater potential for release of silt when fine grained overburden is removed from the southwest and central part of Area A.

The ponded and flowing water observed in the channel that separates Areas A and B likely reflect melt of both snow incorporated in the dumps and buried ice. The measured settling of organic storage piles and loose fill is consistent with melting of snow incorporated with this material. The thaw settlement cracks in disturbed terrain are consistent with melting of buried ice and ice rich sediments. A small spring, observed at the base of the borrow pit close to Lake 155 in early September 1991, may account for much of this meltwater. This would suggest that the buried ice was actively melting but it is not possible with the information currently available to determine ice thickness or how much deeper melting will progress.

There are two artificial berms between the borrow pit and Lake 155. The older berm, closer to the lake, is a linear mound less than 0.5 metres high. The berm furthest from the lake was 0.5-0.75 metres high when constructed in early April 1991 (R. Burns pers. comm.). By June this berm was less than 0.5 meter high and a meter wide. The level survey indicates that further settling occurred during the summer. The foregoing would suggest that this berm was constructed partly of snow. The berms have been breached and would be inadequate to contain large volumes of drainage. They are not extended far enough north and south to provide a barrier between Lake 155 and the pit.

Storage of Organics

Hardy (1989) recommended that Source 155N be worked in sections. The organics and overburden were to be stockpiled separately and, when extraction was completed in any area, the base of the borrow pit was to be uniformly covered with overburden and the base and slopes of the pit topped with the organic material. Where possible, the natural cover was to be stockpiled the aggregate removed and the cover replaced in one season. Hardy further recommended that overburden and organics not be pushed over the edge of the deposit. Similar recommendations are in Environmental Guidelines, Pits and Quarries (1982).

Organics are stockpiled on the north side of the pit and along the channel. On the west slope of area A organics have been partially stripped off and stockpiled within 30 metres of Lake 155. It is uncertain if the stripping in this area is a result of snow clearing operations or preparation for future extraction. Organic material has been pushed over the edge of the slope at the northeast side of the borrow pit near the pond. Organics have not been replaced in any area.

FUTURE DEVELOPMENT AT 155N

Aggregate Reserves

Calculated reserves at 155N were 388,000 cubic metres (Hardy 1987-2). Extraction to date is 84,098 cubic metres (S. Kerr, pers. comm.). This is more than twice predicted recoveries for the area worked. The total area of the workings is 55,000-60,000 square metres. Hardy (1987-2] indicated that, of this area, only 20,000-25,000 square metres would contain extractable aggregate and provide about 30,000-35,000 cubic metres of aggregate [Figure 2]. Recoveries are better than anticipated because the borrow pit extends 100 metres further east than expected [Figures 2 and 3] and aggregate was extracted from the slopes of the plateau [Figures 10 to 12].

The deposit is considered to be limited to the plateau areas (Hardy 1987-2]. Reinterpretation of aerial photographs as a part of this report indicates that, in Area B, the plateau extends 50-100 metres further east and north than expected. The southwest margin of area A is bounded by a highland. This area is untested and could contain extractable aggregate. The foregoing suggests that there may be more aggregate at 155N than initially expected.

Aggregate Quality

Aggregate extracted at the end of the 1991 winter season was sandy and not ideal for community use (S. Kerr pers. comm.). Based on the exploration drill holes [Hardy 1987-2] the south side of area B is sandier than average for the deposit. Furthermore, visual evaluation of the pit would suggest that extraction on the sides of the plateaus extended into the underlying sand. This is consistent with the amount of aggregate extracted from this area. Even assuming a larger than expected plateau and substantial recoveries from the slopes, thickness of material extracted would exceed the 1.0-1.8 metres predicted by Hardy to provide the material recovered to date. It would appear that material extracted was sandy because some of the underlying sands were incorporated with the gravel. There is no data available at this stage to indicate that aggregate at Source 155N will be less suitable for community use than originally anticipated by Hardy.

Overburden Cover

In the south-central part of Area A overburden thickness is 1.0 to 1.5 metres (Hardy 1987-2). This amount of cover can significantly increase extraction costs. Shovel pits were excavated, as a part of this project, in an attempt to penetrate the cover in this area. It was possible excavate to gravel on the south side of Area A but it was impossible to penetrate the overburden in central Area A. Most shovel pits in this area intersected 0.4 to 0.6 metres of organics and silt. This is consistent with the Hardy data. The pit operator notes that up to 1 meter of overburden does not pose a problem for pit development and that aggregate buried under 2 metres of overburden can generally be extracted. Furthermore, it will likely be possible to work the areas of thick overburden from margins with thin overburden to permit draining and thaw which would facilitate extraction in subsequent years (R. Newmark pers. comm.). Overburden at 155N is not expected to exceed 2 metres in thickness and, although costs may increase, full extraction of the aggregate should be possible.

Environmental Limitations

Permafrost terrain is very sensitive to surface disturbance and slow to heal. Where buried ice is exposed to melting and thaw settlement is initiated:

1. Drainage control can be difficult.
2. Uncontrolled drainage can cause flooding of the base of the pit and siltation of adjacent waterbodies.
3. Access to remaining aggregate reserves can be restricted by flooding and thermokarst collapse.
4. Resultant landscape can be unstable and unnatural in appearance.

It is recommended in Environmental Guidelines, Pits and Quarries (1982) that any borrow pit be at least 30 metres from a water body to restrict introduction of drainage which could damage the ecological balance of aquatic life. Hardy (1989) recommended that, at 155N, no terrain disturbance occur within 30 metres of any water body and that a 5 meter deep undisturbed rim be left along any border of the deposit adjacent to a water body. The objective of this rim was to contain meltwater within the pit. Hardy further suggested that, where massive ice was exposed, a thicker recovering of organics be considered in an attempt to reduce thaw settlement and ponding.

Depth of thaw may be as much as 2 metres where the organic cover is removed and thaw settlement should be expected if buried ice occurs within 2 metres of the base of the borrow pit. The extent of such surface disturbances will be dependent on the lateral extent and thickness of ice exposed to thaw. Buried massive ice, within one meter of the planned base of the borrow pit, was intersected in 3 adjacent boreholes on the north side of Area B [exploration boreholes 29, 30 and GSC borehole 17]. The exploration boreholes were terminated in less than one metre of ice so thickness is unknown but GSC borehole 17 intersected 4.9 metres of massive ice with some fine sand underlain by sand with some zones containing excess ice. Buried massive ice was also intersected, within one meter of the planned base of the borrow pit, on the narrow northeast limb of Area A [exploration borehole 12] and on the west side of Area A [exploration borehole 20]. Adjacent boreholes, 50 to 100 metres away, did not intersect ice and the ice may not be laterally extensive. Ice thickness was 2.9 and 1.7 metres in boreholes 20 and 12 respectively but both boreholes were terminated in ice so full thickness is unknown

If thaw settlement is to be avoided, a minimum 2 meter buffer between the base of the borrow pit and the top of buried ice would be required. Where buried ice was intersected at 155N this buffer zone would include most of the aggregate. Leaving these areas undeveloped would reserve 45,000 to 55,000 cubic metres of aggregate. Thickness of the buffer zone required could be reduced if the organic cover is replaced before the seasonal melt. Depth of thaw where the cover has been replaced would be dependent on type and thickness of the cover.

If the buried ice is left exposed to thaw, there will be substantially more meltwater than there has been to date and more sophisticated drainage control systems may be required to control meltwater. Access to some of the aggregate may be impractical in subsequent years due to thermokarst collapse and full extraction of the aggregate in these areas should be completed in the first year.

Source 155N is situated on a plateau 10-35 metres above the surrounding lowlands. If thaw settlement is initiated on any margin of the deposit drainage from the pit may be difficult to control. Exposure of the broad area of buried ice on the west side of Area B could initiate drainage into Lake 155. If this is to be avoided, an undisturbed buffer between the area of extraction and the edge of the plateau would be required.

Massive ice and ice-rich sediments were not intersected in other parts of the borrow pit. However, distance between boreholes is 60-120 metres and most of the exploration boreholes were terminated 1.5-2.0 metres below the proposed base of the borrow pit. Therefore, the full extent and thickness of buried ice that could be exposed to thaw when the aggregate is removed is uncertain. Smaller areas of buried ice may occur between boreholes. Buried ice may also occur below the limit of the exploration boreholes but within two metres of the base of the borrow pit.

Kittigazuit Creek lies at the base of the slope, 70-100 metres east of and 25-35 metres below area A. Kittigazuit Creek and the region where it empties into the Beaufort Sea is valuable to local people as a traditional whaling, fishing and camping area. It also has important archaeological and cultural significance. The Inuvik Hunters and Trappers Committee expressed concern with development at 155N (Hardy, 1988). Further development was approved on the condition that fish populations and fish habitat would not be affected and that a buffer zone between the developed area and drainage into the creek be maintained (Hardy, 1988). The proposed width of this undisturbed fringe is 30 metres [J. Bicknell pers. comm.] and would reserve 20,000 to 30,000 cubic metres of aggregate. Exploration drilling at the crest of the steep slope above the creek did not intersect buried ice and no thaw settlement was observed at the small borrow pit at the edge of this slope. The foregoing would suggest that this slope is not underlain by large volumes of massive ice or ice rich sediments that would be exposed by borrow pit activities.

The eastern half of the channel which separates Areas A and B drains to the pond which in turn drains into Kittigazuit Creek.. Drainage control may be required along the channel if buried ice is exposed near the edge of the plateaus on this side of the deposit.

BORROW PIT DEVELOPMENT AND RESTORATION IN THE TUKTOYAKTUK COASTLANDS AREA

Several studies have been conducted to evaluate granular resources in the Tuktoyaktuk coastlands area. The objectives of these studies were to determine which deposits contain economically viable aggregate and how these deposits can be developed to maximize recoveries while at the same time minimizing environmental damage. The reports include suggestions for how these sites can be rehabilitated after abandonment.

The following section is based on; review of the consultants reports of the granular deposits in the region, on-site evaluation of Source 155N, on-site evaluation of Source 160/161 [Thompson 1992], and discussions with the pit operators.

Resource Evaluation

Exploration drilling at Source 155N provides reliable information on the quality and extent of the aggregate [R. Newmark, pers. comm.). At some of the deposits in the region evaluated prior to 155N the pit operator maintains he encountered subsurface conditions other than that reported (R. Newmark pers. comm). It is possible that this reflects positional errors. Exploration drilling and extraction activities are conducted in winter when land features are subdued by snow cover and it can be difficult to accurately identify location. It is, however, more likely that exploration boreholes were too widely spaced to fully evaluate the thickness and extent of; aggregate, overburden cover and buried ice.

At Source 155N forty boreholes were drilled to evaluate 270,000 square metres of land surface [one borehole per 6,700 square metres]. At Source 160/161, 2 to 4 exploration boreholes were drilled to evaluate deposits which ranged in size from 15,000-75,000 square metres [approximately one borehole per 5,000 to 20,000 square metres]. It is recommended in Environmental Guidelines, Pits and Quarries (1982) that exploration boreholes be at 50 metre centres [one borehole per 2,500 square metres].

The density of exploration boreholes required to evaluate subsurface conditions is dependent on the size and type of deposit. Large and relatively consistent deposits such as 155N may be adequately evaluated by the density of boreholes employed at this site. The deposits at Source 160/161 are small and stratigraphically variable. The density of boreholes employed could not have been expected to provide reliable information on subsurface conditions.

Exploration programs are also designed to provide data on the extent of buried ice. Where the organic cover has been removed depth of thaw may be as much as 2 metres. Unless depth of extraction is rigidly controlled, boreholes should be extended a minimum of 3 metres below the planned base of the pit to locate buried ice that could be exposed to thaw. Boreholes should also be extended through any massive ice or ice rich sediments to determine the full thickness of such ice.

Rehabilitation

It is generally recommend that the organic cover be stockpiled and later replaced when the pit or a section of the pit is abandoned. Stockpiling organics for future replacement is difficult. The natural cover at most gravel deposits in this region is thin and organics stockpiled for several years lose part of their volume due to desiccation and wind erosion. Quarry operations and rehabilitation measures are conducted when the materials are frozen because it is unsuitable to use heavy earth moving equipment on soft tundra in the summer. As a result it is difficult to separate organics from the underlying material. In practice, the material available after abandonment may be a frozen mix of overburden, gravel, and organics that can only provide a thin and discontinuous coverage to the area quarried.

Although a thin and discontinuous organic cover provides some thermal protection and permits limited revegetation, it does not provide an environment similar to that of the undisturbed organic mat. Even where the organics have been replaced, it could take decades for vegetation to recover, the active layer will be deeper and if buried ice is exposed thermokarst collapse will occur.

It may be possible to provide a more complete rehabilitation if the organics are better stored and replaced. The manner in which the organics have been stored at Sources 155N and 160/161 may not be the most suitable way to preserve them for future recovering of the borrow pits. Organics are generally pushed into loose piles and left exposed for several years to wind and water erosion. In some instances they have just been pushed off the edge of the deposit making recovery without disturbing the underlying intact organics almost impossible. Investigations as a part of this report indicate that, at the abandoned borrow pits on the east side of Tuktoyaktuk Harbour [Thompson 1992], the organic cover has not been replaced and there is very little organic material available to cover these pits.

Thaw penetration could be reduced and handling of organics facilitated if, as recommended by Hardy (1989), the pit is worked in sections and the organic cover and overburden replaced as soon as work is completed in any area. It may be possible to reduce wind erosion by securing fabric covers over stockpiles and recently replaced organics.

Development and Restoration Plans

To generate plans for development and restoration of borrow pits requires:

1. Reliable information on the extent and quality of aggregate, type and thickness of overburden cover and extent and thickness of buried ice. This data can be provided by suitably detailed exploration drilling.

2. An understanding of how deeply thaw will penetrate, how thaw settlement may progress after the aggregate is removed and how depth of thaw can be limited. The basis for improved scientific understanding of thermal conditions in borrow pits is provided in the body of this report.

3. An understanding of the most suitable methods to store organics and to rehabilitate abandoned borrow pits. Further studies are required to determine the best methods to preserve stockpiled organics and to provide a suitable cover for thermal protection and revegetation.

The pit operator suggests that some of the recommendations for development and restoration of borrow pits provided in earlier consultants reports are not suitable for northern winter conditions and frozen terrain (R. Newmark pers. comm.). It is possible that the consultants do not appreciate some of the practical difficulties of working in the north or that the reports have been misunderstood. The foregoing indicates a need for improved communication between the consultants or scientific advisors and the pit operators.

Plans for the development and restoration of borrow pits should be determined in consultation between the consultants or scientific advisors, the ILA and the pit operator. Such cooperation could provide realistic and cost effective plans for extracting aggregate and restoring borrow pits that will maximize recoveries and provide suitable environmental protection. For these plans to be effective:

1. The responsibilities of the ILA and pit operator should be clearly defined.

2. There should be a monitoring procedure to determine that the plans are been followed and an annual review to modify them as required

3. The limits of the borrow pit should be laid out on the ground in advance to avoid development in areas that are unsuitable due to thick overburden cover, poor quality aggregate or environmental concerns.

CONCLUSIONS AND RECOMMENDATIONS

1. Depth of seasonal thaw at Source 155N is generally less than 0.6 metres in undisturbed terrain but can be as much as 1.7 metres where the natural organic cover has been removed. This is considered a minimal figure, depth of thaw could be greater in other parts of the pits or in other years. The foregoing suggests that, in the Tuktoyaktuk Coastlands Area, melting of buried ice and thaw settlement could be initiated if massive ice or ice rich sediments occur within 2 metres of the floor of any borrow pit.

   Ground temperatures one metre below surface in undisturbed terrain remain below freezing throughout the year. Temperatures at this depth in the borrow pit, where the organic cover has been completely removed, are 2.5 C above freezing by the end of the thaw season. Where the organic cover is in place but thin and discontinuous due to disturbances associated with borrow pit activities, end of thaw season ground temperatures at a depth of 1 meter are nearly 1 C above freezing. The foregoing demonstrates that partial disturbances to the organic cover can increase depth of thaw but also suggests that it may be possible to significantly reduce depth of thaw with an incomplete organic cover.

2. Thaw settlement and drainage at Source 155N has, to date, been modest because very little ice has been exposed by borrow pit activities. There are a few linear depressions and ponds where the organic cover has been disturbed, buried or removed . These depressions are commonly 0.5-2.0 metres wide, up to 1 meter deep and locally exceed 10 metres in length. Along the dry channel which separates Areas A and B they appear to reflect an active ice polygon network that was buried during extraction activities. On the plateau these linear depressions appear to reflect meltout of a fossilized ice polygon network that was exposed by stripping of the organic cover and aggregate. The ice was melting in September 1991 but there is insufficient information to determine the thickness of ice exposed or depth of thaw settlement expected.

3. Across the west end of the dry channel which separates Areas A and B at least two berms, probably reflecting the annual post-extraction closure of the pit, have been constructed between the borrow pit and Lake 155. Observed settling of the 1991 berm suggests that it was constructed partly of ice or snow. The berms are small, less than 0.5 meter high and a meter wide, have been breached and are inadequate to contain large volumes of pit drainage. However, drainage from the borrow pit has been moderate, meltwater contains very little silt, and low areas ponded by the berms served as small settling ponds. There was no evidence of siltation of Lake 155 during the 1991 thaw season. There may be a greater potential for release of silt and a need for improved drainage control if fine grained overburden is encountered or if large areas of buried ice are exposed by future extraction activities.

The eastern half of this channel slopes east to a small pond which in turn drains into Kittigazuit Creek. If ice is exposed by extraction activities on this side of the deposit, berms may be required to control drainage from the pit that could enter this pond at the east end of the channel.

At this and other borrow pits in the region it may not always be suitable or possible to contain all meltwater in the pit. Berms should be constructed such that they contain drainage from the pit adequately to permit settling of fine sediment and allow controlled escape of clear water. A series of berms and settling ponds may prove to be the most effective method to control drainage and limit introduction of silt to adjacent natural waterbodies. If the extent of ice that may be exposed and the amount of fine grained sediment is defined by exploration drilling it would be possible to estimate the amount of silt and water flow expected and design drainage control systems to fit the need. Influx of large volumes of water of a different temperature or chemistry can also have a negative impact on aquatic life and water quality. Therefore the chemistry, temperature and silt content of water contained in any borrow pit should be monitored to determine if pit drainage is incompatible with the natural waterbodies.

In continuous permafrost the water table is generally confined to the zone above frozen ground. Water flow can occur at the base of the active layer. In the design of any water control system, in addition to surface water flow, the depth of the active layer and potential path of subsurface water flow should also be considered.

4. Exploration drilling intersected buried ice within one meter of the planned base of the borrow pit at 3 adjacent sites, over a distance of 250 metres, along the north side of area B and in single sites on the west side of area A and on the narrow northeast limb of Area A.. The thickness of ice intersected was 1 to 5 metres but most of these boreholes were terminated in ice so the full thickness is unknown. These areas have not yet been exploited but if the aggregate is extracted and the buried ice left exposed to thaw, thaw settlement should be expected. The extent of such surface disturbances will be dependent on the lateral extent and thickness of ice exposed to thaw.

If thaw settlement is to be avoided entirely, a minimum 2 meter buffer between the base of the borrow pit and the top of buried ice would be required. This buffer zone would include almost all of the aggregate in the areas with known buried ice. The thickness of buffer zone required to protect the ice from thaw could be reduced if the organic cover is replaced before the seasonal melt. If areas with buried ice are exploited the aggregate should be completely extracted in the first year as extraction in subsequent years may be impractical due to the development of thermokarst ponds. More sophisticated water containment or drainage control systems than have been employed to date would be required to control meltwater.

If buried ice is exposed near the edge of the elevated margins of the deposit, drainage control may be difficult. The west side of Area B is 10 metres above and less than 40 metres from Lake 155. Exposure of the buried ice in the northwest corner of Area B could initiate drainage into the lake. If this is to be avoided an undisturbed fringe between the borrow pit and the edge of the plateau would be required. Because the full extent of buried ice is unknown, the width of buffer required is uncertain but a 30 metre fringe can be expected to provide adequate protection in most situations. Any protective margin or berm designed to contain pit drainage should be monitored during the thaw season to determine if it is working effectively.

Massive ice and ice-rich sediments were not intersected in other parts of the borrow pit. However, distance between boreholes is 60-120 metres and most of the exploration boreholes were terminated 1.5-2.0 metres below the proposed base of the borrow pit. Therefore, the full extent of buried ice that could be exposed to thaw when the aggregate is removed is uncertain. Buried ice may occur between boreholes or below the limit of drilling but within 2 metres of the base of the borrow pit.

Although substantial thaw settlement is not expected on other margins of the borrow pit, a narrow 5 to 15 metre undisturbed fringe on all margins of the borrow pit would provide an added measure of environmental protection and would also provide a more natural visual appearance for the site as viewed from the surrounding low areas such as Lake 155 and Kittigazuit Creek.

5. Kittigazuit Creek lies at the base of a steep slope, 70 to 100 metres east of and 25 to 35 metres below Area A. It has been recommended in an earlier study that a 30 metre undisturbed buffer be maintained between the borrow pit and the edge of the slope to protect this environmentally sensitive and culturally important watercourse. Exploration drilling at the crest of the steep slope above the creek did not intersect buried ice and no thaw settlement was observed at the small borrow pit at the edge of this slope. The foregoing would suggest that the slope is not underlain by large volumes of massive ice or ice rich sediments that would be exposed by borrow pit activities.

6. Exploration drilling indicated that pre-extraction reserves at Source 155N were 388,000 cubic metres. Extraction to date is 84,098 cubic metres and recoveries exceeded expectations. Investigations as a part of this report suggests that Area B extends 50 to 100 metres further north and east than reported and may contain additional reserves. The highland on the southwest margin of Area A is not fully tested and could contain aggregate.

The requirement that a 30 meter undisturbed fringe be left between the borrow pit and Kittigazuit Creek would reduce reserves by 20,000 to 30,000 cubic metres. Leaving an undisturbed fringe between Lake 155 and ice rich parts of the deposit would reduce reserves by a further 5,000 to 7,000 cubic metres. Leaving a 5 to 15 metre undisturbed fringe on all other elevated margins of the deposit would reduce reserves by 5,000 to 15,000 cubic metres. Even with the foregoing environmental protection measures remaining reserves are expected to exceed 300,000 cubic metres Leaving all areas with known buried ice undeveloped to avoid thaw settlement would reduce these reserves by an additional 45,000 to 55,000 cubic metres.

Assuming that the exploration drilling provides reliable information on subsurface conditions it would appear that Source 155N contains substantial aggregate reserves that can be exploited with relatively limited environmental complications. Furthermore, the potential of this deposit to provide aggregate suitable for community needs does not appear to be limited by overburden cover or by quality of the material.

7. Exploitation of Source 155N is relatively expensive because of the long haul road required. When annual demand for aggregate is low, less than 10,000 cubic metres, road building costs are a significant factor in the local price of aggregate. Demand for aggregate by the community of Tuktoyaktuk is variable and has declined in recent years due to reduced oil and gas exploration activity. It may prove suitable to define a smaller source, closer to Tuktoyaktuk, to supply community needs when demand is low or to stockpile enough aggregate in town in one year to satisfy demand for two years.

8. Results of extraction activity to date at Source 155N would suggest that the exploration drilling provides reliable information on the type and thickness of overburden, and on the extent and quality of aggregate. Extraction activity at other deposits in the Tuktoyaktuk Coastlands region indicates that some of the earlier exploration drilling projects may not have been detailed enough to provide accurate information on subsurface conditions.

The density of exploration boreholes required to evaluate a deposit is dependent on the size and type of deposit. Large deposits such as 155N may be adequately evaluated by the density of boreholes employed at this site [one borehole per 6,700 square metres]. The density of boreholes employed to evaluate the smaller and more geologically variable deposits at Source 160/161 [approximately one borehole per 5,000 to 20,000 square metres] may not provide reliable information on subsurface conditions. One borehole per 7000 square meter should be considered a minimum density for exploration drilling projects in the region. More detailed drilling would be required to evaluate small or geologically variable deposits.

Because depth of thaw may be as much 2 metres and extraction of aggregate in some cases extends deeper than proposed, boreholes should be drilled a minimum of 3 metres below the planned base of the pit to locate buried ice that could be exposed to thaw. Boreholes should also be extended through any massive ice or ice rich sediments to determine the full thickness of ice and full extent of potential post-extraction thaw settlement.

9. Extracting aggregate in permanently frozen ground is difficult and expensive. Work is generally conducted in the winter because it is unsuitable to use heavy earth moving equipment on soft tundra in the summer. Cold weather complicates logistics. The working season is often limited to a few weeks in late winter and must be completed while the ice road is thick enough to support hauling equipment. Frozen overburden and aggregate is difficult to extract and, in some cases, requires stripping of the organics a year in advance to permit thaw and drainage. Presence of ice in the aggregate complicates handling and increases the volume of material extracted to provide a given volume of aggregate. Furthermore, where buried ice is exposed to thaw, thermokarst collapse will occur and meltwater runoff may be difficult to control. This can restrict further access to the deposit and pose environmental concerns. Restoration of abandoned borrow pits is difficult because of thermokarst ponding, paucity of organic material and slow vegetation growth.

Because of the inherent difficulties and environmental problems associated with extracting aggregate in permanently frozen ground, it is critical that subsurface stratigraphy be fully evaluated to determine the extent and quality of aggregate, type and thickness of overburden cover and extent and thickness of buried ice. To determine where thaw settlement will occur requires an understanding of thermal conditions in borrow pits. To permit future restoration requires an understanding of the most suitable methods to stockpile organics and to rehabilitate abandoned borrow pits.

An understanding of subsurface stratigraphy, thermal conditions and rehabilitation measures is necessary to design plans for development and restoration of borrow pits that maximize aggregate recoveries and minimize environmental damage. To assure that such plans are practical and fully understood by all parties involved they should be determined in cooperation between the consultants or scientific advisors, the ILA and the pit operator. For these plans to be effective the responsibilities of the ILA and pit operator should be clearly defined, there should be a monitoring procedure to determine that the plans are being followed and an annual review to modify them as required. The limits of the borrow pit should be laid out on the ground during the summer in advance of extraction activity to avoid development in areas that are unsuitable due to thick overburden cover, poor quality aggregate or environmental concerns.

FURTHER STUDIES

1. The natural vegetation and organic cover on granular deposits is generally thin and organics stockpiled for several years lose part of their volume due to desiccation and wind erosion. Consequently, organics remaining after extraction activities are completed are generally insufficient to permit complete covering of the base of the borrow pit. Vegetation may take decades to reestablish where there is no organic material at surface. A more complete rehabilitation may be possible if the organics are better stored.

   The manner in which organics have been stored at Sources 155N and 160/161 is not the most suitable way to preserve them for future recovering of the borrow pits. Organics are generally pushed into loose piles and left for several years exposed to wind and water erosion. In some instances they have been pushed off the edge of the deposit making recovery without disturbing the underlying intact organics impossible. In the borrow pits at Source 160/161, abandoned for over 7 years, there is almost no organic material or vegetation growth and no organic storage piles available to cover these pits. Clearly there is a need to design and implement improved methods for storage and replacement of organics.

   Research should be conducted to determine the most effective methods for storing organics to minimize loss and for rehabilitating abandoned borrow pits. For example, it may be possible to reduce wind erosion by securing fabric covers over stockpiles and recently replaced organics. It may be possible to reduce thaw penetration in the borrow pit and facilitate handling of organics if the pit is worked in sections and the organic cover replaced as soon as work is completed in any area.

   The small abandoned pits at 160/161 provide an ideal laboratory for such studies because they demonstrate present storage practices and provide examples of borrow pits in different stages of organic cover and revegetation. They are also within easy commuting distance of the Polar Shelf Base in Tuktoyaktuk and would not require expensive support.

2. The thermistor cables at 155N should be monitored to determine how the thermal regime changes during the year and from one year to the next. Future extraction activities are expected to overrun the boreholes and limit these studies to less than 4 years. Longer term thermal and active layer studies could be coupled with rehabilitation and revegetation studies at 160/161.

3. Instrumentation designed to detect buried ice from surface, such as the ground probing radar and the equipment presently used by the pit operator, could be tested where the extent of buried ice is known to determine their accuracy and depth penetration. This "ice detecting" equipment could also be employed to more accurately define the extent of buried ice between boreholes and on the margins of the plateau at 155N to identify areas that could be subjected to thaw settlement.

Down-hole and surface geophysical instrumentation could also be tested to determine if it is possible to more accurately define the extent, quality and bonding of the aggregate.

4. They information in the present report and from the proposed studies could be used to help establish more comprehensive guidelines for exploration, development, rehabilitation and regulation of borrow pits in the Tuktoyaktuk Coastlands Area.

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APPENDIX A

GROUND TEMPERATURES

MANUAL TEMPERATURE READINGS [DEGREES CELCIUS]

JULY 4, 1991

DEPTH [M]	BH16	BH18	BH19	BH20	BH21
0.5	7.4	10.0	8.2	9.1	8.8
0.0	10.8	3.4	4.4	6.3	6.2
-1.0	2.4	-3.0	-1.6	-0.8	-2.5
-4.0	-5.8	-6.8	-6.2	-6.8	-6.7
-6.5	-7.7	-7.9	-7.2	-8.6	-8.1
-9.0	-7.7	-7.8	-7.2	-8.7	-8.2
-14.0	-6.5	-7.0	-6.4	-7.6	-7.3
-19.0	-6.1	-6.7	-6.2	-7.0	-7.0
-24.0	-6.1	-6.8	-6.2	-6.9	-7.0
-29.0	-6.2	-6.8	-6.3	-6.8	-6.9

DEPTH [M]	BH17
0.5	9.1
0.0	4.8
-0.5	-1.7
-1.0	-3.0
-1.5	-4.5
-4.0	-7.3
-6.5	-8.4
-9.0	-7.9
-11.5	-7.3
-14.0	-6.9

SEPTEMBER 1, 1991

DEPTH [M]	BH16	BH18	BH19	BH20	BH21
0.5	3.7	3.8	3.0	3.0	2.3
0.0	6.1	4.1	3.6	4.8	2.6
-1.0	2.3	-1.4	0.1	0.7	-1.2
-4.0	-3.5	-4.7	-3.7	-3.6	-4.6
-6.5	-5.4	-6.3	-5.4	-6.2	-6.5
-9.0	-6.5	-7.0	-6.4	-7.3	-7.3
-14.0	-6.7	-7.1	-6.4	-7.5	-7.4
-19.0	-6.3	-6.8	-6.2	-7.0	-7.1
-24.0	*-3.6	-6.8	-6.1	-6.7	-6.9
-29.0	-6.3	-6.7	-6.2	-6.8	-6.9

DEPTH [M]	BH17
0.5	4.0
0.0	4.0
-0.5	-0.3
-1.0	-1.6
-1.5	-2.5
-4.0	-5.0
-6.5	-6.9
-9.0	-7.4
-11.5	-7.3
-14.0	-7.1

SEPTEMBER 3, 1991

DEPTH [M]	BH16	BH18	BH19	BH20	BH21
0.5	13.1	12.0	14.1	12.3	14.5
0.0	9.7	3.5	3.2	3.3	9.5
-1.0	2.5	-1.4	0.0	0.8	-1.2
-4.0	-3.1	-4.7	-3.7	-3.4	-4.5
-6.5	-5.4	-6.3	-5.5	-6.2	-6.4
-9.0	-6.5	-7.0	-6.3	-7.4	-7.3
-14.0	-6.7	-7.1	-6.5	-7.5	-7.4
-19.0	-6.3	-6.8	-6.2	-7.0	-7.1
-24.0	*-5.9	-6.8	-6.2	-6.6	-6.9
-29.0	-6.2	-6.7	-6.2	-6.7	-6.9

DEPTH [M]	BH17
0.5	11.7
0.0	2.0
-0.5	-0.4
-1.0	-1.4
-1.5	-2.5
-4.0	-4.9
-6.5	-6.9
-9.0	-7.4
-11.5	-7.4
-14.0	-7.1

SEPTEMBER 5, 1991

DEPTH [M]	BH16	BH18	BH19	BH20	BH21
0.5	4.1	8.1	6.9	1.4	4.2
0.0	3.3	2.7	2.3	2.7	2.2
-1.0	2.4	-1.1	0.1	0.8	-1.1
-4.0	-3.1	-4.3	-3.6	-3.8	-4.5
-6.5	-5.4	-6.2	-5.5	-6.1	-6.4
-9.0	-6.4	-7.0	-6.3	-7.3	-7.3
-14.0	-6.7	-7.1	-6.4	-7.6	-7.4
-19.0	-6.3	-6.8	-6.2	-6.9	-7.1
-24.0	*-5.9	-6.8	-6.1	-6.9	-6.9
-29.0	-6.2	-6.7	-6.2	-6.8	-6.9

DEPTH [M]	BH17
0.5	7.3
0.0	2.5
-0.5	-0.5
-1.0	-1.4
-1.5	-2.4
-4.0	-4.9
-6.5	-6.9
-9.0	-7.4
-11.5	-7.3
-14.0	-7.1

* In borehole 16 the # 9 temperature bead provides erratic readings. There is a loose wire on the connector.

APPENDIX B

LEVEL AND ACTIVE LAYER SURVEYS

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
LINE 1						
0.00 S BH17	100.00	100.00	0.12	0.38	DRILL CUTTINGS ON SURFACE	
5.00 S			0.14	0.50	UNDISTURBED ORGANIC COVER	
10.00 S	100.13	100.05	0.16	0.35	UNDISTURBED ORGANIC COVER	
15.00 S			0.16	0.38	UNDISTURBED ORGANIC COVER	
20.00 S	100.40	100.46	0.19	0.33	UNDISTURBED ORGANIC COVER	
25.00 S			0.13	0.35	UNDISTURBED ORGANIC COVER	
30.00 S	100.51	100.51	0.14	0.32	UNDISTURBED ORGANIC COVER	
35.00 S			0.14	0.36	UNDISTURBED ORGANIC COVER	
40.00 S	100.69	100.64	0.16	0.42	UNDISTURBED ORGANIC COVER	
45.00 S			0.15	0.35	UNDISTURBED ORGANIC COVER	
50.00 S	100.76	100.77	0.15	0.36	UNDISTURBED ORGANIC COVER	
55.00 S			0.13	0.28	UNDISTURBED ORGANIC COVER	
60.00 S	100.99	100.96	0.15	0.34	UNDISTURBED ORGANIC COVER	
65.00 S			0.09	0.32	UNDISTURBED ORGANIC COVER	
70.00 S	100.98	101.04	0.14	0.28	UNDISTURBED ORGANIC COVER	
75.00 S			0.13	0.37	UNDISTURBED ORGANIC COVER	
80.00 S	101.01	100.96	0.10	0.33	UNDISTURBED ORGANIC COVER	
85.00 S			0.11	0.32	UNDISTURBED ORGANIC COVER	
90.00 S	101.04	101.04	0.09	0.26	UNDISTURBED ORGANIC COVER	
95.00 S			0.16	0.32	UNDISTURBED ORGANIC COVER	
100.00 S	101.14	101.14	0.12	0.30	UNDISTURBED ORGANIC COVER	
105.00 S			0.13	0.30	UNDISTURBED ORGANIC COVER	
110.00 S	101.25	101.29	0.11	0.37	UNDISTURBED ORGANIC COVER	
115.00 S			0.31	0.50	UNDISTURBED ORGANIC COVER	PROBE ON HUMMOCK
120.00 S	101.35	101.32	0.18	0.31	UNDISTURBED ORGANIC COVER	
125.00 S			0.10	0.30	UNDISTURBED ORGANIC COVER	
130.00 S	101.29	101.32	0.14	0.60	UNDISTURBED ORGANIC COVER	PROBE IN SILT/CLAY
135.00 S			0.13	0.32	UNDISTURBED ORGANIC COVER	
140.00 S	101.41	101.35	0.13	0.33	UNDISTURBED ORGANIC COVER	
145.00 S			0.16	0.30	UNDISTURBED ORGANIC COVER	
150.00 S	101.30	101.32	0.09	0.26	UNDISTURBED ORGANIC COVER	
155.00 S			0.15	0.27	UNDISTURBED ORGANIC COVER	
160.00 S	101.42	101.37	0.35	0.53	UNDISTURBED ORGANIC COVER	PROBE ON HUMMOCK IN ORGANICS
165.00 S			0.31	0.42	UNDISTURBED ORGANIC COVER	
170.00 S	101.31	101.29	0.12	0.46	UNDISTURBED ORGANIC COVER	PROBE IN SILT/CLAY
175.00 S			0.20	0.37	UNDISTURBED ORGANIC COVER	
180.00 S	101.37	101.34	0.21	0.42	UNDISTURBED ORGANIC COVER	
185.00 S			0.18	0.40	UNDISTURBED ORGANIC COVER	
190.00 S	101.27	101.32	0.15	0.34	UNDISTURBED ORGANIC COVER TO 195M	
195.00 S	101.46	101.46	0.17	0.25	ORGANIC DUMP	
200.00 S	101.78	101.78	0.20	0.29	ORGANIC DUMP	
205.00 S	101.50	101.51	0.20	0.27	ORGANIC DUMP	

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
210.00 S	101.25	101.24	0.16	0.36	ORGANIC DUMP	
215.00 S	101.52	101.48	0.27	0.61	LOOSE PILE OF GRAVEL AND ORGANICS	
220.00 S	101.29	101.31	0.39	>0.46	LOOSE PILE OF GRAVEL AND ORGANICS	SPRING/FALL ACTIVE LAYER UNCERTAIN
225.00 S	101.01	101.03	0.33	0.54	LOOSE PILE OF GRAVEL AND ORGANICS	SPRING/FALL ACTIVE LAYER UNCERTAIN
230.00 S	101.04	101.06	0.38	0.48	LOOSE PILE OF GRAVEL AND ORGANICS	SPRING/FALL ACTIVE LAYER UNCERTAIN
235.00 S	99.98	100.00			BORROW PIT	
240.00 S	99.68	99.68	1.02	>1.20	BORROW PIT	0.2M RIDGE
245.00 S	99.65	99.62	1.10		BORROW PIT	
250.00 S	99.80	99.78	>1.20	1.70	BORROW PIT	0.4M OF GRAVEL OVER SAND
257.00 S				1.52	BORROW PIT	
260.00 S	99.63	99.58	1.07		BORROW PIT	SANDY
270.00 S	100.14	100.14	>1.20		BORROW PIT	SANDY
274.00 S BH16	100.25	100.26	1.16	1.46	BORROW PIT	0.28M OF GRAVEL OVER SAND
280.00 S	99.79	99.79	0.94	1.65	BORROW PIT	SANDY/WET
290.00 S	99.64	99.63	0.96		BORROW PIT	SANDY/WET
300.00 S	99.31	99.32	0.90	1.50	BORROW PIT	0.3M OF GRAVEL OVER SAND/WET AREA
310.00 S	98.84	98.83	0.93		BORROW PIT	
315.00 S		98.45			BORROW PIT	
320.00 S	98.14	98.13	0.33	0.72	FILL--LOW WET AREA	0.25M GRAVEL OVER ORGANICS
325.00 S	98.66	98.66		0.84	FILL--LOW WET AREA	
330.00 S	98.23	98.16	0.30	0.56	LOW WET AREA-THIN ORGANIC DUMP	
333.00 S	98.15	97.99			ORGANIC DUMP 330-347M	
335.00 S	98.51	98.62			ORGANIC DUMP	
340.00 S	99.76	99.63	0.36	0.45	GRAVEL/ORGANIC DUMP	
345.00 S	99.17	98.99			ORGANIC DUMP	
350.00 S	99.41	99.41	0.45	1.15	LOW WET AREA-THIN ORGANIC/GRAVEL DUMP	ORGANICS UNDER LOOSE FILL
355.00 S	99.85	99.83			BORROW PIT	
360.00 S	100.08	100.07	0.31		BORROW PIT	
365.00 S				>O.50	BORROW PIT	GRAVEL--FALL ACTIVE LAYER UNCERTAIN
370.00 S	100.82	100.80	0.57	>O.85	EDGE OF BORROW PIT-ORGANICS STRIPPED OFF	GRAVEL--FALL ACTIVE LAYER UNCERTAIN
378.00 S BH20	101.13	101.12	0.48		THIN LAYER OF DRILL CUTTINGS	
380.00 S	100.95	100.93	0.46	>O.74	MOST OF ORGANICS STRIPPED OFF	GRAVEL--FALL ACTIVE LAYER UNCERTAIN
385.00 S				>O.66	MOST OF ORGANICS STRIPPED OFF	GRAVEL--FALL ACTIVE LAYER UNCERTAIN
390.00 S	101.20	101.17	0.30	1.10	MOST OF ORGANICS STRIPPED OFF	
400.00 S	101.43	101.46	0.10	0.32	UNDISTURBED ORGANIC COVER FROM 398M	
405.00 S			0.11	0.30	UNDISTURBED ORGANIC COVER	
410.00 S	101.57	101.57	0.15	0.32	UNDISTURBED ORGANIC COVER	
415.00 S			0.11	0.23	UNDISTURBED ORGANIC COVER	
420.00 S	101.54	101.64	0.13	0.33	UNDISTURBED ORGANIC COVER	
425.00 S			0.14	0.29	UNDISTURBED ORGANIC COVER	
430.00 S	101.68	101.71	0.22	0.47	UNDISTURBED ORGANIC COVER	PROBE IN SILT/CLAY
435.00 S			0.10	0.22	UNDISTURBED ORGANIC COVER	
440.00 S	101.77	101.80	0.12	0.27	UNDISTURBED ORGANIC COVER	

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
445.00 S			0.13	0.27	UNDISTURBED ORGANIC COVER	
450.00 S	101.77	101.84	0.19	0.27	UNDISTURBED ORGANIC COVER	
455.00 S			0.13	0.22	UNDISTURBED ORGANIC COVER	
460.00 S	101.85	101.90	0.10	0.23	UNDISTURBED ORGANIC COVER	
465.00 S			0.10	0.25	UNDISTURBED ORGANIC COVER	
470.00 S	101.93	101.99	0.09	0.28	UNDISTURBED ORGANIC COVER	
475.00 S			0.12	0.27	UNDISTURBED ORGANIC COVER	
480.00 S	102.00	102.03	0.12	0.28	UNDISTURBED ORGANIC COVER	
485.00 S			0.12	0.30	UNDISTURBED ORGANIC COVER	
490.00 S	101.99	102.01	0.11	0.30	UNDISTURBED ORGANIC COVER	
495.00 S			0.11	0.27	UNDISTURBED ORGANIC COVER	
500.00 S	102.06	102.16	0.13	0.25	UNDISTURBED ORGANIC COVER	

LINE 2

0.00 W BH19	101.94	101.97	0.36	0.42	DRILL CUTTINGS ON SURFACE	
5.00 W				0.78	UNDISTURBED ORGANIC COVER	SAND UNDER ORGANICS
10.00 W	101.99	101.89	0.34	0.71	UNDISTURBED ORGANIC COVER	
15.00 W				0.88	UNDISTURBED ORGANIC COVER	
20.00 W	102.25	102.16	0.48	0.83	UNDISTURBED ORGANIC COVER	
25.00 W				0.90	UNDISTURBED ORGANIC COVER	
30.00 W	101.28	101.11	0.24	0.70	UNDISTURBED ORGANIC COVER	AT BREAK IN SLOPE-SAND UNDER ORGANICS
35.00 W				0.52	UNDISTURBED ORGANIC COVER	
40.00 W	99.45	99.34	0.17	0.70	UNDISTURBED ORGANIC COVER	SAND UNDER ORGANICS
45.00 W				0.53	UNDISTURBED ORGANIC COVER	
50.00 W	96.94	96.96	0.13	0.50	UNDISTURBED ORGANIC COVER	SAND UNDER ORGANICS
55.00 W				0.41	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
60.00 W	95.64	95.65	0.24	0.42	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
65.00 W					UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
70.00 W	95.63	95.59	0.23	0.47	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
75.00 W					UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
80.00 W	95.52	95.31	0.33	0.40	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	AT EDGE OF ICE WEDGE TROUGH
85.00 W					UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
90.00 W	95.30	95.29	0.20	0.30	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
95.00 W					UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
100.00 W	95.37	95.37	0.18	0.40	UNDISTURBED ORGANIC COVER--POLYGON NETWORK	
105.00 W	95.44	95.38		0.32	UNDISTURBED ORGANIC COVER	
110.00 W	95.68	95.70	0.12	0.42	UNDISTURBED ORGANIC COVER	
115.00 W	95.77	95.74	0.18	0.50	UNDISTURBED ORGANIC COVER	WET DUE TO RUNOFF FROM ORGANIC PILE
120.00 W	96.19	96.19	0.23	0.78	LOOSE AND WET GRAVEL/ORGANIC DUMP	
125.00 W	96.62	96.82	0.17	0.87	LOOSE AND WET GRAVEL/ORGANIC DUMP	
130.00 W	97.74	97.69	0.19	0.74	LOOSE AND WET GRAVEL/ORGANIC DUMP	
135.00 W	98.38	98.39	0.41	0.75	LOOSE AND WET GRAVEL/ORGANIC DUMP	FALL ACTIVE LAYER DEPTH UNCERTAIN
140.00 W	98.96	98.95	0.42	0.92	EDGE OF BORROW PIT	MIXED GRAVEL AND ORGANICS

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
145.00 W	99.10	99.10	0.93		BORROW PIT	GRAVEL
150.00 W	99.45	99.50	0.91	1.50	BORROW PIT	THIN COVER OF GRAVEL OVER SAND
155.00 W					BORROW PIT	
160.00 W	99.70	99.69	1.00		BORROW PIT	LOOSE SAND
165.00 W					BORROW PIT	
170.00 W	99.74	99.74			BORROW PIT	DENSE PEBBLY GRAVEL-ACTIVE LAYER UNCERTAIN
175.00 W					BORROW PIT	
180.00 W	99.45	99.45	>1.2		BORROW PIT	
185.00 W					BORROW PIT	
190.00 W	99.69	99.70	0.88		BORROW PIT	
195.00 W					BORROW PIT	
200.00 W	99.64	99.66	0.86	1.43	BORROW PIT	THIN COVER OF GRAVEL OVER SAND
205.00 W					BORROW PIT	
210.00 W	99.59	99.57	0.93		BORROW PIT	
215.00 W					BORROW PIT	
220.00 W	99.38	99.36	0.91		BORROW PIT	
225.00 W				1.50	BORROW PIT	SAND
230.00 W	99.72	99.71	0.94		BORROW PIT	
235.00 W					BORROW PIT	
240.00 W	99.35	99.40	0.92		BORROW PIT	
245.00 W					BORROW PIT	
250.00 W	99.57	99.57		1.65	BORROW PIT	0.7 M OF GRAVEL OVER SAND
255.00 W					BORROW PIT	
260.00 W	99.71	99.68	1.15		BORROW PIT	FINE SANDY GRAVEL
265.00 W					BORROW PIT	
270.00 W	100.04	100.04	1.10		BORROW PIT	FINE SANDY GRAVEL
275.00 W					BORROW PIT	
280.00 W	99.89	99.89			BORROW PIT	DENSE PEBBLY GRAVEL-ACTIVE LAYER UNCERTAIN
284.50 W BH16	100.25	100.26	1.16	1.46	BORROW PIT	
285.00 W					BORROW PIT	
290.00 W	99.82	99.78	1.14		BORROW PIT	
295.00 W					BORROW PIT	
300.00 W	99.37	99.25	0.93	1.46	BORROW PIT	SAND
305.00 W					BORROW PIT	
310.00 W	98.53	98.53	0.80		BORROW PIT	
315.00 W					BORROW PIT	
320.00 W	98.10	98.08	>0.80		BORROW PIT	WET SANDY/SPRING PROBE DEPTH UNCERTAIN
325.00 W	97.87	97.84			BORROW PIT	
330.00 W	97.60	97.60	0.41		LOW AREA--GRAVEL FILL	THIN GRAVEL COVER OVER ORGANICS
335.00 W	97.65	97.64	0.44		LOW AREA--GRAVEL FILL	THIN GRAVEL COVER OVER ORGANICS
340.00 W	97.57	97.65	0.38	0.55	LOW AREA--GRAVEL FILL	THIN GRAVEL COVER OVER ORGANICS
345.00 W	97.73	97.69	0.45		GRAVEL/ORGANIC DUMP 346-361	
350.00 W	98.74	98.61	0.43	0.40	GRAVEL/ORGANIC DUMP	

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
355.00 W	99.32	99.13	0.32		GRAVEL/ORGANIC DUMP	
360.00 W	98.21	98.17	0.72		GRAVEL/ORGANIC DUMP	
365.00 W	97.85	97.90	0.91		BORROW PIT	GRAVEL
370.00 W	98.07	98.10	0.82		BORROW PIT	SAND
375.00 W				1.30	BORROW PIT	SAND AT SURFACE
380.00 W	98.40	98.43	0.80		BORROW PIT	
385.00 W					BORROW PIT	
390.00 W	98.51	98.52	0.82		BORROW PIT	
395.00 W					BORROW PIT	
400.00 W	98.99	98.98	0.76	1.20	BORROW PIT	GRAVEL/ORGANICS TO 0.6M-OVERLIES SAND
405.00 W					BORROW PIT	
410.00 W	99.53	99.56	0.92		BORROW PIT	LOOSE GRAVEL OVER BASE OF EXCAVATION
415.00 W					BORROW PIT	
420.00 W	99.71	99.67	0.90		BORROW PIT	
423.00 W					MELTOUT ICE WEDGE-0.3M WIDE SPRING/0.5 FALL	
425.00 W				1.30	BORROW PIT	SAND AT SURFACE
430.00 W	99.50	99.46	>0.35		BORROW PIT	SPRING ACTIVE LAYER DEPTH UNCERTAIN
435.00 W					BORROW PIT	
440.00 W	99.69	99.74	0.40		BORROW PIT	GRAVEL--FALL ACTIVE LAYER UNKNOWN
445.00 W	100.30	100.31	0.28		BORROW PIT	
450.00 W	100.84	100.85	0.65		DISTURBED ORGANICS FROM 446M	GRAVEL--FALL ACTIVE LAYER UNKNOWN
455.00 W	100.77	100.76	0.49		DISTURBED ORGANICS	
460.00 W	101.04	101.10	0.49		DISTURBED ORGANICS	GRAVEL--FALL ACTIVE LAYER UNKNOWN
465.00 W			0.30		DISTURBED ORGANICS	
470.00 W	101.38	101.34	0.24	0.35	UNDISTURBED ORGANIC COVER FROM 467M	
475.00 W			0.18		UNDISTURBED ORGANIC COVER	
480.00 W	101.33	101.40	0.22	0.33	UNDISTURBED ORGANIC COVER	
483.00 W 21	101.67	101.67	0.25		UNDISTURBED ORGANIC COVER	
485.00 W			0.16		UNDISTURBED ORGANIC COVER	
490.00 W	101.48	101.54	0.22	0.28	UNDISTURBED ORGANIC COVER	
495.00 W			0.23		UNDISTURBED ORGANIC COVER	
500.00 W	101.62	101.61	0.16	0.25	UNDISTURBED ORGANIC COVER	GRAVEL UNDER ORGANICS

LINE 3

0.00 N 21	101.67	101.67	0.25	0.36	UNDISTURBED ORGANIC COVER	GRAVEL UNDER ORGANICS
5.00 N					UNDISTURBED ORGANIC COVER	
10.00 N	101.37	101.32		0.36	UNDISTURBED ORGANIC COVER	GRAVEL UNDER ORGANICS
15.00 N	101.31	101.37			UNDISTURBED ORGANIC COVER	
20.00 N	101.10	101.00			BORROW PIT	GRAVEL/ORGANICS TO 0.3M-GRAVEL TO +0.7M
25.00 N	100.84	100.67			BORROW PIT	
30.00 N	100.31	100.22		>0.70	BORROW PIT	
35.00 N	99.63	99.58			BORROW PIT	
40.00 N	99.40	99.36		>0.60	BORROW PIT	SAND TO 0.5M/GRAVEL TO +0.6M

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
45.00 N		99.11			BORROW PIT	
50.00 N	98.34	98.33		1.45	BORROW PIT	SAND
55.00 N	97.98	97.91			BORROW PIT	
60.00 N	97.27	97.25			BORROW PIT	
65.00 N	96.96	96.92			BORROW PIT	
70.00 N	97.00	96.97		1.55	BORROW PIT	0.12M COVER OF GRAVEL OVER SAND
75.00 N	96.83	96.71			BORROW PIT	
80.00 N	96.20	96.13		1.35	BORROW PIT	SAND
85.00 N	96.37	96.33			BORROW PIT	
90.00 N	96.25	96.22			BORROW PIT	
95.00 N	96.04	95.98			BORROW PIT	
100.00 N	95.84	95.75		1.74	BORROW PIT	SMALL SAND MOUND
105.00 N	95.54	95.44			BORROW PIT	
110.00 N	94.91	94.82			BORROW PIT	
115.00 N	94.31	94.23		1.40	BORROW PIT	PIT SIDE OF BERM-0.8M GRAVEL OVER SAND
117.50 N		93.84			BORROW PIT	
120.00 N	93.31	93.34			1991 BERM 120.5-125.5	
121.70 N		93.53			MELTOUT DEPRESSION ON BERM	
122.50 N	93.27	92.97			TOP OF BERM	
125.00 N	92.95	92.94			BERM 128.4-130.4	
130.00 N	92.56	92.66		0.60	GRAVEL FILL	0.27M COVER OF GRAVEL OVER ORGANICS
135.00 N	92.26	92.33			BERM 133.5-138.2	
140.00 N	91.23	91.28			POND 141.7-146.9	
145.00 N	90.92	90.95			GRAVEL FILL	
150.00 N	90.88	90.93			RIDGE-TOP OF BEACH	WELL SORTED GRAVEL
155.00 N	90.31	89.84			BEACH	
161.00 N	89.73				SPRING LAKE LEVEL	
162.20 N		89.65			FALL LAKE LEVEL	

LINE 4

0.00 E	89.82	89.87			BEACH	LINE 4 STARTS AT LINE 3-160N
5.00 E	90.59	90.63			BEACH	
10.00 E	91.24	91.27			FILL	
15.00 E	91.40	91.42			FILL	
20.00 E	91.74	91.77			FILL	
25.00 E	91.97	92.01			BERM 26.0-27.4M	
30.00 E	92.14	92.19			BERM-31.0-33.5M	
32.30 E		92.70			TOP OF BERM	
35.00 E	92.57	92.60			FILL	
40.00 E	92.65	92.61			MELT WATER CHANNEL 39.3-42.0	
45.00 E	93.05	93.08			GRAVEL FILL	
50.00 E	93.39	93.40		0.60	GRAVEL FILL	THIN COVER OF SAND/GRAVEL OVER ORGANICS
55.00 E	93.80	93.77			GRAVEL FILL	

LOCATION	ELEVATION		ACTIVE LAYER		DESCRIPTION	COMMENTS
	SPRING (m)	FALL (m)	SPRING (m)	FALL (m)		
60.00 E	93.99	93.93		0.82	GRAVEL FILL	0.5M COVER OF SAND/GRAVEL OVER ORGANICS
65.00 E	94.11	94.03			THAW POND-67.0-69.0(SPRING) 66.1-69.8(FALL)	
70.00 E	94.05	93.94			GRAVEL FILL	0.4M COVER OF SAND/GRAVEL OVER ORGANICS
75.00 E	94.36	94.33		0.80	GRAVEL FILL	
80.00 E	94.49	94.41			GRAVEL FILL	
85.00 E	94.63	94.57		0.75	GRAVEL FILL	
90.00 E	94.92	94.88			GRAVEL FILL	
95.00 E	95.01	94.90			GRAVEL FILL	
96.40 E		94.56		0.63	THAW CHANNEL 95-98(SPRING)-94.2-98.7(FALL)	
100.00 E	95.32	95.24		1.20	GRAVEL FILL	FILL TO.22M/ORGANICS TO.5M/GRAVEL TO +1.2M
105.00 E		95.71			GRAVEL FILL	
110.00 E	95.91	95.85		1.33	BORROW PIT	WET SAND WITH .25M COVER OF LOOSE GRAVEL
115.00 E					BORROW PIT	
120.00 E	96.57	96.49			BORROW PIT	
125.00 E					BORROW PIT	
130.00 E	97.03	96.94		1.30	BORROW PIT	SAND
135.00 E					BORROW PIT	
140.00 E	97.49	97.44			BORROW PIT	
145.00 E					BORROW PIT	
150.00 E	97.97	97.93			BORROW PIT	
155.00 E					BORROW PIT	
160.00 E	98.45	98.43			BORROW PIT	
165.00 E					BORROW PIT	
170.00 E	98.81	98.77			BORROW PIT	
175.00 E					BORROW PIT	
180.00 E	99.24	99.15			BORROW PIT	
185.00 E					BORROW PIT	
190.00 E	99.29	99.27			BORROW PIT	
195.00 E		98.85			BORROW PIT	
200.00 E	99.22	99.20			BORROW PIT	
205.00 E					BORROW PIT	
210.00 E	99.94	99.94			BORROW PIT	
215.00 E					BORROW PIT	
220.00 E	100.52	100.48			BORROW PIT	
225.00 E					BORROW PIT	
230.00 E	100.89	100.85			MOST OF ORGANICS STRIPPED OFF	
235.00 E					MOST OF ORGANICS STRIPPED OFF	
240.00 E	100.82	100.89			MOST OF ORGANICS STRIPPED OFF	
244.00 E BH 20	101.13	101.12	0.48		THIN LAYER OF DRILL CUTTINGS	

APPENDIX C

PHOTOGRAPHS

Plate 1. Aerial view of Source 155N (June, 1991). Both borrow pits are visible as light areas on the photograph. South is to the left.

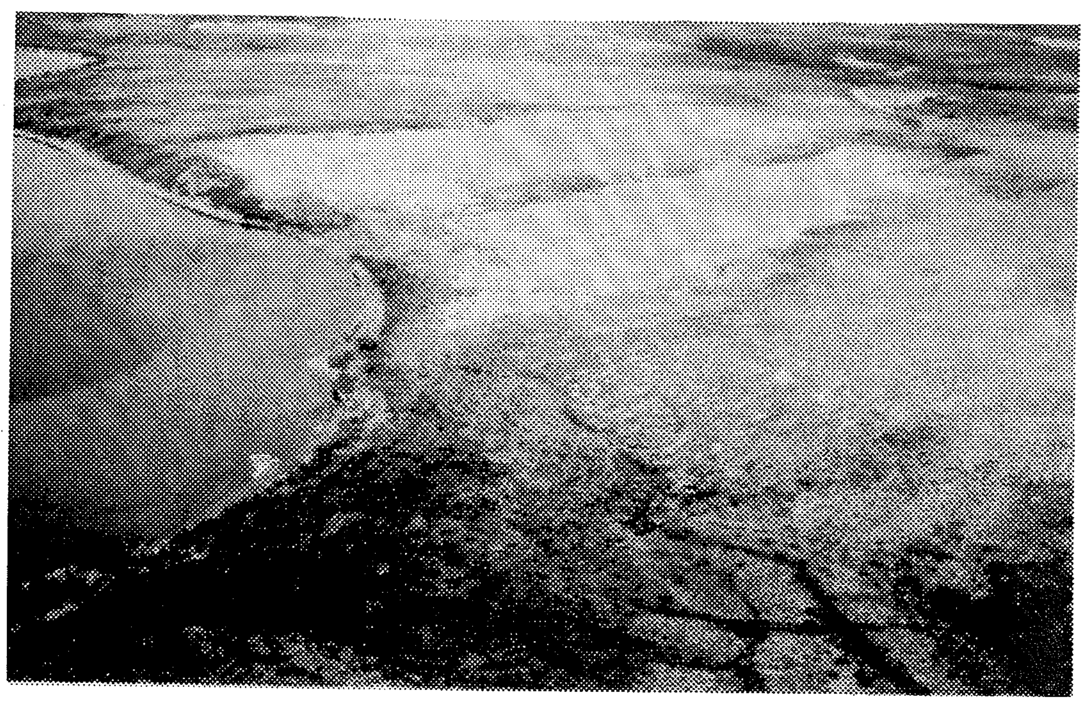

Plate 2. Aerial view of the main borrow pit at 155N looking north (June, 1991). Note the active ice polygon network in the near foreground and the partially stripped organics on the west slope of Area "A" (also in the near foreground).

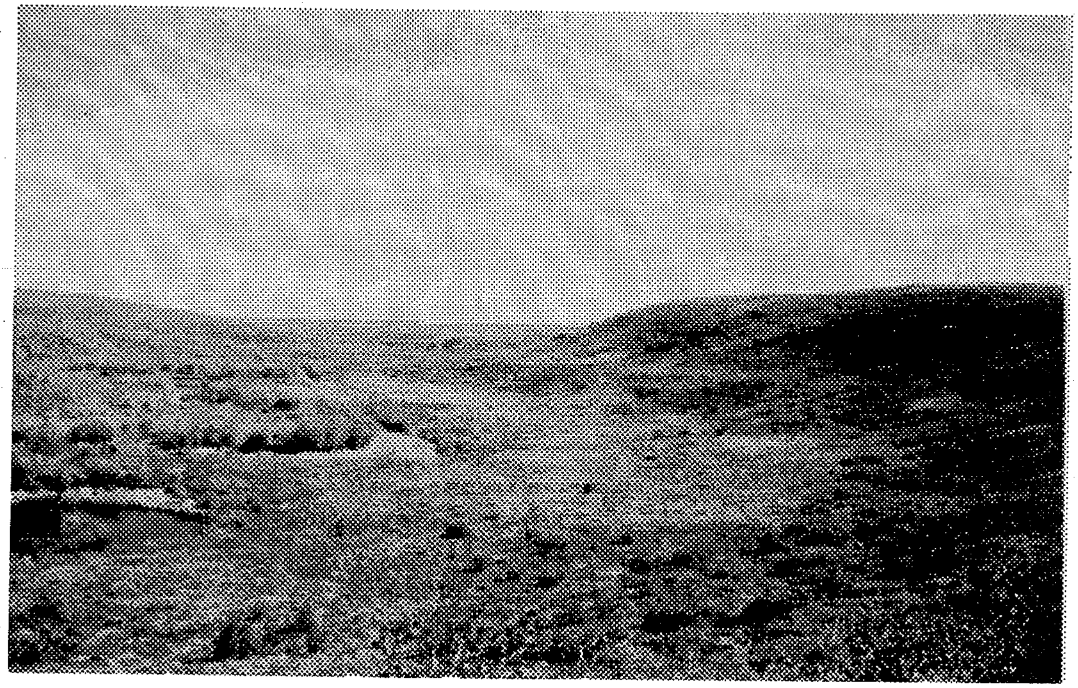

Plate 3. Kittigazuit Creek Valley looking south to the plateau of the east side of Area "A".

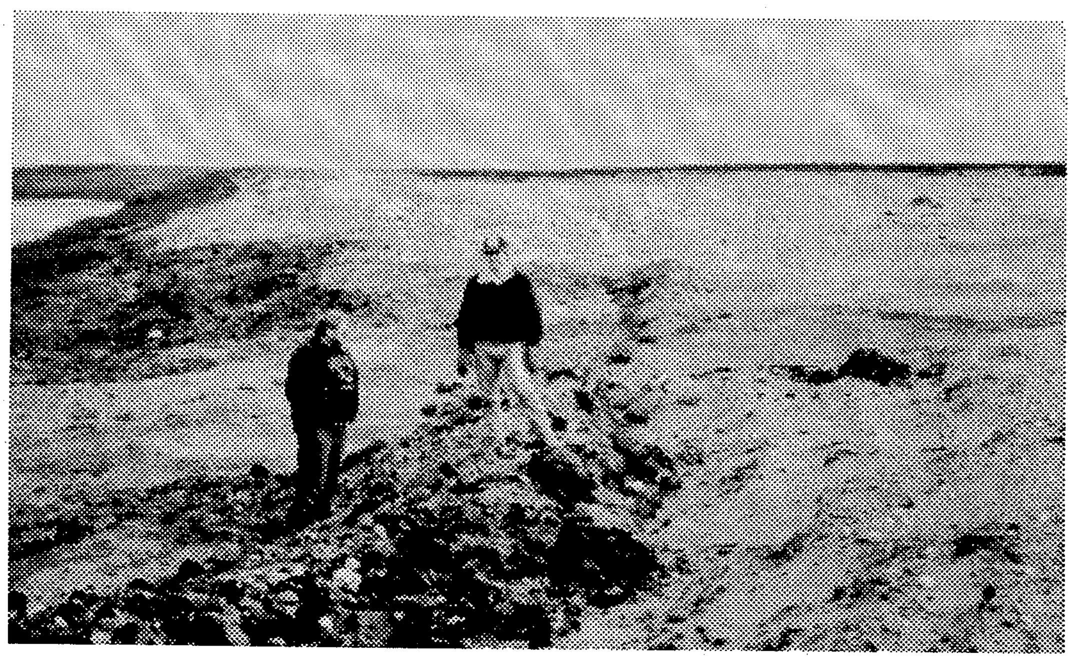

Plate 4. The 1991 berm looking to the west (June, 1991). Lake 155 is to the left of the photo.

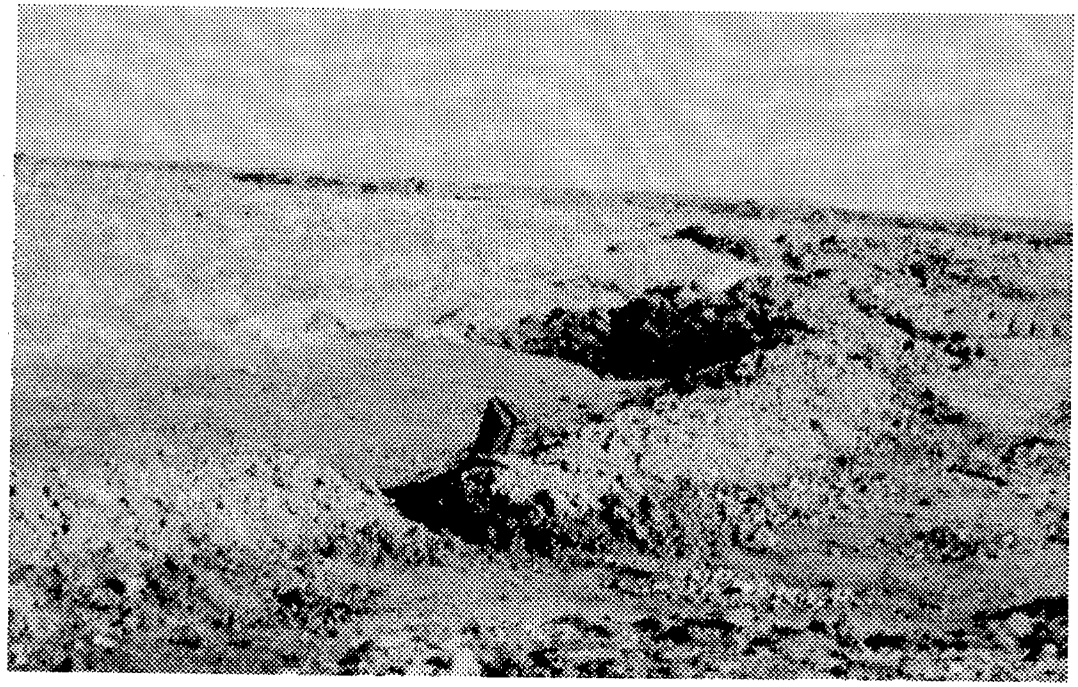

Plate 5. Breach in the 1991 berm (June, 1991). Packsack on the berm is for scale.

Plate 6. The 1991 berm looking northwest to Lake 155 (September, 1991). Note the small ponds dammed by the series of berms.

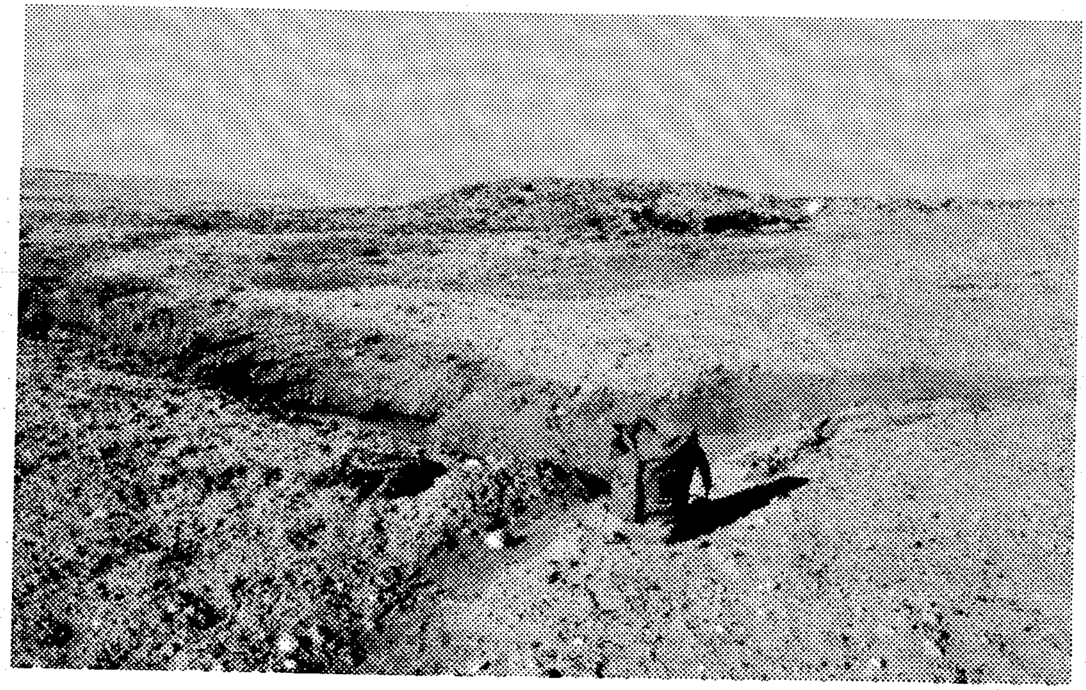

Plate 7. Thaw settlement cracks in the base of the channel which separates Areas "A" and "B" (June, 1991). Pack for scale.

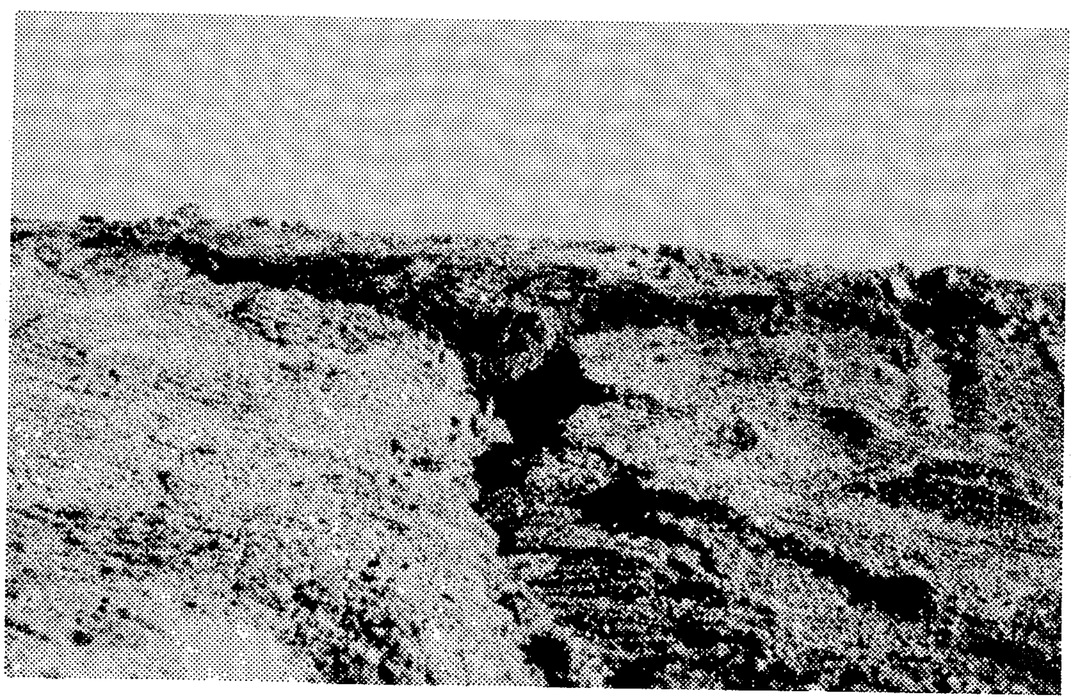

Plate 8. Thaw settlement cracks in the borrow pit on the north facing slope of Area "A" (September, 1991). The opening is approximately 1.5 metres across.

Plate 9. Thaw settlement crack on the west facing slope of Area "A" (September, 1991). The organic cover is only partially stripped from this slope.

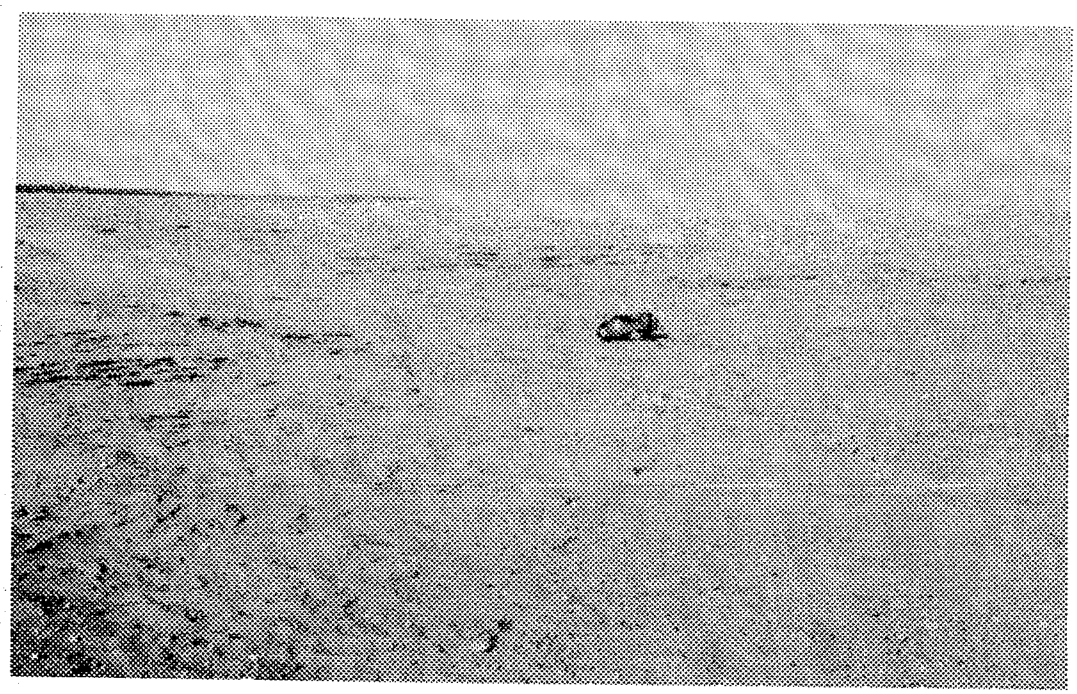

Plate 10. Stratified sands exposed on the south facing slope of Area "B". Packsack in the centre of the photograph is for scale.

APPENDIX D

MAPS AND FIGURES

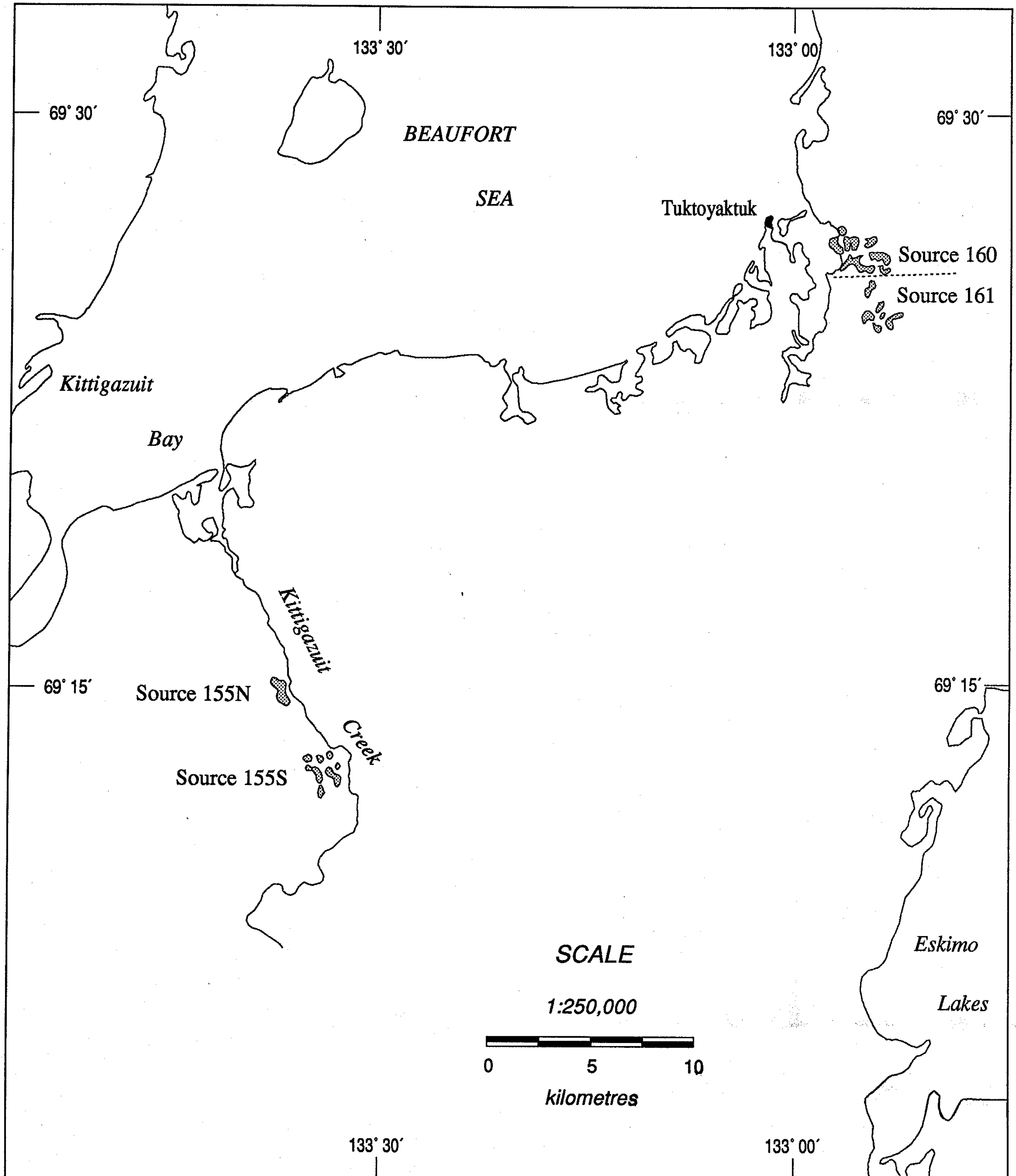

Figure 1. Location map (modified after Hardy 1986)

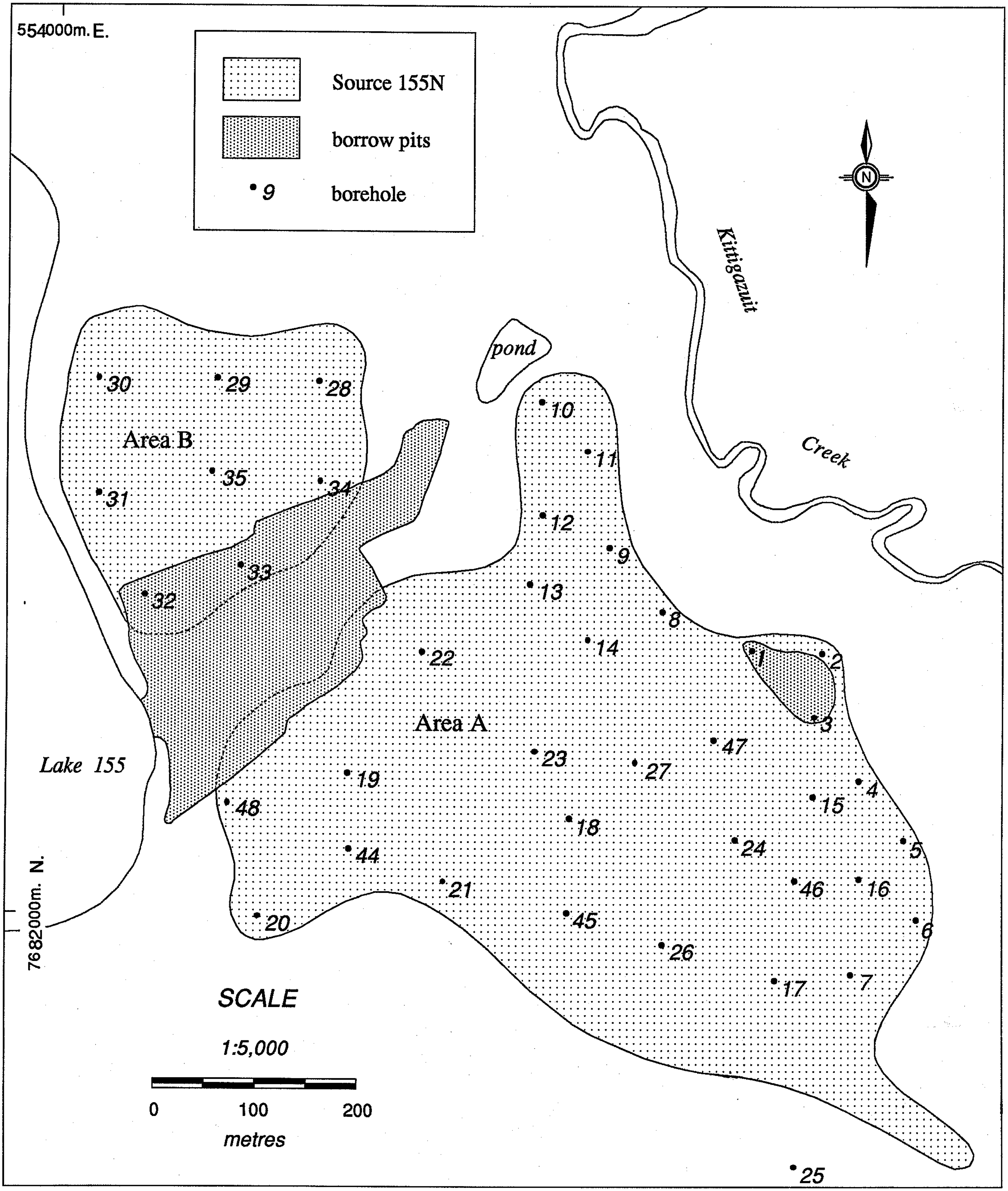

Figure 2: *Source 155N with exploration boreholes and outline of the deposit. (after Hardy 1988) Extent of borrow pit as of June, 1991 based on field work and aerial photography.*

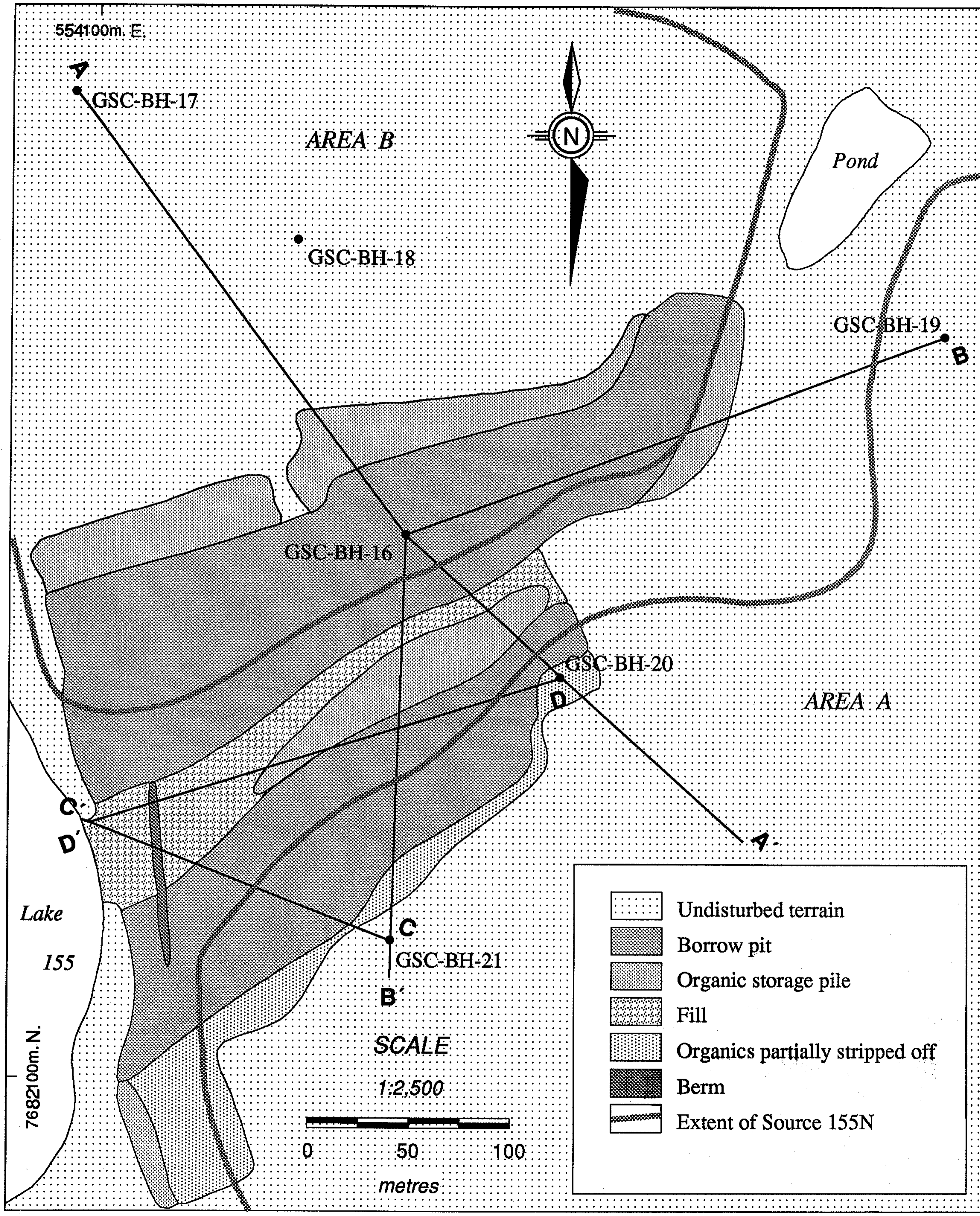

Figure 3. *Borrow pit (June, 1991) shown with survey line and GSC boreholes. Boundary of the deposit redefined as the edge of the plateau.*

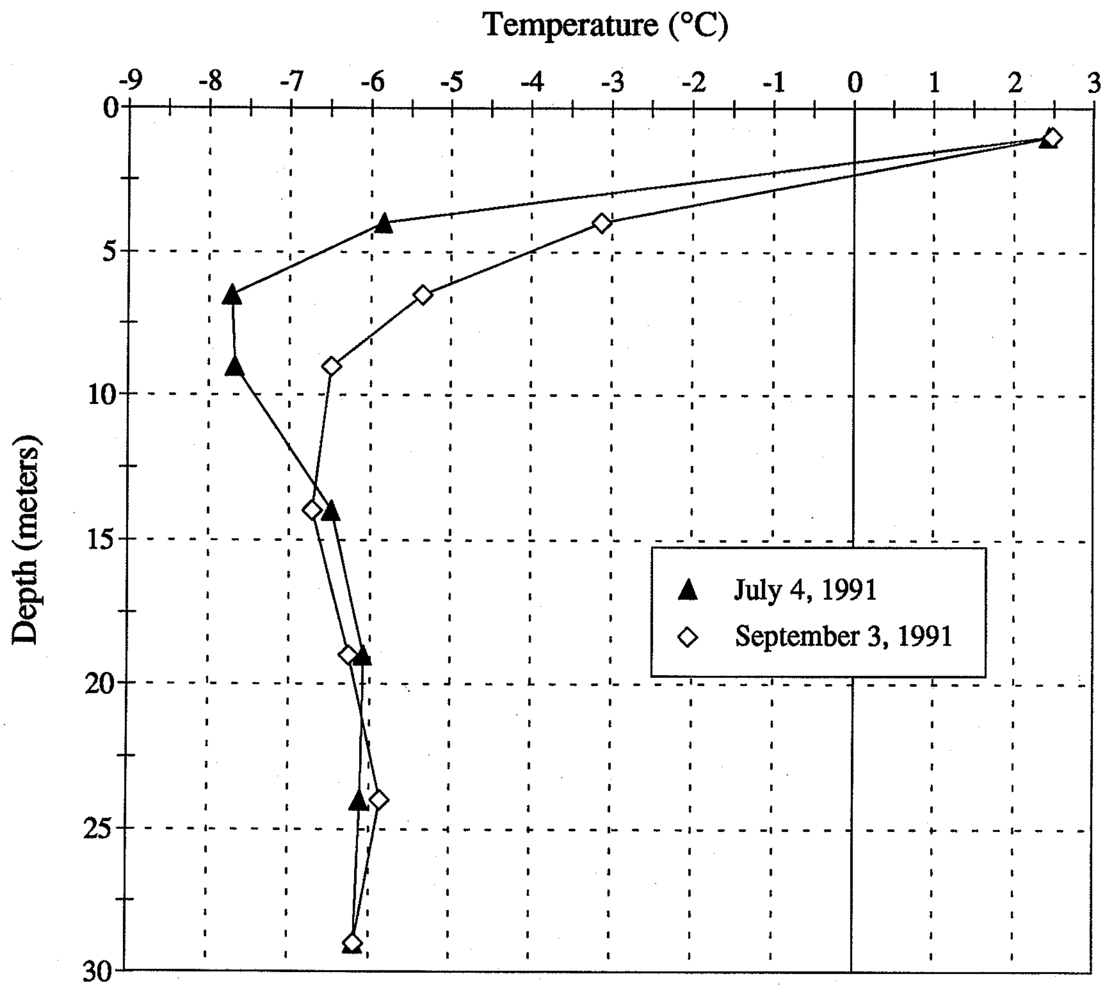

Figure 4. *Ground temperature - Borehole 16*

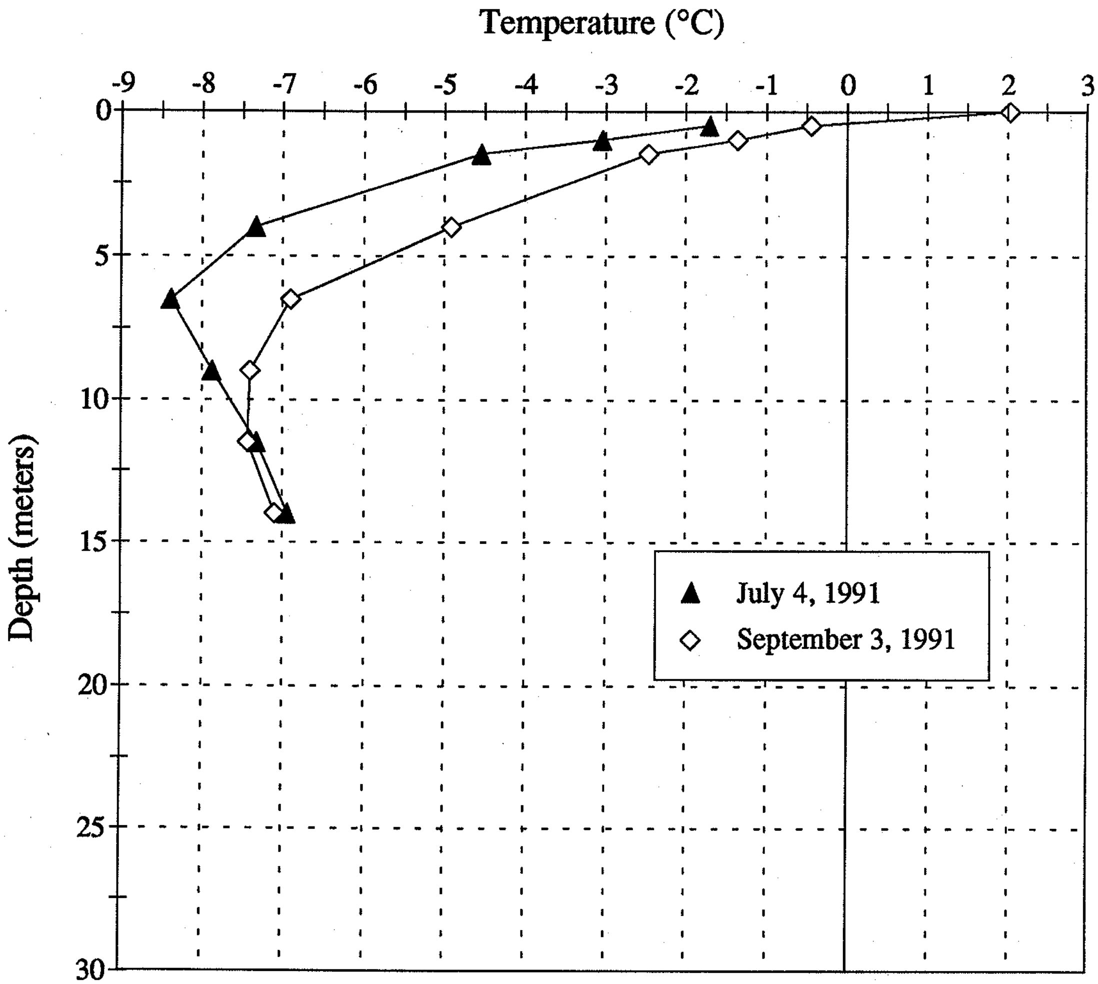

Figure 5*. Ground temperature - Borehole 17*

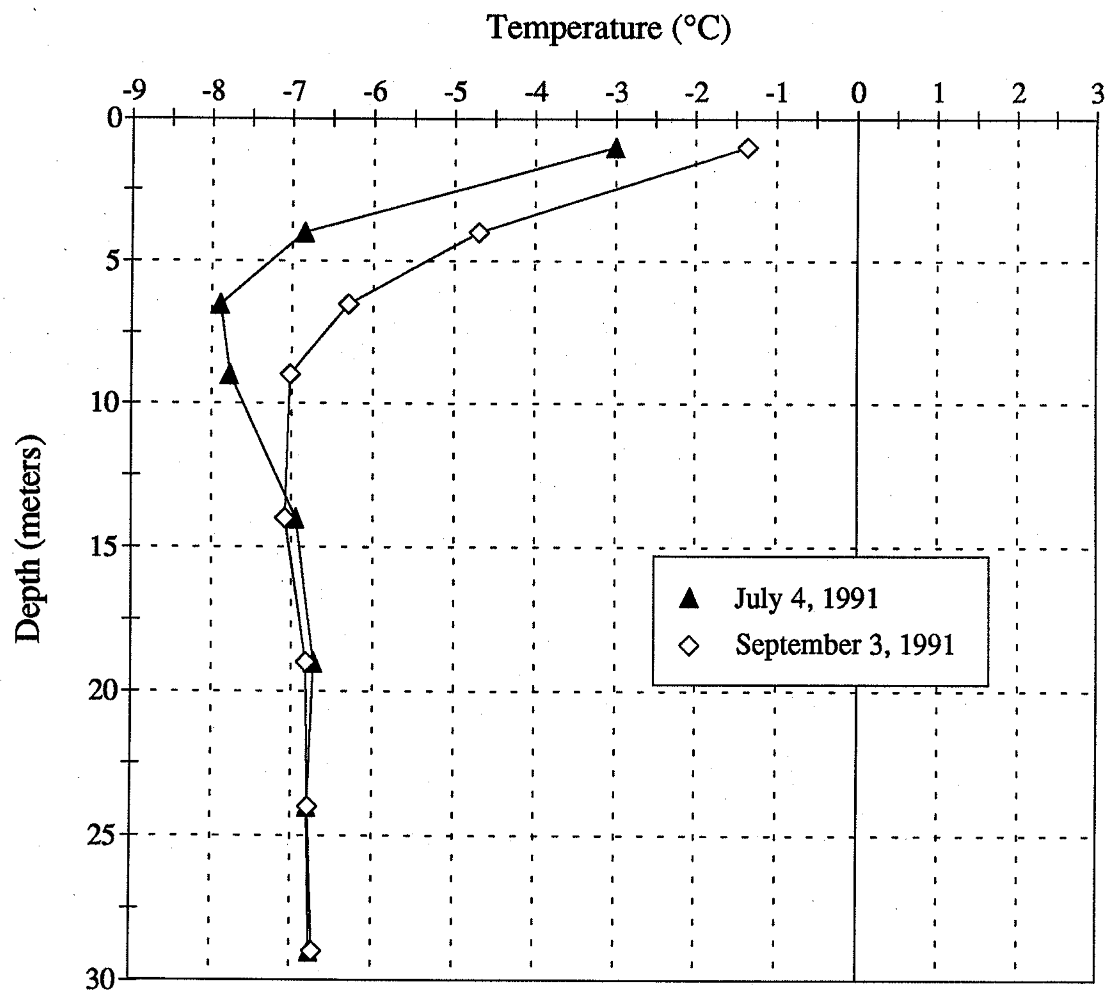

Figure 6. *Ground temperature - Borehole 18*

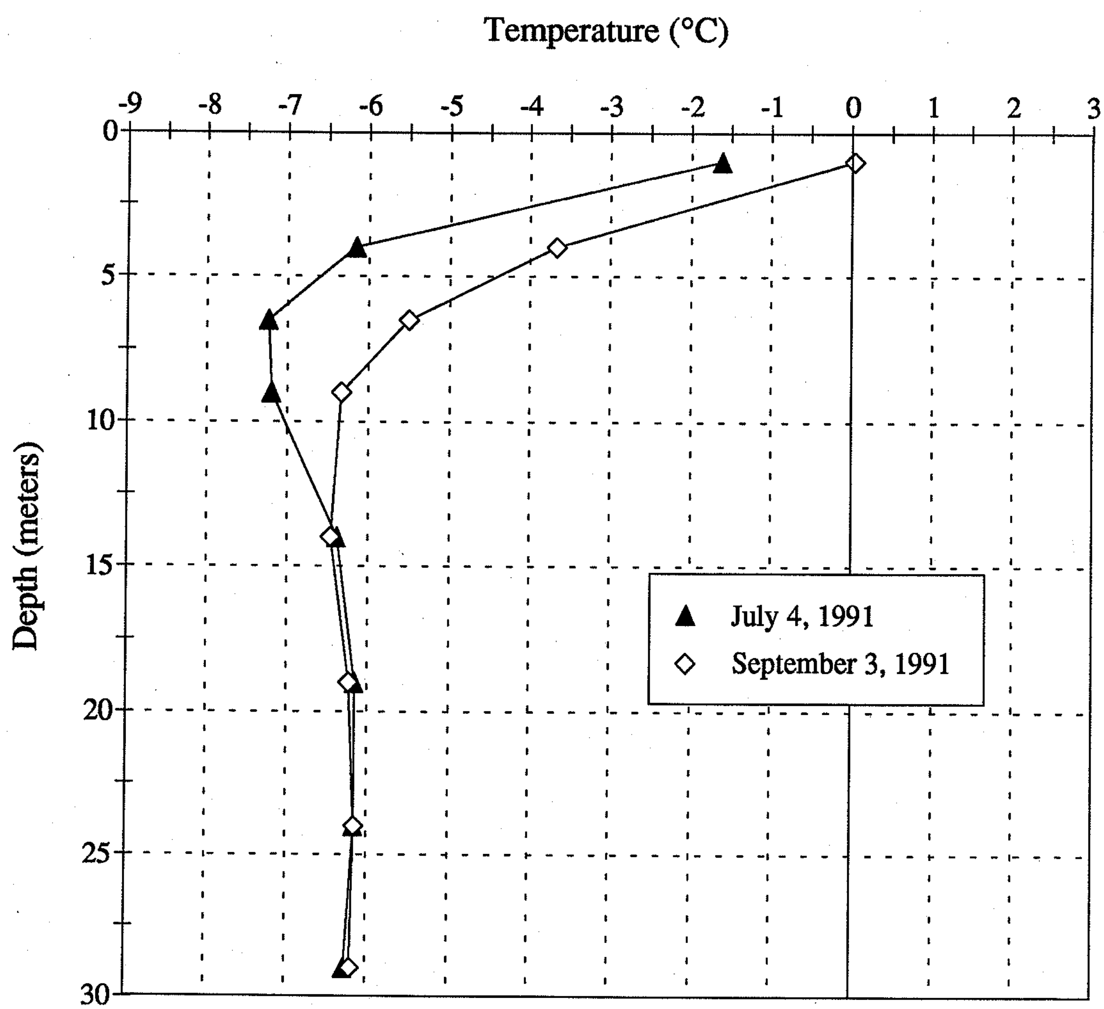

Figure 7. *Ground temperature - Borehole 19*

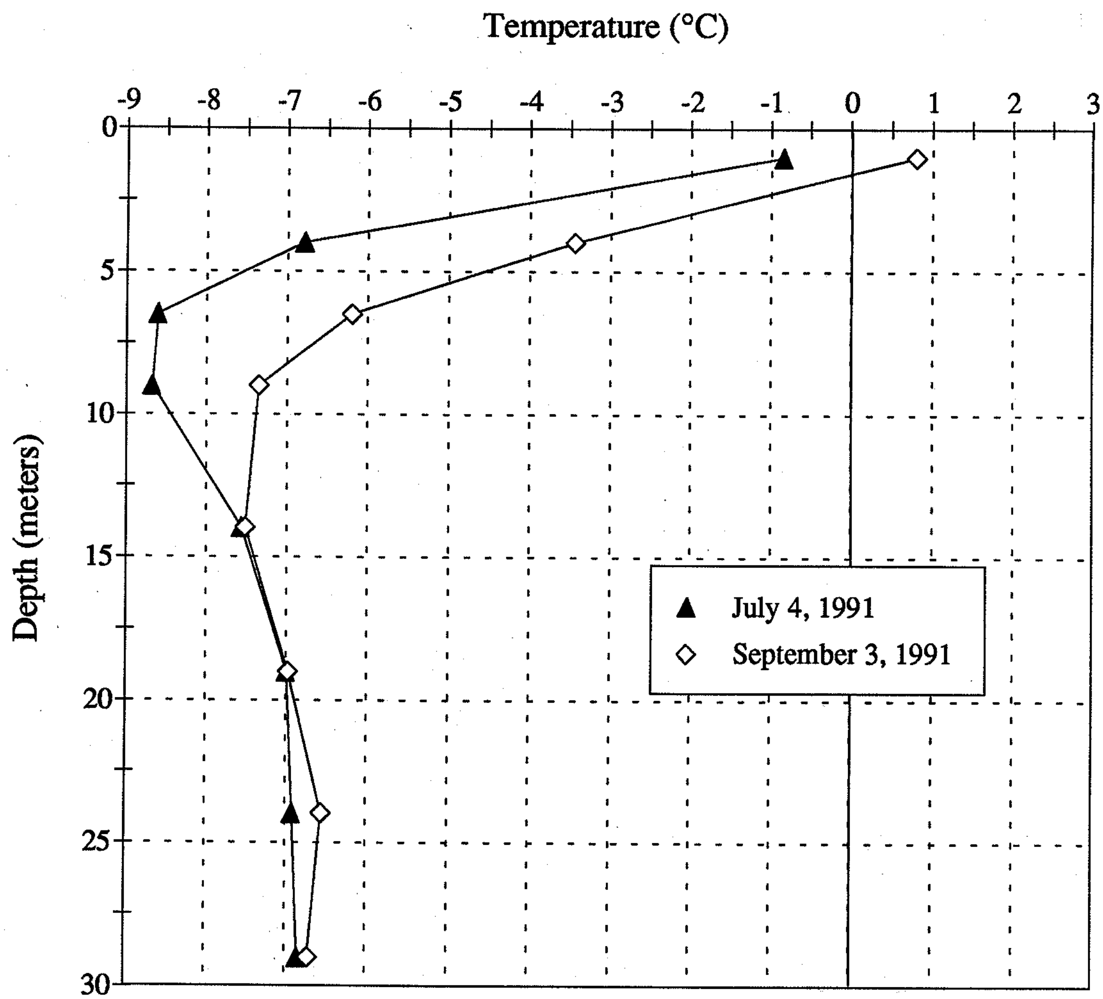

Figure 8. *Ground temperature - Borehole 20*

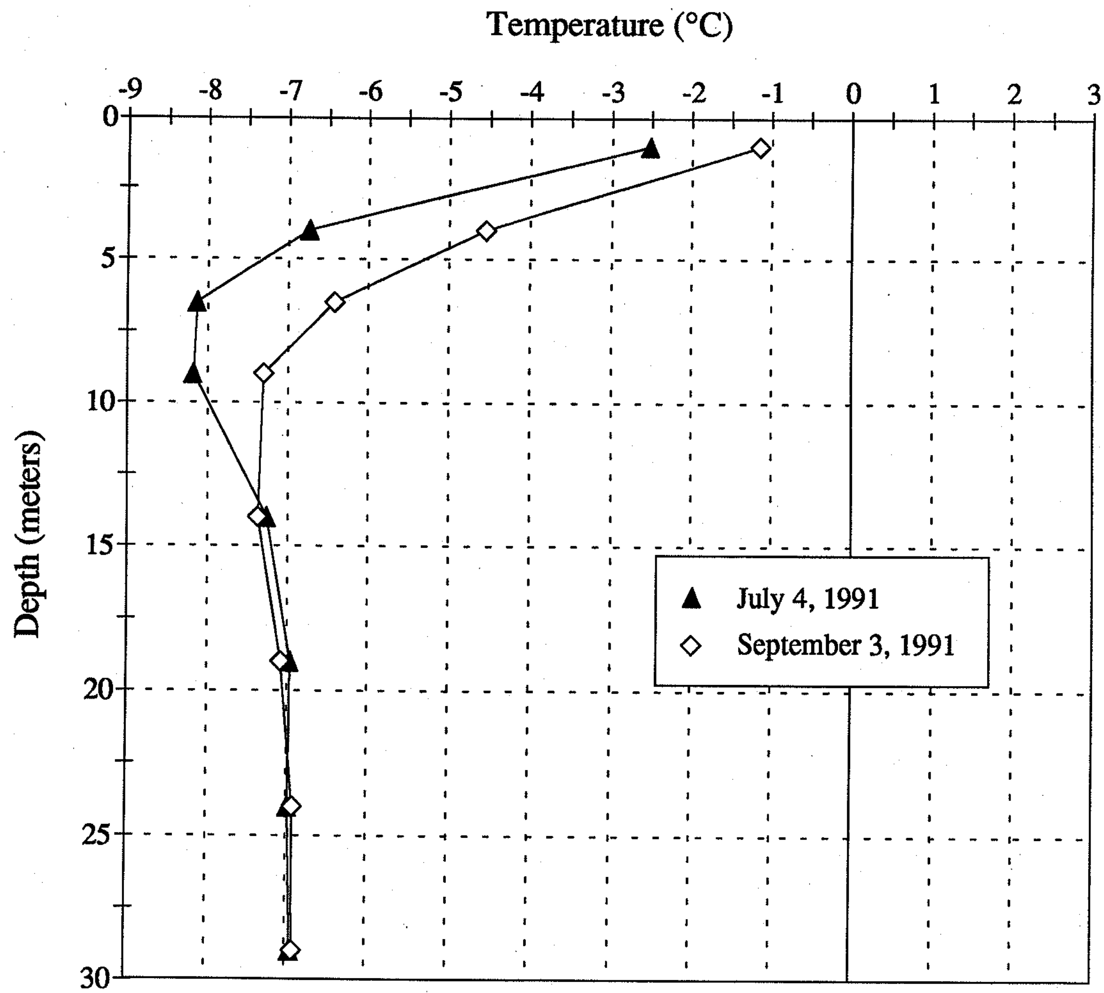

Figure 9. *Ground temperature - Borehole 21*

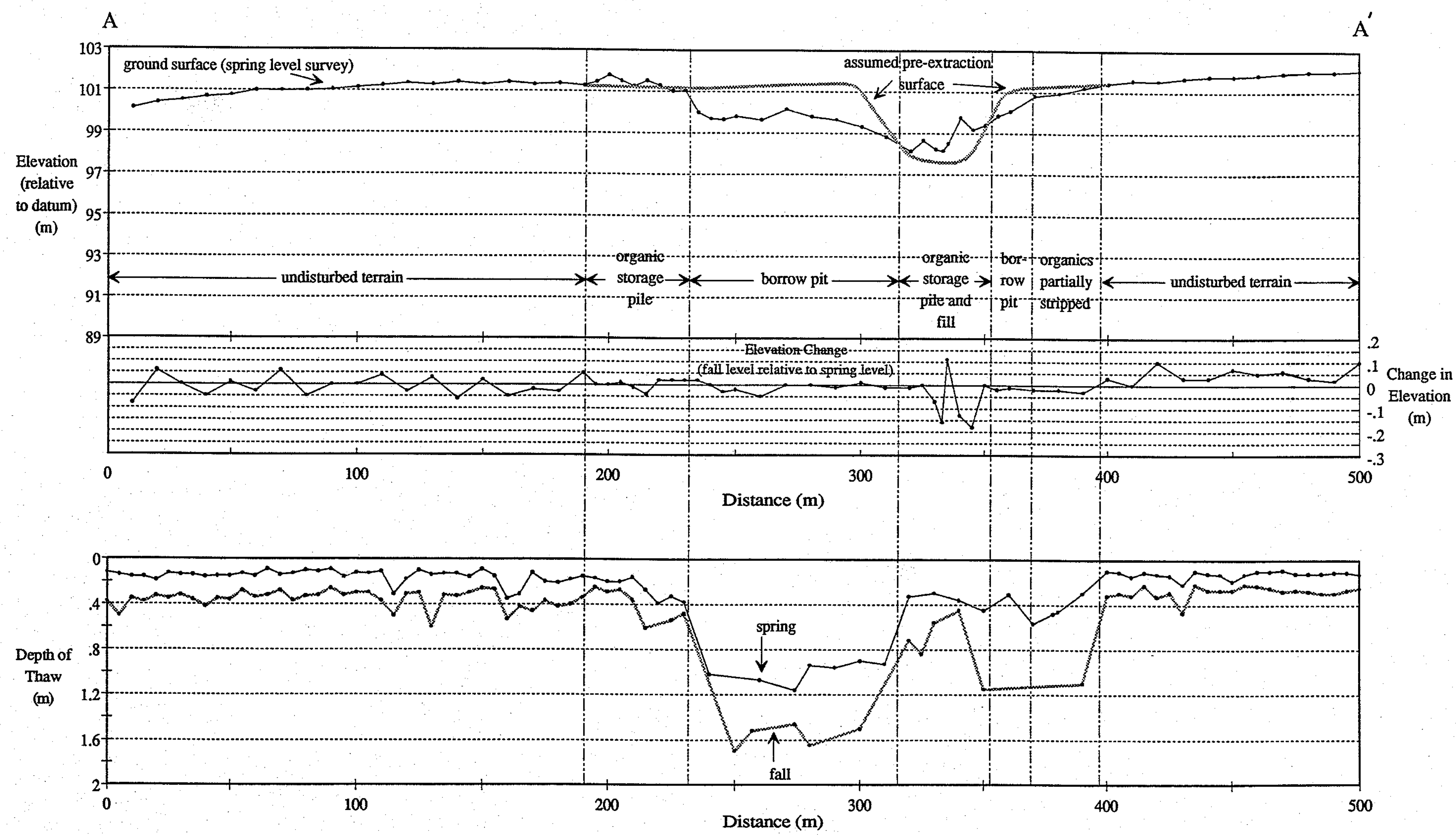

Figure 10. Level survey and depth of thaw - line AA′

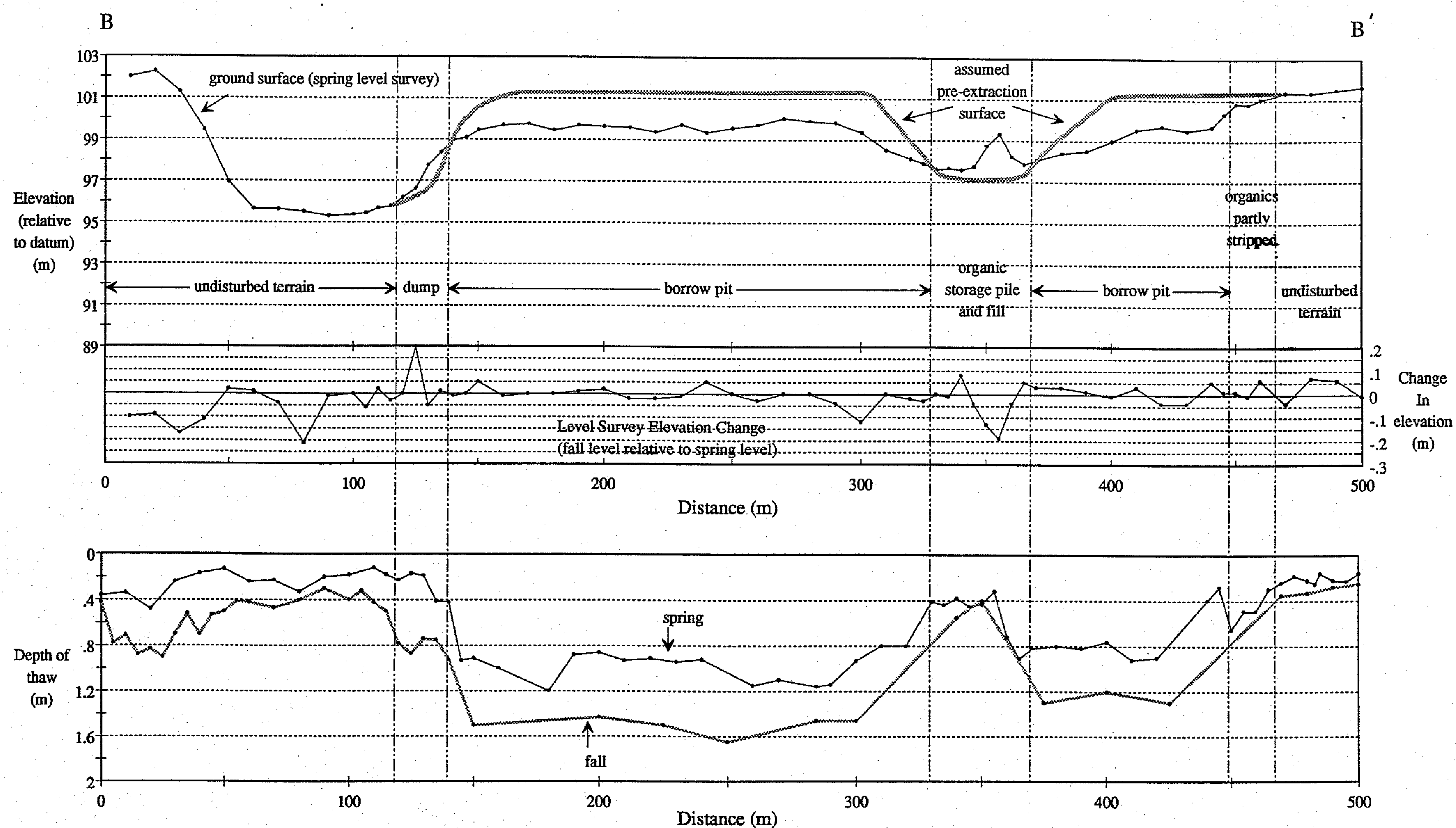

***Figure 11.** Level survey and depth of thaw - line BB′*

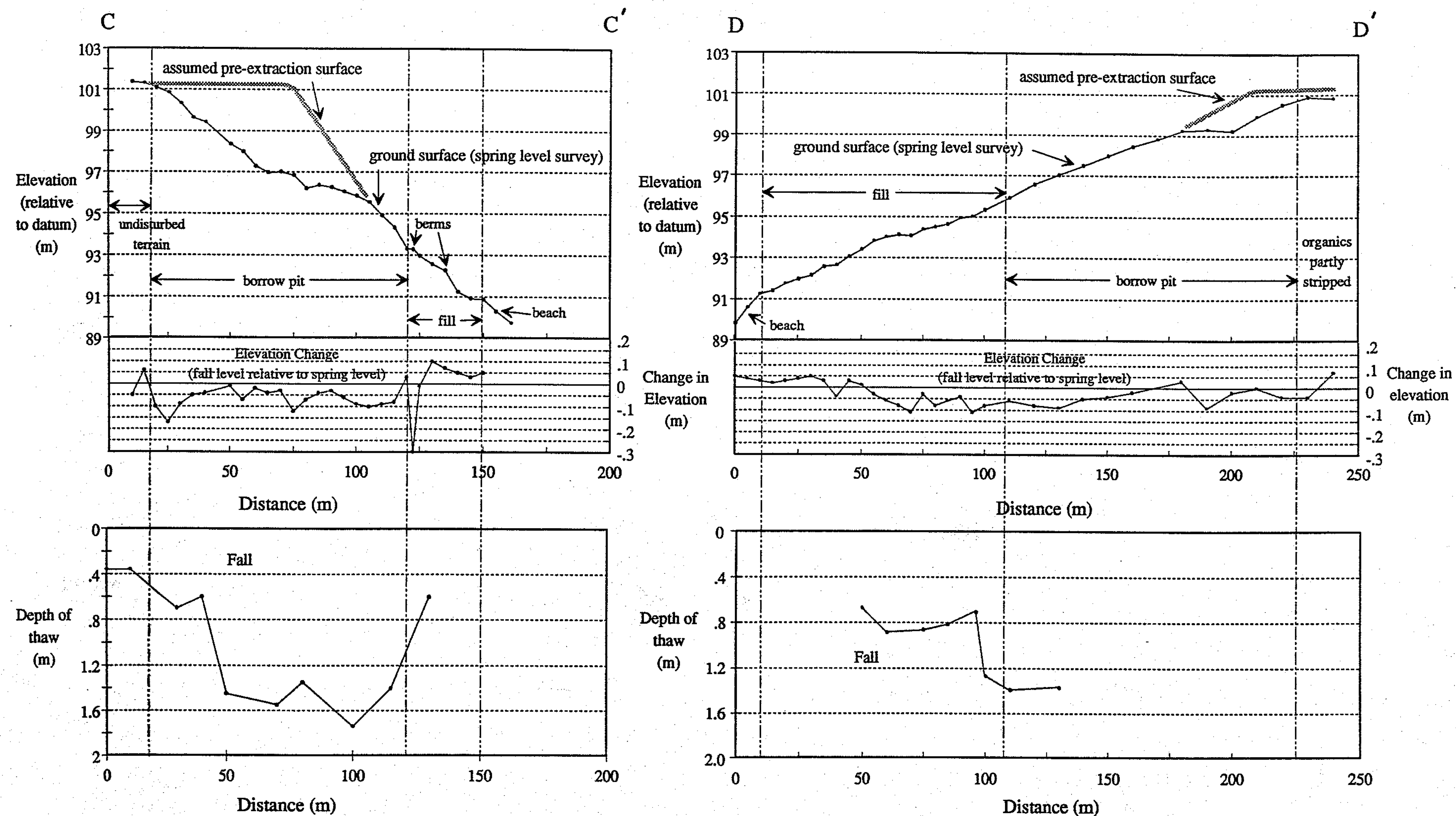

Figure 12. Level survey and depth of thaw - lines CC′ and DD′.

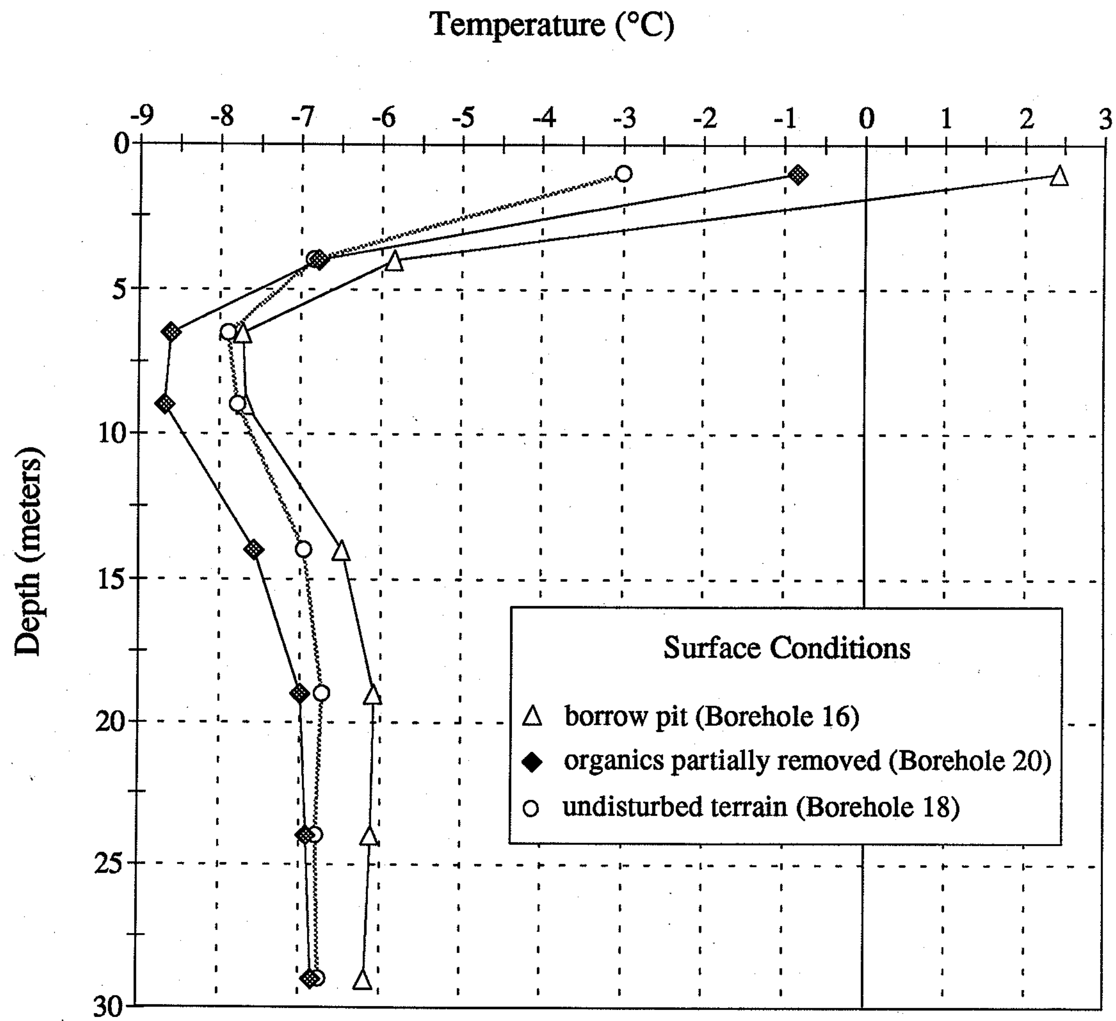

Figure 13. *Ground temperature - July 4, 1991*

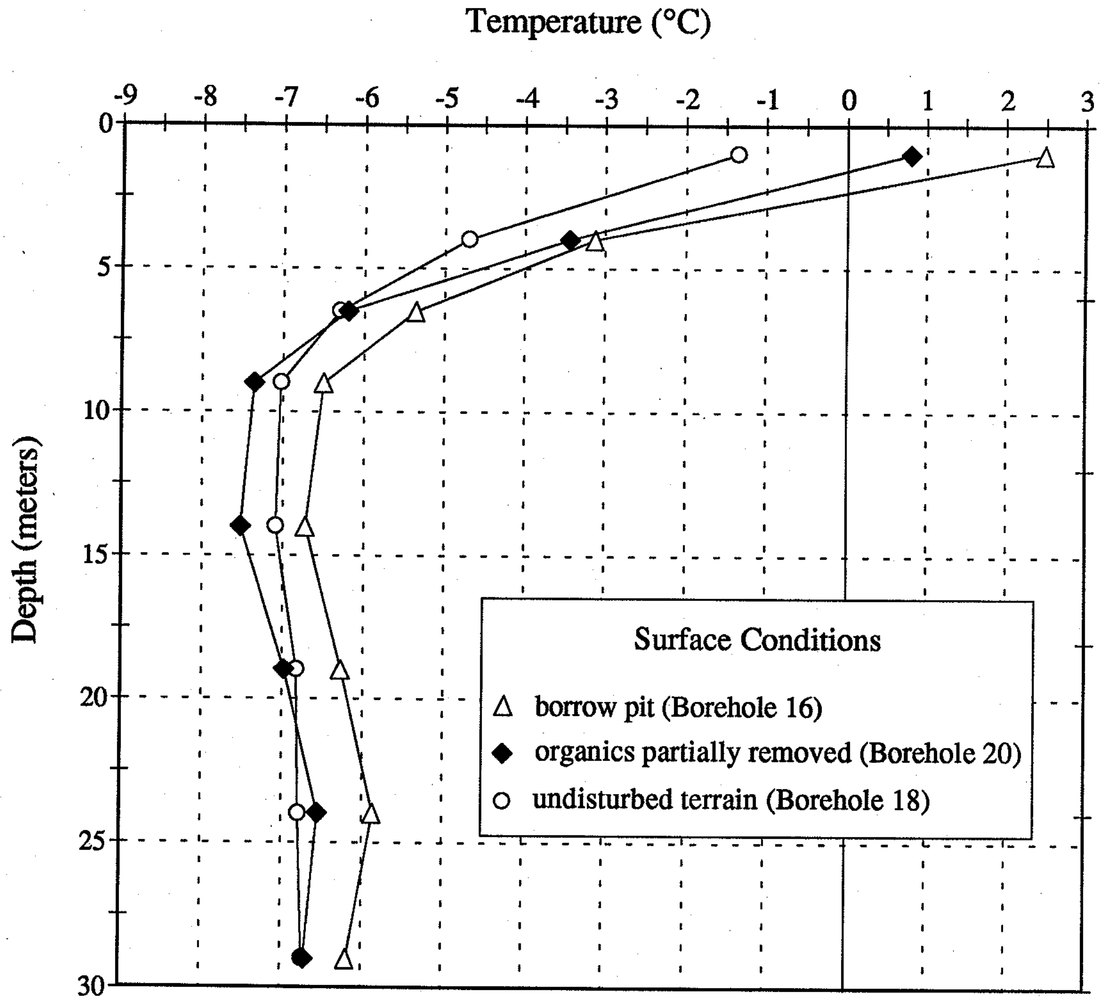

Figure 14. *Ground temperature - September 3, 1991*