INVESTIGATION OF GEOLOGICAL CONSTRAINTS ON GRANULAR RESOURCE EXTRACTION IN THE TUKTOYAKTUK COASTLANDS AREA N.W.T.

SOURCE 160/161

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EXECUTIVE SUMMARY

A study was undertaken to evaluate the present environmental condition and potential remaining reserves at a number of abandoned borrow pits in the immediate vicinity of Tuktoyaktuk. This report documents the history of extraction and the post-extraction performance of each of the pits while presenting, in a preliminary way, how each deposit might be restored or rehabilitated.

The deposits were originally exploited in the early to mid 1980's but closed to further development in 1985 due to concerns for their negative impact on the landscape and possible hazards to nearby drinking water supplies. During the original development of the area some 13 deposits were opened ranging in size from 1,000 to 40,000 square metres and collectively occupying an area of 140,000 square metres. Approximately 300,000 to 400,000 cubic metres of aggregate was removed.

These abandoned borrow pits are less than 5 kilometres from Tuktoyaktuk and could potentially provide additional low priced aggregate for the community. Our surface studies and review of earlier exploration drill results suggest there may be a further 150,000 to 250,000 cubic metres of aggregate, primarily sand, in these borrow pits and their undeveloped extensions. However, unmapped buried ice could limit extractable aggregate to less than 100,000 cubic metres. Furthermore, environmental problems associated with any additional extraction activity could restrict exploitation of these deposits. If further work is limited to restoration of the pits it is estimated that 5,000 to 15,000 cubic metres of aggregate could be recovered in conjunction with recontouring and rehabilitation measures.

More than six years after abandonment there is almost no vegetation growth in the borrow pits. Recovery of the vegetation has been slow due to the absence of organic cover on the pit surfaces. There are no stockpiled organics on-site and any future revegetation projects will be constrained by the lack of local organic material. Vegetation is well established around the margins of most of the borrow pits where the organic cover has been disturbed or partially removed by borrow pit activities.

Extraction of the aggregate has led to deeper seasonal thaw and exposure of buried ice in the borrow pits. Since abandonment 125,000 to 145,000 cubic metres of buried ice underlying the deposits has melted. The depressions thus formed range in size from shallow linear cracks to water filled depressions 8,000 to 10,000 square metres in area and 4 to 7 metres deep. Total volume of water contained in the ponds is approximately 100,000 cubic metres and some individual ponds contain up to 20,000 cubic metres of water. This process of thaw and collapse is still active 6 to 8 years after abandonment at several of these sites. Continued lateral expansion of these depressions could pose a threat to adjacent natural water bodies.

It is recommended that the extent of drainage presently issuing from the borrow pits, rate of expansion of the ponds and properties of the water in the ponds be monitored to determine if there is potential for drainage which could have a negative impact on aquatic life and water quality in adjacent natural water bodies. In addition, we recommend experimental studies at these abandoned pits to develop methods for extracting aggregate and rehabilitating abandoned borrow pits which could maximize aggregate recoveries and minimize environmental damage. These suggested studies include determining depth of thaw and rate of melt of buried ice, evaluating methods for delimiting buried ice, and developing improved methods for storing and replacing organic material and encouraging vegetation growth.

We consider it critical that there be extensive community involvement in any studies that are implemented and that such studies be used to provide training in northern landscape management. These studies and training programs should focus on the fragile nature of northern areas due to the presence of permafrost and buried ice as well as the slow rate of vegetation regrowth.

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INTRODUCTION

In the 1970's, Indian and Northern Affairs Canada commissioned 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 for local communities and for the oil and gas exploration industry.

Several small deposits were identified on the east side of Tuktoyaktuk Harbour [Source 160/161]. Some of these deposits were exploited in the early 1980's but post-extraction collapse of the working surface at most of the borrow pits restricted further access and left an irregular landscape with water filled depressions. In 1985, Source 160/161 was closed to further development by the Tuktoyaktuk Development Corporation [TDC] due to local concerns over 'scarring' of the landscape and the possibility that drainage from the excavations could affect drinking water supplies in Kudluk Lake or Fresh Water Creek. In 1988 the southeast part of Source 161 was made available for community needs with the condition that there would be no development within 600 feet [182 metres] of Fresh Water Creek, but large volumes of aggregate have not been extracted from this area since 1985.

In the fall of 1991, a joint Indian and Northern Affairs Canada/Inuvialuit Land Administration/Geological Survey of Canada 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 still available in the pits. A separate project, at Source 155N, was conducted 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

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 identify and evaluate sources of granular material in the Tuktoyaktuk region 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 Ltd, 1986; EBA Engineering Consultants Ltd., 1987; Hardy BBT Ltd, 1987; Hardy BBT Ltd, 1988.

Preliminary surveys, of the natural exposures and shallow [less than 1.5 metres] test pits, indicated prospective reserves of 3,360,000 and 1,450,000 cubic metres of aggregate in several small hills at Sources 160 and 161 respectively [Hardy, 1977]. Hardy recommended a drilling program, with boreholes on 150 to 300 metre centres along the length of the hills and to depths of 6 metres, to verify reserves. The drilling program outlined a total of 617,500 and 128,500 cubic meters of sand and gravel respectively in 6 of these hills (Hardy, 1980). Buried ice was intersected in some of the boreholes and Hardy noted that ponds would form at the base of the borrow pits when the aggregate was removed and the ice exposed to thaw. Hardy [1980] recommended that, where flooding was not expected, the surface should be smoothly graded, organics replaced and the area reseeded.

Subsequent to abandonment of the borrow pits Hardy [1986] recommended that they be regraded, the organic material replaced and the area reseeded. Hardy also noted that there were significant volumes of fair quality granular material remaining in the pits and that this could be taken for community granular supply in the process of restoration. Similar recommendations were made by EBA [1987].

Scope of the Present Study

The objective of this project was to determine if the visual and environmental condition of the abandoned borrow pits at Source 160/161 could be improved and if, associated with restoration measures, additional aggregate could be extracted.

The study has several components:

1. Ground surveys at the abandoned borrow pits to determine such factors as, the type and extent of aggregate remaining near surface, the depth to frozen ground, the extent of post extraction surface disturbances and water depth in the depressions.
2. Aerial photograph interpretation to determine the extent of the borrow pits, time period when the borrow pits were worked and subsequent progression of surface disturbances.
3. A test Ground Probing Radar survey at one of the borrow pits to determine the potential for defining the extent of buried ice.

This study is preliminary in nature. More comprehensive subsurface information, provided by drilling and geophysical studies, on the extent of aggregate and buried ice would be required to fully evaluate the amount of aggregate available or potential environmental problems associated with pit restoration or aggregate extraction.

SITE DESCRIPTION

Source 160/161 is on the east side of Tuktoyaktuk Harbour and less than 5 kilometres from the community of Tuktoyaktuk at approximately 132 55'W, 69 26'N (Figure 1). It comprises in excess of 20 small irregularly shaped hills in an area approximately 5,000 by 1,000 metres. Potential borrow sources are restricted to these hills. They range in size from 3,000 to 100,000 square meters and stand 4 to 10 metres above the surrounding terrain.

The geological setting of the region, as described by Rampton (1988), suggests that sands and gravels of Source 160/161 were deposited in a glaciofluvial channel that occupied a narrow north-south trending corridor. These sediments are considered to be early Wisconsinan in age and associated with the Toker Point Stade. Glaciofluvial terrace deposits, thought to have been originally flat outwash fans or valley trains, are the prime constituent of the borrow sources. The present hummocky nature of the land is probably the result of melt of buried ice [Hardy, 1980].

Subsurface conditions at 160/161 are described in detail by Hardy [1980]. Exploration boreholes, drilled on 150 to 250 metre centres and to depths of 2 to 9.5 metres, outlined a total of 746,000 cubic metres of aggregate, primarily sand with less than 20% gravel, in 6 potential borrow areas. The boreholes intersected 0.2 to 7 meters of massive ice at depths of 0.5 to 9.5 metres in 31 of the 40 boreholes. Twenty four of the boreholes were terminated in ice and consequently full ice thickness is unknown. The boreholes are too widely spaced to determine if either the stratigraphic horizons or the ice are laterally continuous. Distribution of these boreholes that fall within the present study area is shown in Figure 2.

Most of the borrow pits were worked from 1980 to 1985. There are, at present, 13 separate excavations ranging in size from 1000 to 40,000 square meters. Post-extraction depressions occur in most of the abandoned borrow pits. These depressions vary from shallow linear cracks to water filled depressions 8,000 to 10,000 square metres in area and 4 to 7 metres deep.

FIELD PROGRAM

Summary of Activities

In late June of 1991, preliminary evaluations of the borrow pits at Source 160/161 were undertaken as a part of a separate study at Source 155N. This work included one day of on-site investigations to determine the extent of post extraction depressions and the degree of revegetation. Low angle oblique photographs were taken from a helicopter to provide a record of the extent of the borrow pits and depressions. These investigations were conducted by F. Thompson of Northwood Geoscience, R. Gowan of Indian and Northern Affairs Canada and S. Kerr of the Inuvialuit Land Administration (ILA).

Field studies conducted at Source 160/161 in early September included the following activities. Additional low angle oblique photographs of the borrow pits were taken from a helicopter. The depth of water, at 1 to 2 sites in each of the 7 largest depressions, was probed using the helicopter as a floating base. To determine the type of aggregate remaining in the borrow pits, 7 test pits and 21 sections were excavated and samples collected at 13 of these sites for laboratory evaluation. The active layer, the zone between permafrost and ground surface that thaws each summer, was measured at 22 sites in the borrow pits by manually forcing a 1.2 metre steel probe into the ground until resistance was encountered. Ground Probing Radar surveys, 50 megahertz at 1 metre spacing, were conducted across the base of the borrow pit at 160/161 C and along the undisturbed highland on the east site of this borrow pit.

The samples collected at the 13 sites were screened at the Geological Survey of Canada Laboratories in Ottawa to determine grain size distribution. They are not necessarily representative of the material in the pits as only coarse granular aggregate was sampled where it was exposed in test pits or sections.

In October of 1991, aerial photographs available at the airphoto library in Ottawa were studied to determine the sequence of exploitation of the borrow pits and progression of development of the post-extraction depressions in the base of the pits.

Copies of the 1980 exploration boreholes in the study area are presented in Appendix A. The 1991 field data collection sites are summarized in Appendix B. The 1991 grain size analysis is presented in Appendix C. Aerial photographs are shown in Appendix D. Helicopter and ground photographs are in Appendix E. All maps and figures are presented in Appendix F.

The September surveys were conducted by F. Thompson [Northwood Geoscience] and J. Kasper (TSD/GSC). Aerial photograph studies were conducted by F. Thompson. Ground Probing Radar surveys were conducted by A. Judge (TSD/GSC).

Logistics

During the June and September field surveys, accommodation was provided at the Polar Continental Shelf base in Tuktoyaktuk. Transportation to and from the field site was by Bell 206B and 206L helicopter from the Polar Shelf base.

DESCRIPTIONS OF BORROW PITS

The following description of the borrow pits at Source 160/161 is based on the 1991 field investigations, the 1980 exploration borehole results and interpretation of aerial photographs. The exploration boreholes provided information on pre-extraction subsurface conditions. Aerial photographs were studied to determine pre-extraction surface conditions, the time when the pits were opened and the rate and distribution of post-extraction collapse. The photographs used were taken July 1967, July 1972, August 1979, August 1980, June 1981, July 1983, July 1984 and July 1985. More recent aerial photographs were not available. The current extent of the borrow pits [based on a combination of the aerial photographs, helicopter photos and ground observations] and the location of the 1991 data collection sites are shown in Figure 3, Appendix F. The aerial extent of the borrow pits, volumes of aggregate, extent of the thaw ponds and environmental concerns are summarized in Table 1.

Sources 160/161A and B, earlier recommended as the prime sources of aggregate (Hardy 1980), have not been exploited. Areas given a lower priority in the Hardy report, Sources 160/161C, E and F, have been exploited. Smaller sources of aggregate that were drilled but not recommended for development, have also been exploited. The Hardy studies did not include Sources 160/161 North or West.

Records of the volumes of aggregate extracted from these pits were not available. The pit operator for Grubens Transport estimated that they extracted 300,000 to 400,000 cubic metres of aggregate from the 160/161 area between 1980 and 1985 [R. Newmark, pers. comm.]. Additional aggregate may have been extracted by other pit operators working in the Tuktoyaktuk area. Estimates in the following discussion are based on the surface area of the pits and assumed thickness of aggregate removed.

Source 160/161 East

There are four small borrow pits along Fresh Water Creek, each 2 to 5 metres above and 10 to 30 metres laterally from the creek [Fig 3 north]. The development of Source 160/161 East predates the exploration activity in the area and no subsurface information is available. These pits were not studied in detail during the 1991 field investigations and observations are based primarily on aerial photographs.

Aggregate was extracted from these pits between July 1967 and July 1972 and there does not appear to have been any further work after 1972. The total area of the pits is 10,000 to 12,000 square metres and aerial photograph studies suggest that depth of extraction was less than

2 metres. Approximately 12,000 to 18,000 cubic metres of aggregate was extracted from these pits.

There are a few small depressions in the pits which suggest melt of modest amounts of buried ice. The extent of these depressions has not changed significantly in the last 20 years and it would appear that melt of buried ice has stopped. For this reason it is unlikely that there will be significant drainage from the pits although it is possible that pit drainage or aggregate was introduced into Fresh Water Creek during, and/or subsequent to, extraction activity.

There may be additional aggregate in these pits or in neighboring hills but the 1985 TDC requirement that no borrow pit development be conducted within 182 metres of Fresh Water Creek would preclude further extraction of aggregate in this area.

Source 160/161 B

This area was not studied in detail during the 1991 field investigations so the discussion is based primarily on aerial photographs and exploration drilling. Source 160/161B was a north-south trending hill, 550 metres long by 50 to 150 metres wide and standing 6 to 8 metres above the surrounding terrain [Fig 2 north]. Exploration drilling, boreholes 6 to 8 [Appendix A], outlined 2.7 to 4.8 metres of aggregate. Overburden cover included 0.3 metres of peat in borehole 6 and 2.5 metres of organics and silt in borehole 7. No overburden cover was recorded in borehole 8. Massive ice was intersected from 3 to 9.5 metres in borehole 6 and from 4.8 to 8.5 metres in borehole 8.

At several locations organics have been pushed off to the low flanks of the hill [Fig 3 north]. Total area disturbed by stripping activities is 28,000 to 32,000 cubic metres. Organics were scraped back from the extreme south end of the hill between August 1980 and June 1981 and from the south-central part of the hill between June 1981 and July 1983. Interpretation of aerial photographs suggests that no aggregate was removed. The pit operator noted that, despite repeated attempts, it was not possible to penetrate the thick overburden cover on this hill [R. Newmark, pers. comm.].

The work conducted at this site has had only a modest effect on surface conditions. Where the organics have been pushed back vegetation growth has started to reestablish and there are only a few small water filled depressions. The foregoing suggests that the overburden cover that could not be removed provided a suitable medium for vegetation growth and insulation cover over the massive ice.

Source 160/161 C

The pre-extraction morphology of Source 160/161 C was a low broad hill measuring 300 by 100 metres and standing 3 to 6 metres above the surrounding terrain [Figure 2 south]. This formed the highest part of a hill which extended a further 70 metres to the east. A small lake [herein called Lake C] is situated 30 to 40 metres north of Source 160/161C [Figure 2 north]. Exploration drilling [boreholes 17, 18 and 19, Appendix A] indicated that the aggregate was primarily sand, underlain by massive ice at depths of 4.5, 2 and 4 metres in boreholes 17, 18 and 19 respectively. The ice is in excess of 2 metres thick but the boreholes were terminated in ice so full thickness is unknown. Interpretation of aerial photographs indicates a continuous vegetation mat prior to excavation but no organic or overburden cover was recorded in the borehole logs. The foregoing suggests that cover over the aggregate was thin.

Most of this hill has been removed to a level less than 1 metre above the surrounding terrain [Figure 3 south]. The central part of the deposit was not entirely removed leaving an elevated rib separating the pit into north and south areas. The borrow pit did not include the eastern extension of the hill but was cut below the level of the hill and partly around its south side leaving a steep slope with in excess of 3 metres vertically between the base of the pit and the top of this hill. The borrow pit is 30 metres south of Lake C and separated from the wetland at the edge of the lake by a narrow ridge which appears to be the base of the pre-extraction hill. Around the margins of the borrow pit and extending into low wet areas was a 10 to 60 metre wide fringe of disturbed organic material.

A thickness of 2 to 5 metres of material was removed from most of the borrow pit and extraction likely stopped at the top of the buried ice. The pit is approximately 28,000 to 32,000 square metres in area and produced an estimated 70,000 to 100,000 cubic metres of aggregate.

The borrow pit was first worked between August 1980 and June 1981. Although the lateral extent of the pit has not changed substantially since 1981 there may have been some further extraction of aggregate and deepening of the pit between June 1981 and July 1983. By July 1983 several small water filled depressions had developed in the base of the pit. By July 1985 one large depression, in the north part of the pit, had formed but it appeared to be shallow and well above the water level in Lake C. Depressions in the south part of the pit were starting to form from linear cracks that were suggestive of a pre-existing ice polygon network. The north and south parts of the pits remained separated by the central rib.

When the pit was visited in 1991 it was deeply and irregularly pitted and comprised 3 main ponds, one in the north pit and two in the south pit. The ponds were substantially deeper, 1.5 to 2.6 metres, and more extensive, 3,000 to 7,000 square metres, than they were in July 1985. The largest pond, in the north pit, was 30 to 40 metres from Lake C and connected to the lake by a small dry channel. Water level in this pond was approximately the same as that in the lake. There does not appear to have been any extraction activity subsequent to 1983 and it is assumed that the depressions observed reflect post extraction melt of buried ice. On most margins of both the borrow pit and the ponds in the borrow pit there were fresh tension cracks and collapse structures. The foregoing suggests that melt of buried ice and consequent thermokarst collapse is continuing. The full extent of buried ice is unknown so it is not possible to predict how much further the ponds will expand either laterally or vertically, or how quickly any change will occur.

The central rib in the borrow pit has become more pronounced as the surrounding land collapsed. Buried ice may have been slow to melt here because less aggregate was removed from this part of the hill and the insulating layers left in place. However, broad 4 to 5 metres deep wedge-shaped depressions have formed between this hill and the east side of the borrow pit and, by 1991, the north and south pits were connected through these depressions. Cracks that appeared to reflect an ice polygon network were observed in this area in the 1985 aerial photographs and it is assumed that these depressions reflect melt of buried ice wedges. The foregoing indicates that buried ice is melting and it is probable that this high ridge will continue to disintegrate as its margins are eroded and buried ice melts.

In the borrow pit there is no organic cover and vegetation growth is minimal. Vegetation has started to reestablish on the fringe around the pit where there are some organics on surface. There are no storage piles of organic material at this site.

Shallow shovel pits excavated during the 1991 field surveys indicate that aggregate remaining at the base of the pit and in low wet ground on the undeveloped north, south and west margins of this pit is primarily fine sand. Test pits and sections excavated at the top of the steeper slopes left standing when the pits were abandoned, the ridge across the centre of the pit and the steep east margin of the pit intersected in excess of one metre of coarse granular aggregate. These slopes rise 2 to 4 metres from the floor of the borrow pit but fresh material was exposed and could be assessed only near the top.

The undeveloped eastern extension of the hill is untested by exploration drilling but sections exposed on this side of the pit suggest that it may contain in excess of 1 metre of coarse granular aggregate. This hill is 15,000 square metres in area and 2 to 3 metres above low ground. On its west side, near the borrow pit, there is less than 0.5 metres of organics over the aggregate. Further to the east test shovel pits indicate a cover of in excess of 0.5 metres of organics and silt. The extent of buried ice is unknown but the ice polygon network on part of this hill indicates at least some shallow buried ice.

Source 160/161 E

Source 160/161E was a crescent-shaped hill wrapped around the south end of a lake [herein called Lake E] and standing 3 to 5 metres above the lake and surrounding low wet ground [Fig. 2 south]. Exploration drilling [boreholes 20, 21 and 22, Appendix A] indicated that the hill contained 3 to 6.3 metres of sand with some gravel sections. The aggregate was underlain by massive ice at 3.6 and 6.3 metres in boreholes 20 and 21 respectively but full ice thickness is unknown because the boreholes were terminated in ice. Interpretation of aerial photographs indicates a continuous vegetation mat prior to excavation but organic material at surface was recorded only in borehole 20. The foregoing suggests that cover over the aggregate was thin.

Most of this hill has been excavated to a level less than 1 metre above the surrounding terrain [Fig. 3 south]. The borrow pit was separated from Lake E by a raised border less than 10 metres wide that appears to be the base of the pre-extraction hill. The low southeast end of the hill has not been extracted leaving a steep slope of 2 to 3 metres between the base of the pit and the top of this hill. Around the margins of the borrow pit and extending into low wet areas was a 10 to 40 metre wide fringe of organic material disturbed by borrow pit activities.

A thickness of 2 to 4 metres of aggregate was removed from most of the borrow pit. The pit extends further north and south than proposed by Hardy [1980] into low parts of the hill that likely provided less than 2 metres of aggregate. Total area of the pit is 33,000 to 37,000 square metres and approximately 70,000 to 100,000 cubic metres of aggregate was extracted.

The borrow pit was first worked between August 1980 and June 1981. Although the lateral extent of the pit has not changed substantially since 1981 there may have been some further extraction of aggregate and deepening of the pit between June 1981 to July 1983. By July 1983 water-filled depressions had started to develop in the base of the pit. By July 1985 there were several shallow disconnected depressions well above water level in Lake E.

When this borrow pit was visited in September 1991 it was deeply and irregularly pitted and there were a few high standing mounds of aggregate. The largest water-filled depression, approximately 10,000 to 12,000 square metres, was in the central part of the pit and separated from Lake E by the narrow raised border. This border was 3 to 10 metre wide and 2 metres to, at the narrowest point, less than 25 centimetres high. Water level in this pond was less than 20 centimetres above that in Lake E and depth of water in the pond was 2.5 metres. There does not appear to have been any extraction activity subsequent to 1983 and it is assumed that the depressions observed reflect melt of buried ice exposed to thaw by removal of the aggregate and organic cover. Deep dry depressions on the east margin of the borrow pit are suggestive of melt of ice wedges. Locally, on margins of the borrow pit and of the ponds in the borrow pit, there were fresh tension cracks and collapse structures in September 1991. The forgoing suggests that melt of buried ice and consequent thermokarst collapse is continuing. The full thickness of buried ice is unknown and it is not possible to predict how much further the ponds will expand either laterally or vertically.

There is almost no organic material or vegetation growth in the borrow pit and there are no organic storage piles at this site. Vegetation has started to reestablish on the fringe around the pit where some organic material exists at surface. This new vegetation growth is primarily a light brown grass which was observed only in areas where the natural vegetation cover has been disturbed. There is no record of reseeding and this grass may be a fast growing native species that reestablishes first when the mature vegetation is destroyed.

Shallow shovel pits excavated during the 1991 field surveys indicate that aggregate remaining at the base of the pit and in low wet ground on the undeveloped north and west margins of this pit is primarily fine sand. Sections excavated in the mounds in the pit and the slopes on the southeast side of the deposit intersected 1 to 3 metres of sand with some gravel sections. The undeveloped southeast extension of the hill is untested by exploration drilling but these sections suggest that it may contain aggregate. This hill is approximately 12,000 square metres and 2 metres above low ground. The extent of buried ice is unknown but ice was exposed in other parts of the pit and it is expected that this hill would also contain shallow buried ice. The south side of this hill is 50 metres from Kudluk Lake.

Source 160/161 F

Source 160/161F was a north-south trending ridge 370 metres long by 50 to 100 metres wide [Fig. 2 south]. There were two high hills, one at each end of the ridge, connected by a low saddle. They stood 2 to 7 metres above low wet ground to the west and 6 to 10 metre above Kudluk Lake to the east. The hills are separated from the lake by a 20 to 80 metre wide wetland. Exploration drilling [boreholes 24 and 25] indicated that the hills were dominantly sand with some gravel. Thickness of aggregate exceeded 9 metres in borehole 25. Borehole 25 intersected 0.2 metres of buried ice at a depth of 7 metres. Interpretation of aerial photographs indicates a continuous vegetation mat prior to excavation but organic material at surface was recorded only in borehole 24. The foregoing suggests that cover over the aggregate was thin.

The two borrow pits forming this deposit centre on the high hills from which 2 to 6 metres of aggregate has been extracted [Fig. 3 south]. The area of the north and south pits is approximately 7,000 and 9,000 square metres respectively and the estimated volume of aggregate produced by these pits was 50,000 to 70,000 cubic metres. Around the margins of both pits and extending to the base of the hill was a 20 to 70 metre wide fringe of organic material disturbed by borrow pit activities. This fringe terminates in a low mound of organics at the base of the east side of the hill.

These borrow pits were first worked between August 1980 and June 1981. Work at the north pit may have been completed by July 1984 but additional material was removed from the south pit between 1984 and 1985.

In the south pit there are 3 small water filled depressions. These ponds were not probed but appeared to be shallow, likely less than one metre. Total depth of these depressions, including the depth of water, was less than 3 metres. The extent of the ponds in 1991 is similar to that observed in the 1985 airphoto. There are a few tension cracks in the south pit which reflect some continued settlement but the depressions do not appear to be expanding rapidly. In the north pit the surface is irregular, suggestive of some differential settlement which may reflect melt of buried ice.

As at other abandoned borrow pits in the area new vegetation growth is primarily a light brown grass and it is best established on the disturbed fringe around the pit where there is some organic material at surface. There is almost no organic material and only limited vegetation growth in the borrow pits. Where there is some organic material in the base of the south pit vegetation is slowly starting to reestablish. In the north pit the surface is dry and there are no organics or pebbles to stabilize the surface As a result the surface material is loose windblown sand and there is no vegetation growth. There are no recoverable organics available at either pit for rehabilitation purposes.

Both pits were extended to the east and west edges of the hill. However, thermokarst activity has been modest and there does not appear to have been any escape of water from the pit to the surrounding low areas or Kudluk Lake. It is possible that ponds in the south pit could drain to the low ground but they are not expanding rapidly at this stage and this appears to be not an immediate concern.

It may be possible to extract additional aggregate from this hill by draining the ponds and deepening the pit. The 1980 exploration drilling suggests that there is a further 4 to 5 metres of aggregate at the south pit. Test pits and sections excavated in September 1991 indicated that there is approximately 0.5 metres of gravel remaining at the base of the south pit but most of the aggregate exposed on the west side of this pit is sand. The material remaining at surface in the north pit is also dominantly sand.

Source 160/161 G

Source 160/161G was a hill, 140 by 140 metres, standing 2 to 4 metres above the surrounding low wet areas [Fig. 2 south]. Exploration drilling [borehole 26] intersected gravel to a depth of 3.5 metres with a sand bed from 1.6 to 2.6 metres. The sand and gravel was overlain by 0.2 metres of organic material and underlain by in excess of 2.5 metres of ice. The borehole was terminated in massive ice so the full thickness is unknown.

The borrow pit is 100 by 50 metres and centered on the high part of the hill [Fig. 3 south]. Approximately 1 to 3 metres of aggregate was extracted and total volume of material removed was 9,000 to 12,000 cubic metres.

The borrow pit was first worked between July 1983 and July 1984. Although the lateral extent of the pit has not changed substantially since 1984 there may have been some further extraction of aggregate and deepening of the pit between 1984 and 1985.

The post-extraction surface was flat. Linear cracks, suggestive of an ice polygon network, had developed in this surface by July 1984 and by July 1985 small water filled depressions had developed. When the borrow pit was visited in September 1991 there were two nearly circular ponds. Total depth of these depressions, including a water depth of 2.1 metres in the southern pond, was 4 to 5 metres. Tension cracks on the margins of the ponds suggest continued thermokarst collapse. The ponds could potentially expand further and drain to the surrounding low areas but no water bodies are directly threatened by pit drainage.

There is almost no organic material and only limited vegetation growth in the borrow pits. Vegetation has started to reestablish, on the margins of the pit and in a thin belt between the ponds, where there are some organics at surface. The organic cover between the ponds could reflect a small saddle from which no aggregate was removed or organics stripped from the surface may have been replaced here when the pit was abandoned. The lack of collapse structures in this area may reflect the better insulation cover provided by the organic material.

It may be possible to extract additional aggregate from this hill by draining the ponds and deepening the pit. Test pits and sections excavated in September 1991 indicate that remaining material at surface is dominantly sand with a few granular beds.

Source 160/161 H

Source 160/161H is the most southerly of the borrow pits worked in this area. The source of aggregate was a sinuous hill, 300 by 60 metres, trending northwest southeast [Fig. 2 south]. The hill was 2 to 4 metres above the surrounding terrain with a low saddle near the north end. Exploration drilling [Hardy 1980] indicated that the north part of the hill [borehole 27] contained 1.4 metres of gravel underlying less than 0.2 metres of organics and overlying in excess of 7 metres of sand. Only organics and silt, to a depth of 2.3 metres, were intersected in the south part of the hill [borehole 28]. No ice was intersected in either borehole.

Aggregate was extracted from the north part of the hill on each side of the saddle. The two pits together occupy an area of approximately 2500 square metres [Fig. 3 south]. Less than 2 metres of aggregate was removed from these pits and they provided an estimated 3000 to 4000 cubic metres of aggregate.

The pits were worked between July 1984 and July of 1985 and their lateral extent has not changed substantially since 1985. There is no evidence of thermokarst activity. There is a fringe of disturbed organics around the pits and extending into the surrounding low areas. On the disturbed organic fringe grasses are well established whereas only small patches of grass are growing in the borrow pit which lacks organics.

The floor of the pit is gravel and probing in this area indicates that gravel extends to at least 0.5 metres. The 1980 exploration drilling indicates that there is additional sand below the present workings.

Source 160/161 North

Source 160/161N was a northeast-southwest trending hill, 450 metres long by 70 to 120 metres wide, extending from the mouth of Fresh Water Creek on the west to Pikiolik Lake on the east [Fig. 2 north]. The hill stood 6 to 8 metres above surrounding low wet ground with a sharp drop-off to adjacent water bodies. The distance from the top of this slope to Fresh Water Creek and Pikiolik Lake was 10 to 20 metres laterally and 9 to 11 metres vertically. No exploration drilling results were available and subsurface conditions are unknown. There may have been some early exploration work conducted in this area but no reports were uncovered during this study.

A thickness of approximately 1 to 4 metres of material was removed from most of this hill and the floor of the west part of the pit is approximately 1 metre lower than that on the east side of the pit. The borrow pit extends to the edge of the slope above Fresh Water Creek [Fig 3 north]. On the east side of the deposit, although the organic cover has been removed, the borrow pit was set back 10 to 20 metres from the edge of the slope. There is a 10 to 40 metre wide fringe of disturbed organics on the northwest and southeast flanks of the hill.

The surface area of the borrow pit is 38,000 to 42,000 square metres and it provided approximately 90,000 to 120,000 cubic metres of aggregate. Less than 3000 cubic metres of aggregate was extracted from a small satellite pit on a hill 100 metres south of the main pit.

Extraction activity began between August 1980 and June 1981 when a small area in the centre of the hill was opened. The rest of the hill was worked between June 1981 and July 1983. Although the lateral extent of the pit has not changed substantially since 1983 there may have been some further extraction of aggregate and deepening of the pit between July 1983 and July 1985. By July 1983 a water filled depression [herein called the west pond] had formed in the part of the pit worked between 1980 and 1981. Linear cracks, had formed throughout the pit by July 1983 and, by July 1985, the cracks on the east side of the deposit had broadened to form several small disconnected ponds. These linear depressions were suggestive of an extensive ice polygon network with a distance of 20 to 60 metres between ice wedge cracks.

When the pit was visited in September 1991 there were several linear depressions and two large ponds. The western pond had not expanded substantially since 1985 and there were only a few tension cracks and collapse structures along its margin. The total depth of this depression was 3 to 4 metres including water depth of 0.7 to 1.3 metres. There is a drainage channel from the west pond to Fresh Water Creek. Water flow in this channel was modest in September of 1991 and this drained directly into the sandy deposits at the base of the slope. However the size of the channel, 4 to 4.5 metres deep, suggests that water flow was greater in other years or earlier in the season.

A large water filled depression [herein called the east pond] had formed on the east side of the deposit by September 1991. This depression was approximately 7,000 square metres in area and total depth was 6 to 7 metres including a water depth of 3.3 metres. Fresh tension cracks and collapse features on all margins of the pond and drowned vegetation in the centre of the pond all indicate continued rapid expansion due to melt of buried ice. Water has escaped from this pond to the undisturbed organics on the north side of the deposit and accelerated melt of ice wedges. The thickness of buried ice is unknown and it is not possible to predict how much further the pond will expand either laterally or vertically. The distance between this depression and the edge of the slope above Pikiolik Lake is less than 15 metres.

There is almost no organic material or vegetation growth in the borrow pit and no organic storage piles exist at this site. Vegetation has started to reestablish on the disturbed fringe around the pit where there is some organic material at surface.

Shallow shovel pits and sections excavated during the 1991 field surveys indicate that the aggregate remaining in the base of the pit is primarily sand with some gravel sections. It may be possible to extract additional aggregate from this hill by draining the ponds and deepening the pit. However, any further work at this site can be expected to expose buried ice and cause additional thermokarst collapse and meltwater runoff. The danger of drainage to the adjacent water bodies may restrict further development. The 1985 TDC regulation that no borrow pit activities be conducted within 182 metres of Fresh Water Creek would preclude further development of the west half of this deposit.

DEPOSIT	BORROW PIT		AGGREGATE		PONDED WATER		COMMENTS
	Aerial extent square metres	Area disturbed square metres	extracted cubic metres	remaining cubic metres	Aerial extent square metres	Volume cubic metres	
160/161 East	10,000-12,000 5 separate small pits	10,000-12,000	12,000-18,000				Further development precluded due to proximity of Fresh Water Creek.
160/161 B		28,000-32,000	none		a few small ponds		Organics were stripped off the surface but aggregate was not extracted due to thick overburden cover. Vegetation growth has started to reestablish in most areas.
160/161 C	28,000-32,000	58,000-62,000	70,000-100,000	30,000-40,000	18,000-22,000 in 3 ponds	35,000-40,000	Seasonal discharge of modest volumes of ponded water to Lake C. Potential for larger volumes of water to enter the lake if thermokarst collapse continues. Steep slopes were left standing when the pit was abandoned. If this pit is regraded to improve its visual appearance 5,000 to 10,000 cubic metres of aggregate could be extracted.
160/161 E	33,000-37,000	58,000-62,000	70,000-100,000	20,000-30,000	12,000-15,000 primarily in 1 pond	25,000-30,000	Seasonal discharge of modest volumes of ponded water to Lake E. The narrow margin between the pond and the lake is disintegrating and it is expected that these waterbodies will coalesce within the next few years. Steep slopes were left standing when the pit was abandoned. If this pit is regraded to improve its visual appearance 3,000 to 5,000 cubic metres of aggregate could be extracted.
160/161 F	15,000-17,000 2 separate pits	42,000-44,000	50,000-70,000	50,000-80,000	3000	3000	There has been no escape of large volumes of water from the pit but proximity [20-80 metres] to Kudluk Lake may preclude further develpment
160/161 G	5000	5000	9,000-12,000	15,000-25,000	2000 in 2 ponds	3,000-5,000	There has been no escape of large volumes of water from the pit and no adjacent waterbodies are directly threatened.
160/161 H	2500	7,000-8,000	3,000-4,000	3,000-6,000			
160/161 North	38,000-42,000	48,000-52,000	95,000-125,000	50,000-100,000	9,000-12,000 in 2 ponds	20,000-25,000	Drainage channel from the smaller pond to Fresh Water Creek suggests previous indroduction of large volumes of water to the creek. Potential for rapid introduction of large volumes of water from the pond to Pikiolik Lake due to continued thaw collapse. Proximity [20metres] to Fresh Water Creek and Pikiolik Lake may preclude further development.

Table 1. Preliminary estimates of the volumes of aggregate extracted and remaining in the borrow pits and extent of thaw ponds.
Environmental concerns and potential constraints on development are noted.
Except as noted vegetation growth is minimal.

DISCUSSION AND RECOMMENDATIONS

Description of Source 160/161

Source 160/161 comprises 13 separate excavations that range in size from 1000 to 40,000 square meters. The total area of the borrow pits is approximately 140,000 square metres. Total area disturbed by borrow pit activities, including the fringe of disturbed organic material around most of the pits, is approximately 270,000 square metres. Aggregate was extracted from Source 160/161 West in the late 1960's or early 1970's and from the other borrow pits between August 1980 and July 1985. There has been no extraction of large volumes of aggregate from this area since 1985.

Based on pre-extraction topographic maps, aerial photographs and field observations, it is estimated that a thickness of 1 to 6 metres of material was removed from these borrow pits yielding approximately 320,000 to 420,000 cubic metres of aggregate. No complete records of material extracted from these pits were available but this calculated volume is consistent with estimates by the pit operator. Exploration drilling [Hardy, 1980] indicated that Source 160/161, not including Source 160/161 West or North, contained in excess of 700,000 cubic metres of aggregate. Some of the deposits recommended for development have not been exploited and aggregate at Source 160/161 B was not extracted due to thick overburden cover.

In the abandoned borrow pits there is almost no organic material, only limited vegetation growth and no stockpiles of organic material. Any rehabilitation measures will be constrained by the lack of local organic material. Aerial photographs indicates that there was a continuous vegetation mat prior to excavation of the aggregate. However, the 1980 exploration drilling indicated that the pre-extraction organic cover was absent or thin at most of the borrow pits.

Around the margins of most of the borrow pits is a 10 to 50 metre wide fringe of disturbed organic material. This is clearly visible in the fall 1991 helicopter photographs where the vegetation growth on the disturbed organic material stands out from the unvegetated surface of the borrow pit and the mature vegetation growth in undisturbed areas. The disturbed organics extend into low areas not expected to provide aggregate and locally terminate in a small mound of organics. The foregoing suggests that organics and snow cover removed from the working surface in preparation for extracting aggregate were spread out well beyond the limits of the borrow pit. The total area disturbed by borrow pit activities is approximately twice that required for the borrow pit alone. Furthermore, the thin layer of organic material removed from the borrow pits cannot be reclaimed without creating more bare, unvegetated ground.

Post-extraction depressions occurred in most of the borrow pits at Source 160/161. They range in size from shallow linear cracks less than 1 metre across to water filled depressions

8,000 to 10,000 square metres in area and 4 to 7 metres deep. Water filled depressions now occupy 45,000 to 55,000 square metres or approximately 35% of the area of the borrow pits. The largest of these occur in borrow pits 160/161 C, E and North.

Depth of Thaw

An intact organic cover and vegetation mat limits depth of thaw. Where this natural organic cover is removed or disturbed, the depth of seasonal thaw [the active layer] will increase. Where previously permanently frozen massive ice or ice rich sediments are captured by this deeper active layer, thermokarst depressions are formed due to the melting of ice and subsequent collapse of the ground surface. The depth of these depressions is dependent on the thickness of ice exposed to thaw. As the depressions deepen, they can expand laterally into undisturbed areas due to melt of buried ice exposed along their walls and collapse of the walls.

At Source 160/161, depth of thaw in September 1991 was 1.2 to 1.8 meters in the borrow pits where there is no organic cover and 0.5 to 1.2 metres where the vegetation mat has been disturbed but there is still some organic material left at surface. The foregoing would suggest that buried ice at a depth of 1.8 metres in the borrow pit or 1.2 metres on the disturbed fringe could be exposed to thaw. Active layer studies at Source 155 N indicated that depth of thaw in September 1991 was less than 0.6 meters in undisturbed terrain and 1.2 to 1.7 meters where there was no organic cover over the aggregate [Thompson 1992]. These studies also indicated that it may be possible to significantly reduce depth of thaw with an incomplete organic cover. In areas of sand or gravel a cover of nearly 2 metres of aggregate is required to protect ice from thaw but this can be reduced to approximately 1 to 1.5 metres if there is a discontinuous cover of organic material at surface.

Depth of thaw may be greater at the base of the thermokarst ponds. The largest ponds are 1.3 to 3.3 metres deep and expected depth of seasonal ice cover is approximately 1.5 metres [A. Judge pers.comm.]. Therefore, some of these ponds may not freeze to the bottom and ground temperatures could remain above freezing throughout the year thus enhancing the rate of thermokarst development.

Buried Ice and Thaw Settlement

Development of post-extraction depressions varied considerably both within and between the borrow pits. In some areas there has been no thaw settlement while in other areas broad depressions developed within the first few years following extraction of the aggregate and have continued to deepen and expand. Collapse of the land surface in the base of some the borrow pits progressed, in less than ten years, from a few widely spaced linear cracks to large water-filled depressions. The linear cracks and depressions were strongly suggestive of a pre-existing ice polygon network with a spacing of 20 to 60 metres between ice wedges. On some of the undeveloped highland, tonal patterns on the aerial photographs suggest a similar ice polygon network. An active ice polygon network with less than 15 metres between ice wedges was observed in undisturbed low wet areas between the hills at Source 160/161.

The foregoing demonstrates, as suggested by the exploration drilling, that the distribution of shallow buried ice at Source 160/161 is variable. Some areas contained no shallow ice and other areas were underlain by large tabular ice bodies or widely spaced ice wedges. Underlying and probably coalescing with this ice wedge network were tabular ice bodies. The depressions reflect melt of ice wedges and tabular ice bodies exposed to thaw by removal of the overlying organics and aggregate. Where large depressions formed at Source 160/161 C, E and G, exploration drilling intersected in excess of 3 metres of buried ice within 2 to 6 metres of the pre-extraction surface. The boreholes were terminated in massive ice and the full thickness is unknown.

Some of the depressions have not changed since the most recent aerial photographs [1985] and appear to have stabilized. However, most of the larger thermokarst depressions have expanded and deepened substantially since 1985. It is not possible to determine the extent of any current expansion of the depressions without more detailed surveys but fresh collapse structures on the margins of these depressions and drowned vegetation in the ponds in September 1991 suggest that melt of buried ice and thermokarst collapse is continuing. Growth of the thermokarst depressions will cease when the ice exposed to thaw has melted or when there is sufficient cover over the ice to insulate it from warm surface temperatures. There is insufficient subsurface information on the extent of remaining buried ice or thickness of cover over the ice to predict how much further the depressions will expand in aerial extent or depth. Based on the current size of the depressions and subtracting an estimate of the aggregate extracted, approximately 125,000 to 150,000 cubic metres of buried ice has already melted. This is equivalent in volume to about 35% of the aggregate extracted from these pits.

Rehabilitation

The abandoned pits at Source 160/161 are unsightly because of the steep slopes, irregular depressions and lack of vegetation. Steep slopes were left on the margins of some of the pits when they were abandoned and others have formed as buried ice melted. Although the development of post-extraction depressions in these pits was initiated by extraction activities, some of the lakes in the Tuktoyaktuk area formed by natural melt of buried ice [Rampton 1988]. In permafrost regions natural thermokarst ponds and lakes tend to coalesce with time. The extraction induced depressions are expected to stabilize and the thermokarst ponds will be similar in appearance to other shallow lakes in the region. However, formation of thaw ponds in the borrow pits and development of new drainage regimes may be more rapid than in natural processes. The pit surfaces are expected to eventually revegetate and visually blend with the natural landscape.. However, because of the steep slopes and lack of organic material, this process may take decades. Recovery of the borrow pits can be encouraged with some human assistance.

Recontouring

Any redistribution of material in these borrow pits could potentially expose additional buried ice and initiate more thermokarst collapse. The extent and location of buried ice is unknown so it is not possible to predict the likelihood or extent of collapse. Exposing additional ice to thaw could create additional steep slopes, expand the ponds and lengthen the time required for the pits to stabilize. For this reason, any attempted recontouring should be limited to minimize further exposure of buried ice. Areas that are in keeping with the natural landscape should not be disturbed. Steep margins of thermokarst depressions should be permitted to stabilize naturally unless there is additional subsurface information on the extent of buried ice, provided by drilling or techniques such as ground probing radar, to guide recontouring efforts.

Sources 160/161 C and E are particularly unsightly because steep slopes on the margins of the pits and mounds inside the pits were left standing when the borrow pits were abandoned in the mid 1980's. The high mounds in the centre of these pits and steep slopes on the east side of Source 160/161 C and the southeast side of Source 160/161E could be regraded. It is recommended in Environmental Guidelines, Pits and Quarries (1982) that, when a pit is abandoned, slopes be graded to no steeper than 2:1 [2 horizontal to 1 vertical]. To provide such slopes would necessitate cutting back about 10 metres from the present edge of the pit. Recontouring may create additional thermokarst depressions but is still expected to improve the overall visual appearance of these pits. Recontouring of slopes above and within 30 metres of natural water bodies should be avoided to minimize potential for introduction of pit drainage to these water bodies.

Revegetation

In the borrow pits and in areas disturbed by borrow pit activities there is new vegetation growth. This new growth is predominantly a grass and it appears to be unique to areas that have been disturbed. It is best established along the disturbed fringe of the pits where there is organic material but some limited vegetation growth also occurs in the base of the pits, particularly where there is some organic material. There is no record of reseeding, so it is assumed that this growth has established from native seeds in the organic material or windblown from adjacent areas.

The foregoing demonstrates that vegetation can reestablish naturally even where there is only a thin and incomplete cover of organics to provide nutrients and seed. However, vegetation is practically non-existent where there is no organic material. At Source 160/161, there is no stockpiled organic material available to cover the pits. It may be possible to establish vegetation growth in these bare areas by fertilizing and reseeding. Any surface that is reseeded should be protected by creating furrows or providing an artificial cover, to minimize wind erosion and facilitate vegetation growth. A more continuous vegetation cover would improve the visual appearance of the pits, help to stabilize slopes, and perhaps reduce thermokarst development.

Drainage from the Borrow Pits

It is recommended in Environmental Guidelines, Pits and Quarries (1982) that any borrow pit be at least 30 meters from a water body to restrict drainage from the pit. Introduction of water of a different chemistry, temperature or silt content can damage the ecological balance of aquatic life. Borrow pits at Sources 160/161 C, E and North were opened to within less than 30 metres of adjacent water bodies and, due to thaw-induced collapse of this narrow margin, there has been escape of water from these pits. The relative water chemistry, silt content and temperature of the natural water bodies and the thermokarst ponds is unknown and therefore the potential effect of pit drainage on adjacent lakes and rivers is uncertain. The thermokarst ponds are developed on aggregate with a silt content of less than 15% [Hardy, 1980] and it is expected that the silt content of the ponds is not significantly different from that of the natural water bodies.

The thermokarst pond at Source 160/161 C is 40 metres south of Lake C and separated from the lake by a narrow raised margin. There is a dry channel around the west end of the ridge indicating seasonal escape of modest volumes of pit water to the lake. It is possible that the margin between the lake and the pond could disintegrate further to permit more substantial water flow. Lake C is connected to Mayogiak Inlet by a small creek and pit drainage could enter the inlet via the creek.

The thermokarst pond at Source 160/161 E is less than 10 metres south of Lake E and separated from the lake by a narrow ridge. At its narrowest point the ridge rises only a few centimeters above water level in the pond. It is expected that this ridge will further disintegrate and that the thermokarst pond will coalesce with the lake. The pond contains approximately 15,000 to 25,000 cubic metres of water.

The volume of water in the thermokarst ponds at Sources 160/161C and E is approximately 5 to 15% of that in the adjacent lakes. Influx of such volumes of pit water could have a negative impact on aquatic life and water quality in the lakes. However, water level in the ponds is less than 40 centimetres above that in the lakes so mixing of waters between the pit and the lake may be slow thus reducing any negative impact. To determine the nature of any impact on the lakes the relative water chemistry, silt content and temperature of the natural water bodies and the thermokarst ponds should be measured.

Lakes C and E are small and not believed to be a critical local resource. However, if introduction of pit water to these lakes or the gradual coalescing of the lakes with the thermokarst ponds is considered unacceptable, it would be advisable to monitor these pits to determine how much water is escaping from the pits and if the protective margin is disintegrating. It may be possible to stop disintegration of these margins and contain drainage by placing additional aggregate along the margin to provide insulation and assist vegetation growth.

The borrow pit at Source 160/161 North is on a highland, 8 to 10 meters above and less than 20 metres laterally from Fresh Water Creek to the south and Pikiolik Lake to the east. These water bodies are believed to be important local resources. Disturbances associated with borrow pit activities extend to the edge of the slope above these water bodies and there is almost no organic cover along this margin. There are at present two thermokarst ponds in the borrow pit.

Although the thermokarst pond in the central part of the pit is 40 to 60 metres from Fresh Water Creek, a drainage channel exists from the pond to creek. Water flow in this channel was modest in September of 1991 and drained directly into the sandy deposits at the base of the slope before reaching Fresh Water Creek. However the size of the channel [4 metres deep and 1 to 2 metres wide] suggests more substantial water flow in other years, possibly associated with partial draining of the pond or with annual spring run-off. It is uncertain if flow will be more extensive in the future. The pond has not expanded substantially since 1985 and did not appear to be growing rapidly in 1991 indicating that, at present, release of water from melt of buried ice is modest. The pond is approximately 1,500 square metres in area and contains 1,200 to 1,600 cubic metres of water.

The thermokarst pond on the east side of the borrow pit has expanded and deepened substantially since 1985. Fresh collapse features observed on the margins of the pond and drowned vegetation in the centre of the pond may indicate continued melt of buried ice and further growth and deepening of the pond in 1991. Water has escaped from this pond to the undisturbed organics in low ground on the north side of the deposit accelerating melt of ice wedges. If melt of buried ice continues on the east side of the pond, the remaining 20 metre wide fringe between the pond and the edge of the slope may eventually be breached and water in the pond could drain rapidly into Pikiolik Lake. The pond contains approximately 18,000 to 22,000 cubic metres of water. This volume of water is less than 0.2% of that in Pikiolik Lake.

Rapid influx of water from the thermokarst pond could have a negative local impact on aquatic life and water quality but is not expected to have any long term impact on the lake.

To determine the nature of any impact on the lake the relative water chemistry, silt content and temperature of the natural water bodies and the thermokarst ponds should be measured. To determine if sudden draining of the thermokarst ponds at Source 160/161 North is likely to occur the borrow pit should be monitored, by ground surveys during the thaw season, to determine the extent of water escaping from the pit and to determine if margins that presently contain the water are disintegrating. If the margins that contain the ponds are disintegrating due to melt of buried ice and erosion, it may be possible to strengthen these areas and limit depth of thaw by placing additional aggregate along the margin and assisting vegetation growth. It may be possible to induce deeper winter freezing and thus limit annual depth of thaw by reducing winter snow cover. If drainage from the ponds is already a problem it may be possible to control it by constructing artificial dams. If it proves impossible to contain water in the thermokarst ponds it may be advisable to permit its controlled release to avoid sudden influx of pit drainage to Fresh Water Creek or Pikiolik Lake .

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

Aggregate Remaining at Source 160/161

There is additional aggregate in the floor of the abandoned borrow pits, along the margins of the pits, and in undeveloped extensions of the deposits. As the thermokarst ponds expand some of this aggregate collapses into the ponds and becomes inaccessible unless the ponds are pumped or drained.

Extracting additional aggregate from the floor of the borrow pits at Sources 160/161 C and E may not be practical. The base of the pits are wet and the aggregate would be frozen and difficult to extract in the winter. Using heavy earth moving equipment on the soft wet floor of these pits in the summer would be difficult. Similarly, extracting material from the undeveloped low wet margins of these pits may not be viable. Furthermore, shallow shovel pits excavated during the 1991 field surveys suggest that most of the material remaining at the base of the pits and their low undeveloped margins is fine sand.

It would be possible to extract additional aggregate from borrow pits that stand above low wet areas, such as Sources 160/161 F, 160/161 G, 160/161 H and 160/161 North, by draining the thermokarst ponds and deepening the pits. Test pits and sections exposed during the

1991 field surveys at these sites indicate that the material remaining is predominantly sand with scattered gravel sections. The 1980 exploration drilling indicated that there may be a further 4 to 5 metres of sand and gravel in the south pit at Source 160/161 F and the north part at Source 160/161 H. Collectively these abandoned borrow pits could contain in excess of 150,000 cubic metres of aggregate but buried ice may limit volumes of aggregate or the depth to which it can be economically extracted. Furthermore, extraction of additional aggregate at any of these pits would expose ice to thaw, initiate additional thermokarst collapse and possible initiate further drainage to adjacent water bodies. The potential for environmental damage may restrict further development at some of these sites. Source 160/161 F is 30 to 80 metres from Kudluk Lake. Source 160/161 North is less than 30 metres from Fresh Water Creek and Pikiolik Lake. Sources 160/161 G and H are small and remaining aggregate in these pits is less than 30,000 cubic metres.

At Source 160/161 C the elevated ridge in the centre of the pit and the steep slopes on the east margin of the pit contain aggregate. Test pits and sections indicate in excess of one metre of coarse granular material in these slopes. The total thickness of aggregate may locally exceed 4 metres. The edges of the slopes are dry and would not be difficult to work in winter. If these slopes are regraded to improve the visual appearance of the pit, it would be possible to reclaim aggregate for community use as well as for reclamation of the borrow pits. The aggregate could be used to insulate areas in the pit undergoing collapse due to melt of buried ice or to construct berms to contain pit drainage. The amount of aggregate that could be recovered for use in the community of Tuktoyaktuk is dependent on how far back the slopes are cut and how much of the aggregate is used for reclamation. If recontouring efforts are restricted to the minimum required to improve the visual appearance of the pit, the amount of aggregate available for community use may be less than 10,000 cubic metres. Larger volumes of aggregate could be recovered if the ridge in the centre of the pit and other mounds of aggregate in the pit are fully extracted but buried ice may limit available volumes or the depth to which it can be economically extracted.

The undeveloped east part of the hill at Source 160/161 C is 15,000 square metres and 2 to 3 metres above low ground. It is estimated, based on field surveys and aerial photograph interpretation, that this highland may contain an additional 20,000 to 30,000 cubic meters of extractable aggregate. Sections excavated on the west side of this hill intersected in excess of one metre of coarse aggregate. However, the hill is untested by exploration drilling and the type of aggregate and extent of buried ice are unknown.

At Source 160/161 E, test pits and sections excavated in the slopes on the southeast side of the pit and in aggregate mounds in the pit intersected 1.5 to 2 metres of sand with some gravel sections. The total thickness of aggregate may locally exceed 3 metres. The edges of these slopes are dry and would not be difficult to work in winter. As at Source 160/161 C, it would be possible to reclaim aggregate for community use and/or for reclamation of the borrow pits if these slopes are regraded to improve the visual appearance of the pits. If recontouring efforts are restricted to the minimum required to improve the visual appearance of the pit, the amount of aggregate available for community use would be less than 5,000 cubic metres.

The highland on the southeast side of Source 160/161 E is 12,000 square metre and 2 metres above low ground. It is estimated, based on field surveys and aerial photographic interpretation, that this highland may contain an additional 15,000 to 25,000 cubic meters of aggregate. Sections excavated on the north side of this hill intersected 1.5 to 2 metres of sand with some gravel sections. However, the hill is untested by exploration drilling and the type of aggregate and extent of buried ice are unknown.

Future Development of Source 160/161

Buried ice was intersected in 75% of the boreholes in the Source 160/161 area and has been exposed in most of the deposits developed to date. Any further extraction of aggregate from these borrow pits, their undeveloped extensions or other undeveloped highlands in this area will expose buried ice to thaw and initiate further thermokarst collapse. If more thermokarst depressions and bare "scarred" ground in the area are considered unacceptable, there should be no further development at Source 160/161.

If in fact these sources of aggregate are to be developed, strategies should be generated to minimize environmental damage. Guidelines for pit development and restoration suggested by Thompson [1992] and in Environmental Guidelines, Pits and Quarries (1982) should be used to formulate development plans. The recommendations by Thompson are summarized below.

Plans for the development and restoration of the borrow pits should be determined in consultation between the 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 would maximize recoveries and provide suitable environmental protection. For these plans to be effective the following is required:

> 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 in advance of extraction activities to avoid development in areas that are unsuitable due to thick overburden cover, poor quality aggregate or environmental concerns.

To develop strategies for exploitation of these deposits that are both cost effective and minimize environmental damage, additional exploration drilling would be required. Such drilling would determine the extent and quality of aggregate, type and thickness of overburden cover and extent and thickness of buried ice. 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]. This concentration of boreholes is 2 to 10 times greater than that generally employed for exploration programs in the Tuktoyaktuk Coastlands area. One borehole per 3,000 to 5,000 square meters should be considered a minimum density to evaluate the deposits at Source 160/161 because they are geologically variable and contain large volumes of erratically distributed ice. Since depth of thaw in the borrow pit may be almost 2 metres and extraction of aggregate, in some cases, extends deeper than initially proposed, boreholes should be drilled a minimum of 3 metres below the planned base of the pit. This will locate all buried ice that could be exposed to thaw by extraction of the aggregate. Boreholes should be extended through any massive ice or ice-rich sediments to determine the full thickness of ice and hence the full potential impact of extraction activities on the surrounding landscape. Instrumentation designed to detect buried ice from surface, such as ground probing radar and the sounding equipment presently used by the pit operator, could be employed in conjunction with the exploration drilling to further evaluate the extent of buried ice.

Any further development of borrow pits in this area could be combined with other studies, as recommended by Thompson [1992] and discussed below, to determine the most suitable methods for storing organics while the pits are being worked and replacing them when the pits are abandoned.

The natural 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 completion of extraction activities are generally insufficient to permit full covering of the borrow pit. However, the organic material is critical in the rehabilitation of abandoned borrow pits. Where there is no organic cover, depth of thaw can be as much as 2 metres [3 times that in undisturbed terrain] and vegetation is very slow to reestablish. Even an incomplete cover of organic material can significantly reduce depth of thaw and provide nutrients and native seed for vegetation regrowth.

The manner in which the organics have been stored at Source 160/161 is not the most suitable way to preserve them for future recovering of the borrow pits. They have been spread out along the margins of the pits or dumped down-slope off the edge of the pits. Reclaiming these organics without creating more unvegetated areas and potentially exposing buried ice to thaw, is impossible.

It would be possible to provide a more complete rehabilitation of abandoned borrow pits if the organics are more suitably stored. Organics should be stored in mounds to permit easy recovery when the work is completed. Where practical organics should be stored in the borrow pit to limit unnecessary damage to vegetation beyond the limits of the borrow pit. Organics should not be stored or replaced where thaw ponds may develop because the organic material could be lost in the pond and could potentially contaminate adjacent water bodies. Securing fabric covers over stockpiles and recently replaced organics may reduce loss of organics from desiccation and wind erosion. Organic material should be replaced as soon as possible because organics stored in piles for several years may become frozen solid and difficult to reclaim. If the pit is worked in sections and the organic cover replaced as soon as work is completed in any area, handling of organics could be facilitated, thaw penetration reduced and recovery of vegetation accelerated.

FURTHER STUDIES

Borrow pit activities at Source 160/161 presented some difficulties during and subsequent to extraction of the aggregate. These problems can be largely attributed to melt of buried ice and handling of organic material. There is need for a better knowledge of the distribution of ground ice, a better understanding of thermal conditions in borrow pits and for improved methods of storing organic material and rehabilitating abandoned borrow pits.

The abandoned pits at Source 160/161 provide an ideal laboratory for experimental studies because they provide examples of borrow pits in different stages of organic cover and revegetation and are deeply pitted with thermokarst ponds. They are also within easy commuting distance of Tuktoyaktuk and would not require expensive or extensive logistic support. Some suggested studies are summarized below. These studies could be conducted in conjunction with any rehabilitation measures and/or additional extraction activity.

1. Temperature recording sites could be established to determine depth of thaw in areas with different amounts of organic/vegetation cover and at the base of the thermokarst ponds at different stages of development. Such studies could help to predict the location, rate and extent of thaw settlement and determine how depth and extent of thaw might be limited. Of particular concern is the potential for thaw ponds to expand laterally, incorporating undisturbed areas, due to melt of buried ice exposed at the edge of the pond. Therefore, temperature recording sites should be established along margins of ponds, such as those at Sources 160/161 C, E and North, that are disintegrating.

2. The margins between the thermokarst ponds and natural water bodies should be monitored to determine to what extent they are disintegrating and the extent of water escaping from the ponds.

3. The chemistry of the water in the thermokarst ponds and the natural water bodies should be monitored to determine if there are significant differences in water chemistry and if there are changes during the year or over a number of years.

4. If additional aggregate is extracted from undisturbed areas, the organic materials removed from the working surface should be used in studies to develop improved methods for storing and replacing organics.

5. Revegetation plots could be established to determine methods for reestablishing vegetation growth both with and without organic material. The present experience and practice at other northern sites should be reviewed.

6. Instrumentation designed to detect buried ice from surface, such as ground probing radar and the equipment presently used by the pit operator, could be tested to determine their accuracy and depth penetration. This instrumentation could be used to augment exploration drilling at other deposits in the Tuktoyaktuk Coastlands area.

The people in the community of Tuktoyaktuk should be involved in these studies and monitoring programs. Scientific organizations such as universities or the Geological Survey of Canada could initiate and oversee the programs and provide training. Such cooperation would provide more continuous monitoring of the abandoned borrow pits at a reduced cost. These studies could also provide an improved understanding of northern landscapes for the people in the community as well as for the scientists.

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APPENDIX A

BOREHOLE LOGS

TEST HOLE LOG 1

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
1	SM		SAND little silt, fine to medium grained, brown trace gravel to 1 cm size		Vx 10%	A1 A2	☒ ☒	1.0 1.5 1.7	
2 3	SP		SAND little gravel to 4 cm size, trace silt		Vc 5%	A3	☒	3.0 3.3	
4 5 6 7 8	I+		ICE+ trace gravel, trace silty sand		I+ 95%	A4	☒	7.0 8.0	
9 10			Bottom of Hole at 9.0 m depth						

DATE: 80.01.21

LOGGED BY: G.D.

DRWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
1

TEST HOLE LOG 2

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 40%				
	I+		ICE+ trace silt		I+ 90%				
1	SM		SAND little silt, fine grained, brown		Vx 10%	A_1	☒	1.0 1.3	
2	SP		SAND fine grained, trace silt, trace coarse sand to 0.5 cm size			A_2	☒	2.0 2.3	
3					Nbe				
4						A_3	☒	4.0 4.3	
5	I+		ICE+ trace sand		I+ 90%				
6									
7									
8	SP		SAND fine to medium grained, light brown		Vc- Vx 30%	A_4	☒	8.5	
9			Bottom of Hole at 9.0 m depth						
10									

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TEST HOLE NO.
2

TEST HOLE LOG 3

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 30%				
1 2	SM		SAND little silt, fine grained, brown		Vx 20%	A_1	☒	1.4 1.6	
3 4 5	I+		ICE+ trace sand		I+ 90%				
6	SP		SAND fine to medium grained, occasional coarse sand sizes		Vx 15%	A_2	☒	5.5 6.0	
7	I+		ICE+ little sand		I+ 80%	A_3	☒	7.2 7.4	
8	SP		SAND fine to medium grained, occasional coarse sand sizes		Vx 40%	A_4	☒	8.2 8.6	
9	I		ICE		I				
10			Bottom of Hole at 9.0 m depth						

DATE: 80.01.21	LOGGED BY: G.D.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
3

TEST HOLE LOG 4

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 30%				
	GP		GRAVEL and fine to coarse sand, trace silt, rounded to subrounded, to 4 cm size, poorly graded, brown		Vx 10%	A_1	☒	0.3 0.6	Grain Size (A-43) w = 10.9%
	SP		SAND and rounded to subrounded gravel to 4 cm size, trace silt, fine to coarse grained, poorly graded, brown			A_2	☒	1.5 2.0	Grain Size (A-44) w = 15.8%
			trace gravel to 4 cm size			A_3	☒	2.5 2.8	Organic Colour: #3+ Grain Size (A-45) w = 23.4%
			trace gravel to 3 cm size			A_4	☒	3.2 3.4	w = 21.0%
	GP		GRAVEL some fine to coarse sand, trace silt, to 10 cm cobble size, rounded, poorly graded		Nbn	A_5	☒	3.8 4.0	Grain Size (A-46) w = 9.1%
						A_6	☒	4.7 5.0	w = 15.4%
	I+		ICE+ trace silty sand		I+ 90%				
			Bottom of Hole at 8.0 m depth						

DATE: 80.01.21

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TEST HOLE NO.
4

TEST HOLE LOG 5

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr				
	ML		SILT little fine sand, dark brown	+ +	20% Vx 30%	A_1	☒	0.3 0.6	w = 59.5%
1			-- trace fine sand	+ +	20%	A_2	☒	1.2 1.5	w = 32.1%
2				+ +	Nbn				
3			-- little fine sand	▨	Vs 40%	A_3	☒	3.5 3.8	w = 64.9%
4	SM		SAND some rounded gravel to 2.5 cm size, little silt, fine to coarse grained	+ +	Vx 10%	A_4	☒	4.2 4.5	Organic Colour: #1+ Grain Size (A-47) w = 16.9%
5			-- trace coarse sand to 0.5 cm size, rounded	+ +	20%				
6				+ +		A_5	☒	5.5 6.0	w = 21.2%
			-- and subangular gravel to 1.5 cm size	+ +					
	I+	▮▮▮	ICE+ trace sand	▮▮▮	I+ 90%				
7	SM		SAND some rounded to subrounded gravel to 3 cm size, little silt	+ +	Vx 30%	A_6	☒	7.3 7.6	w = 22.2%
			-- occasional cobble	+ +					
8	GW		GRAVEL and fine to coarse sand, little silt, rounded to subrounded to 4 cm size, well graded	+ +	20% 10%	A_7	☒	8.5 8.8	Grain Size (A-48) w = 16.3%
9	I+	▮▮▮	ICE+ occasional pebbles	▮▮▮	I+ 80%				
10			Bottom of Hole at 9.5 m depth						

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TEST HOLE NO.
5

TEST HOLE LOG 6

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr				
	SP		SAND trace gravel to 1 cm size, fine to medium grained		30%	A_1	☒	0.3 0.6	w = 23.4%
1					Vx 20%				
2	SW		SAND some subrounded gravel to 4 cm size, little silt, fine to coarse grained, well graded		10%	A_2	☒	2.2 2.6	Grain Size (A-49) w = 18.1%
			--- no gravel						
3	I+		ICE+ trace silt		Vs 50%				
					I+ 99%	A_3	☒	3.5 3.8	
4									
5						A_4	☒	5.0 5.3	
6									
7									
8									
9						A_5	☒	9.0 9.2	
10			Bottom of Hole at 9.5 m depth						

DATE: 80.01.22

LOGGED BY: A.C.

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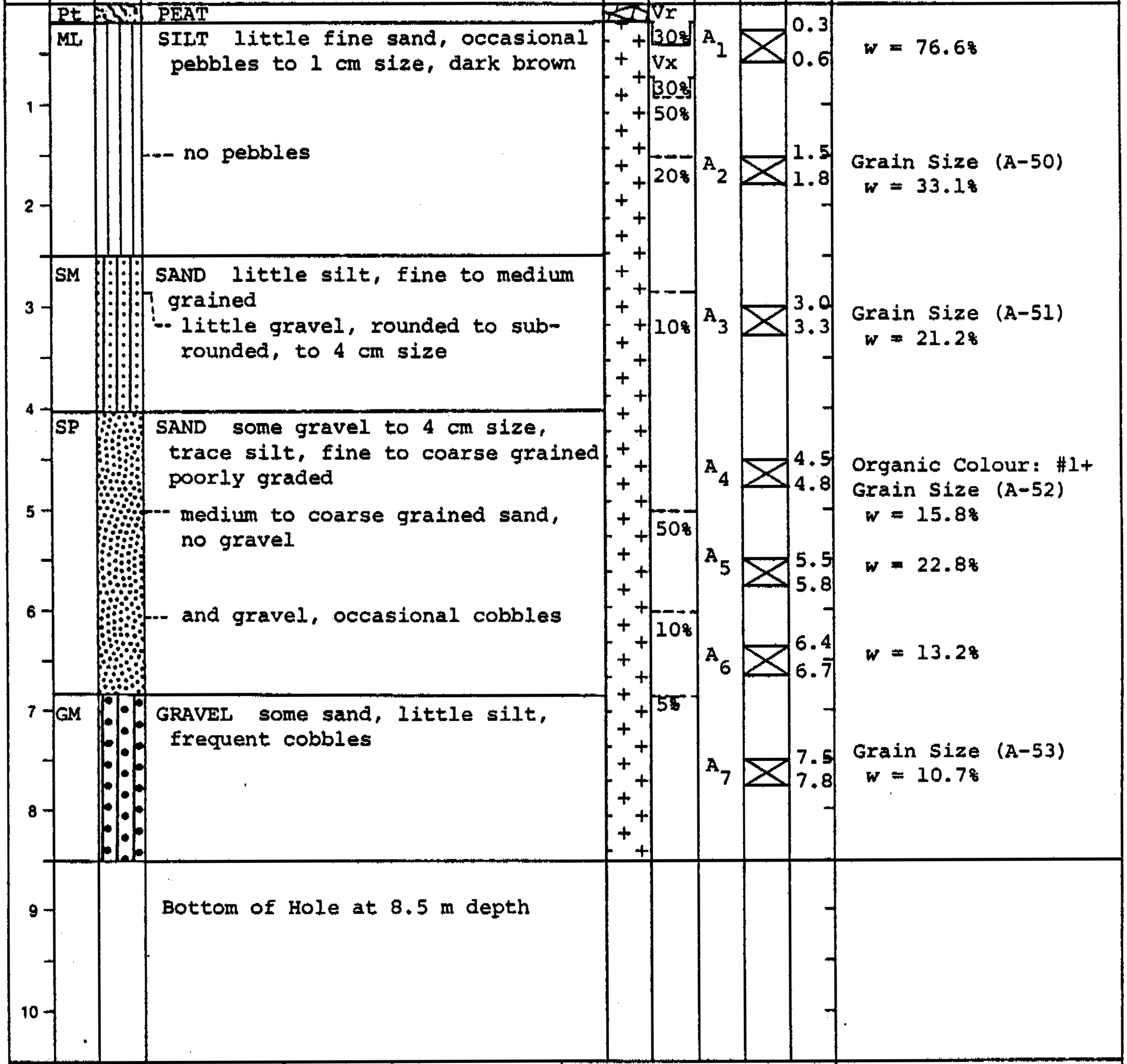
TEST HOLE NO.
6

TEST HOLE LOG 7



DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr				
	ML		SILT little fine sand, occasional pebbles to 1 cm size, dark brown		30% Vx 30% 50%	A_1	☒	0.3 0.6	w = 76.6%
			-- no pebbles		20%	A_2	☒	1.5 1.8	Grain Size (A-50) w = 33.1%
	SM		SAND little silt, fine to medium grained						
3			-- little gravel, rounded to sub-rounded, to 4 cm size		10%	A_3	☒	3.0 3.3	Grain Size (A-51) w = 21.2%
4	SP		SAND some gravel to 4 cm size, trace silt, fine to coarse grained poorly graded			A_4	☒	4.5 4.8	Organic Colour: #1+ Grain Size (A-52) w = 15.8%
5			-- medium to coarse grained sand, no gravel		50%	A_5	☒	5.5 5.8	w = 22.8%
6			-- and gravel, occasional cobbles		10%	A_6	☒	6.4 6.7	w = 13.2%
7	GM		GRAVEL some sand, little silt, frequent cobbles		5%	A_7	☒	7.5 7.8	Grain Size (A-53) w = 10.7%
9			Bottom of Hole at 8.5 m depth						

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TEST HOLE NO.
7

TEST HOLE LOG 8

DEPTH (M)	SOIL GROUP SYMBOL	MATERIAL DESCRIPTION	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
1	SM	SAND little silt, trace gravel to 2 cm size, fine to medium grained	Vx 5%				
2	GM	GRAVEL some silt, some sand, rounded, to 6 cm size		A_1	☒	1.2 1.5	Organic Colour: #5+ Grain Size (A-54) w = 42.0%
3 4	SM	SAND some gravel to 4 cm size, little silt -- and silt, little gravel to 4 cm size, fine to coarse grained	Nbn	A_2	☒	2.0 2.3	Grain Size (A-55) w = 15.1%
				A_3	☒	2.5 2.8	w = 17.5%
				A_4	☒	3.0 3.3	Grain Size (A-56) w = 27.6%
		-- 0.2 m thick layer, trace gravel to 2 cm size					
		ice layers to 10 cm thickness	Vs 50%	A_5	☒	4.5 4.7	w = 24.9%
5 6 7 8	I+	ICE+ little sand, trace gravel	I+ 80%				
9	SP	SAND trace gravel, fine to medium grained	Vs 40%	A_6	☒	8.5 8.7	
10		Bottom of Hole at 9.0 m depth					

DATE: 80.01.22

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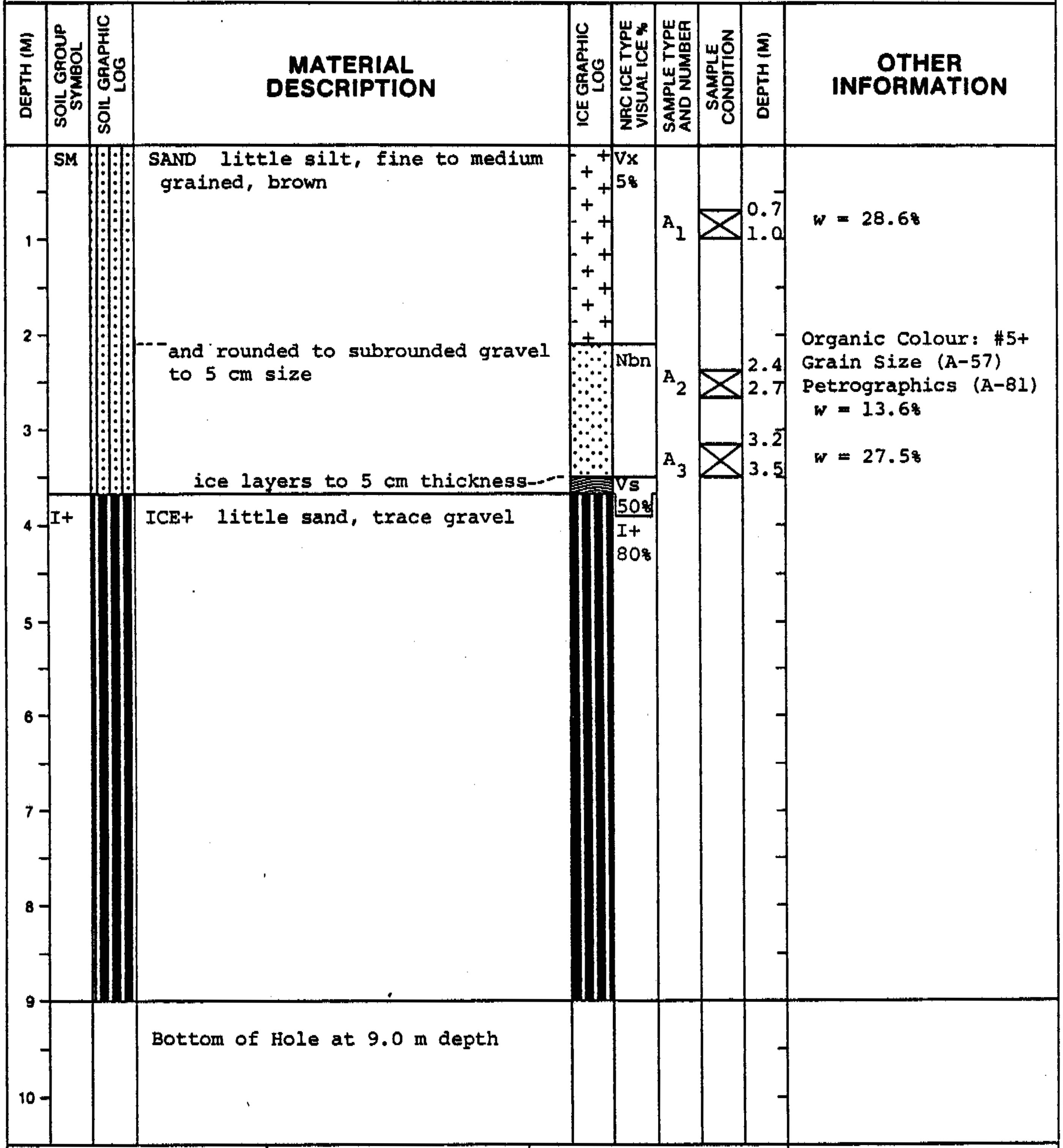
TEST HOLE NO.
8

TEST HOLE LOG 9



DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	SM		SAND little silt, fine to medium grained, brown		Vx 5%				
1						A_1	☒	0.7 1.0	w = 28.6%
2			and rounded to subrounded gravel to 5 cm size		Nbn	A_2	☒	2.4 2.7	Organic Colour: #5+ Grain Size (A-57) Petrographics (A-81) w = 13.6%
3			ice layers to 5 cm thickness		Vs 50%	A_3	☒	3.2 3.5	w = 27.5%
4	I+		ICE+ little sand, trace gravel		I+ 80%				
9			Bottom of Hole at 9.0 m depth						

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TEST HOLE NO.
9

TEST HOLE LOG 10

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	PT		PEAT		Vr				
	ML		SILT trace sand, non plastic, brown		20% Nbe				
1						A_1	☒	1.2 1.5	w = 29.3%
2	SW		SAND little rounded gravel to 4 cm size, trace silt, fine to coarse grained		Nbn	A_2	☒	1.8 2.1	w = 20.9%
3	GP-GM		GRAVEL some fine to medium grained sand, little silt, rounded to subrounded, to 7.5 cm size ice layers to 10 cm thickness		Vs 50%	A_3	☒	2.5 2.8	Grain Size (A-58) w = 9.1%
4 5	I+		ICE+ trace sand		I+ 90%				
6			some sand, fine to medium grained		60%	A_4	▬	5.5 5.6	
7	SP		SAND trace gravel to 1 cm size, fine to medium grained		Vc 30%	A_5	☒	6.3 6.6	
8					Nbe	A_6	☒	8.7	
9 10			Bottom of Hole at 9.0 m depth						

DATE: 80.01.22

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TEST HOLE NO. 10

TEST HOLE LOG 11

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	SM		SAND little silt, occasional pebble to 1 cm size, brown		Nbn				
						A_1	☒	0.5 0.7	
1									
			--- little gravel to 1 cm size			A_2	☒	1.8 2.1	
2									
	I+		ICE+ trace sand		I+ 90%				
3									
4									
			--- little medium grained sand		80%	A_3	☒	4.5 4.8	
5			--- trace sand		95%				
6									
7									
8									
9									
			Bottom of Hole at 9.0 m depth						
10									

DATE: 80.01.22

LOGGED BY: G.D.

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TEST HOLE NO. 11

TEST HOLE LOG 17

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	SM		SAND some silt, little gravel to 3 cm size, dry -- trace gravel to 1 cm size		Nf	A_1	☒	0.6 0.9	
			--- fine to medium grained, little silt		Nbn				
						A_2	☒	2.8 3.0	
			--- little gravel to 2 cm size, occasional cobbles to 8 cm size, little silt			A_3	☒	4.3 4.4	
	I		ICE		I				
			Bottom of Hole at 6.5 m depth						

DATE: 80.01.26

LOGGED BY: G.D.

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TEST HOLE NO. 17

TEST HOLE LOG 18

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
1	SP		SAND trace silt, occasional pebbles to 1 cm size, fine to medium grained --- trace gravel to 6 cm size, rounded --- no gravel		Nf	A_1	☒	0.8 0.9	
2 3	I+		ICE+		I+ 95%				
4 5 6 7 8 9 10			Bottom of Hole at 4.0 m depth						

DATE: 80.01.26

LOGGED BY: G.D.

DRWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
18

TEST HOLE LOG 19

DEPTH (M)	SOIL GROUP SYMBOL	MATERIAL DESCRIPTION	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
0	SP	SAND and rounded gravel to 3 cm size, little silt, fine to coarse grained, poorly graded, dry to 1.0 m depth trace silt	Nf Nbn	A_1 A_2	☒ ☒	0.6 0.8 1.6 1.8	Organic Colour: #5+ Grain Size (A-60) w = 14.1% Grain Size (A-61) w = 14.4%
	SM	SAND little gravel to 5 cm size, little silt --- some gravel to 3 cm size		A_3 A_4	☒ ☒	2.8 3.0 3.5 3.6	Grain Size (A-62) w = 22.4% w = 11.6%
4	I+	ICE+ trace sand	I+ 95%				
6		Bottom of Hole at 6.0 m depth					

DATE: 80.01.26

LOGGED BY: G.D.

DRAWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
19

TEST HOLE LOG 20

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 20%				
1	SP		SAND and rounded to subrounded gravel to 3 cm size, fine to coarse grained, poorly graded, dry --- some gravel, frequent cobbles and boulders		Nf	A_1	☒	0.3 0.6	Organic Colour: #5+ Grain Size (A-63) w = 5.3%
2	SM		SAND some rounded gravel to cobble size, little silt in pockets, fine to medium grained		Vx 10%	A_2	☒	1.8 2.0	
3	GW		GRAVEL and fine to coarse sand, trace silt, rounded, well graded			A_3	☒	3.0 3.2	Grain Size (A-64) w = 11.5%
	SP		SAND little silt in pockets, trace gravel, fine to medium grained		15%				
4 5 6	I+		ICE+ trace silt, trace fine sand ---little sand		I+ 95% 80%	A_4 A_5	☒ ☒	3.9 4.2 6.1 6.3	
7 8 9 10			Bottom of Hole at 6.5 m depth						

DATE: 80.01.25

LOGGED BY: A.C.

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CHKD BY: N.H.

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TEST HOLE NO.
20

TEST HOLE LOG 21

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	SM		SAND trace gravel to 2 cm size, trace silt, dry, gravel to 7 cm size to 0.5 m depth		Nf	A_1	☒	0.6 0.9	Grain Size (A-65) w = 23.9%
1	GP		GRAVEL some fine to medium sand, trace silt, rounded to subangular, to 4 cm size, dry			A_2	☒	1.2 1.4	
2			---to 2 cm size			A_3	☒	2.0 2.2	
						A_4	☒	2.5 2.6	
3	SP		SAND trace gravel to 1 cm size, trace silt, fine to coarse grained		Vc 5%				
4						A_5	☒	3.9 4.0	
			---and gravel to 4 cm size			A_6	☒	4.4 4.5	Grain Size (A-66) w = 14.7%
5			--- trace gravel to 1 cm size		10%				
						A_7	☒	5.5 5.7	
6						A_8	☒	6.0 6.2	
	I		ICE		I				
7			Bottom of Hole at 6.5 m depth						
8									
9									
10									

DATE: 80.01.25

LOGGED BY: G.D.

DRWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
21

TEST HOLE LOG 22

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	SM		SAND little angular gravel to 6 cm size, little silt, medium grained, dry		Nf				
						A_1	☒	0.6 0.9	
1			-- trace gravel to 1 cm size						
2						A_2	☒	1.6 1.9	
3						A_3	☒	2.6 2.9	
4						A_4	☒	3.7	
			Bottom of Hole at 4.0 m depth						
5									
6									
7									
8									
9									
10									

DATE: 80.01.25

LOGGED BY: G.D.

DRWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
22

TEST HOLE LOG 23

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	ML		SILT little sand, trace angular gravel		Vx 5%	A_1	☒	1.2 1.4	w = 17.8%
	SM		SAND and rounded to subangular gravel, little silt, fine to coarse grained		2%	A_2	☒	1.6 1.8	Grain Size (A-67) w = 14.3%
	I+		ICE+ trace sand --- some sand		I+ 90% 70%				
	SP		SAND trace gravel to 1 cm size, fine to medium grained		Vc 40%	A_3	☒	4.3 4.4	
	I		ICE		I				

Bottom of Hole at 4.6 m depth

DATE: 80.01.25	LOGGED BY: G.D.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
23

TEST HOLE LOG 24

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr				
	GM		GRAVEL and sand, little silt, to 10 cm cobble size, rounded		30%	A_1	☒	0.4 0.7	Grain Size (A-68) w = 13.3%
1	SW		SAND some rounded gravel to 3 cm size, trace silt, rounded trace gravel to 2 cm size		Nbn				
2	SM		SAND little silt, occasional pebble to 2 cm size, dark brown			A_2	☒	1.8 2.0	
3						A_3	☒	3.3	
4			Bottom of Hole at 3.5 m depth						
5									
6									
7									
8									
9									
10									

DATE: 80.01.25	LOGGED BY: G.D.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
24

TEST HOLE LOG 25

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	GP		GRAVEL and sand, trace silt, to 8 cm size, rounded		Nf				
	SP		SAND some rounded gravel to 5 cm size, trace silt, fine to coarse grained, poorly graded			A_1	☒	0.8 1.0	Grain Size (A-69) w = 15.0%
1			-- some rounded gravel to 3 cm size						
2						A_2	☒	2.2 2.4	w = 24.9%
3						A_3	☒	3.0 3.2	Organic Colour: #3- Grain Size (A-70) Petrographics (A-82) w = 18.1%
4	SW-SM		SAND little gravel to 2 cm size, little silt, fine to coarse grained, well graded			A_4	☒	4.5 4.7	Grain Size (A-71) w = 19.7%
5			-- some gravel to 3 cm size			A_5	☒	5.1 5.3	Grain Size (A-72) w = 17.7%
			ice layers to 10 cm thickness---						
6	SW		SAND trace gravel to 1 cm size, trace silt, fine to coarse grained		Vs 30% Nbe	A_6	☒	6.2 6.4	
7	I		ICE		I				
	SW		SAND trace gravel to 1 cm size, trace silt, fine to coarse grained		Vs 5%	A_7	☒	7.9 8.0	
8									
9			Bottom of Hole at 9.0 m depth						
10									

DATE: 80.01.25	LOGGED BY: G.D.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
25

TEST HOLE LOG 26

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 20%				
1	GP		GRAVEL and fine to coarse sand, trace silt, numerous cobbles to 5 cm size, poorly graded		Nbn	A_1	☒	0.5 0.7	Organic Color #5+ Grain Size (A-73) w = 17.2%
2	SM		SAND and gravel to 5 cm size, silty, fine to medium grained little gravel to 5 cm size		Vc 5%	A_2	☒	2.0 2.2	w = 24.1%
3	GP		GRAVEL and medium to coarse sand, occasional cobbles, rounded, to 4 cm size		Vx 5% 20%	A_3	☒	3.1 3.3	Grain Size (A-74) w = 10.7%
4 5	I+		ICE+ trace fine sand		I+ 95%	A_4	☒	3.8 4.0	
6 7 8 9 10			Bottom of Hole at 6.0 m depth						

DATE: 80.01.25

LOGGED BY: A.C.

DRWN BY: C.G.

CHKD BY: N.H.

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TEST HOLE NO.
26

TEST HOLE LOG 26a

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 25%				
1	ML		SILT trace fine sand, occasional cobbles to 10 cm size -- frequent large boulders	+ + + + + + + +	Vx 20%	A_1	☒	0.6 0.8	
2			Bottom of Hole at 1.8 m depth						
3									
4									
5									
6									
7									
8									
9									
10									

DATE: 80.01.25	LOGGED BY: A.C.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
26a

TEST HOLE LOG 27

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr 10%				
	GW		GRAVEL some fine to coarse sand, trace silt, occasional boulders, rounded, to 5 cm size		Nbn	A_1	☒	0.4 0.6	Grain Size (A-75) w = 4.8%
1									
	SP		SAND and gravel						
2			--medium grained, little gravel to 3 cm size, silty pockets		Vx 2%	A_2	☒	2.1 2.3	w = 23.2%
3			-- medium grained, clean		Nbn				
						A_3	☒	3.5 3.8	
4									
5									
			-- trace silt, occasional coarse sand sizes to 0.5 cm						
6						A_4	☒	6.0 6.3	
7					Vx 20%				
8						A_5	☒	7.8 8.1	
9			Bottom of Hole at 8.5 m depth						
10									

DATE: 80.01.25	LOGGED BY: A.C.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
27

TEST HOLE LOG 28

DEPTH (M)	SOIL GROUP SYMBOL	SOIL GRAPHIC LOG	MATERIAL DESCRIPTION	ICE GRAPHIC LOG	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
	Pt		PEAT		Vr				
	ML		SILT and fine sand, occasional pebbles to 1 cm size, brown trace sand		20% Vx 40% 30%	A_1	☒	0.6 0.8	
1									
2						A_2	☒	2.1	
			Bottom of Hole at 2.3 m depth						
3									
4									
5									
6									
7									
8									
9									
10									

DATE: 80.01.25	LOGGED BY: A.C.	DRWN BY: C.G.	CHKD BY: N.H.

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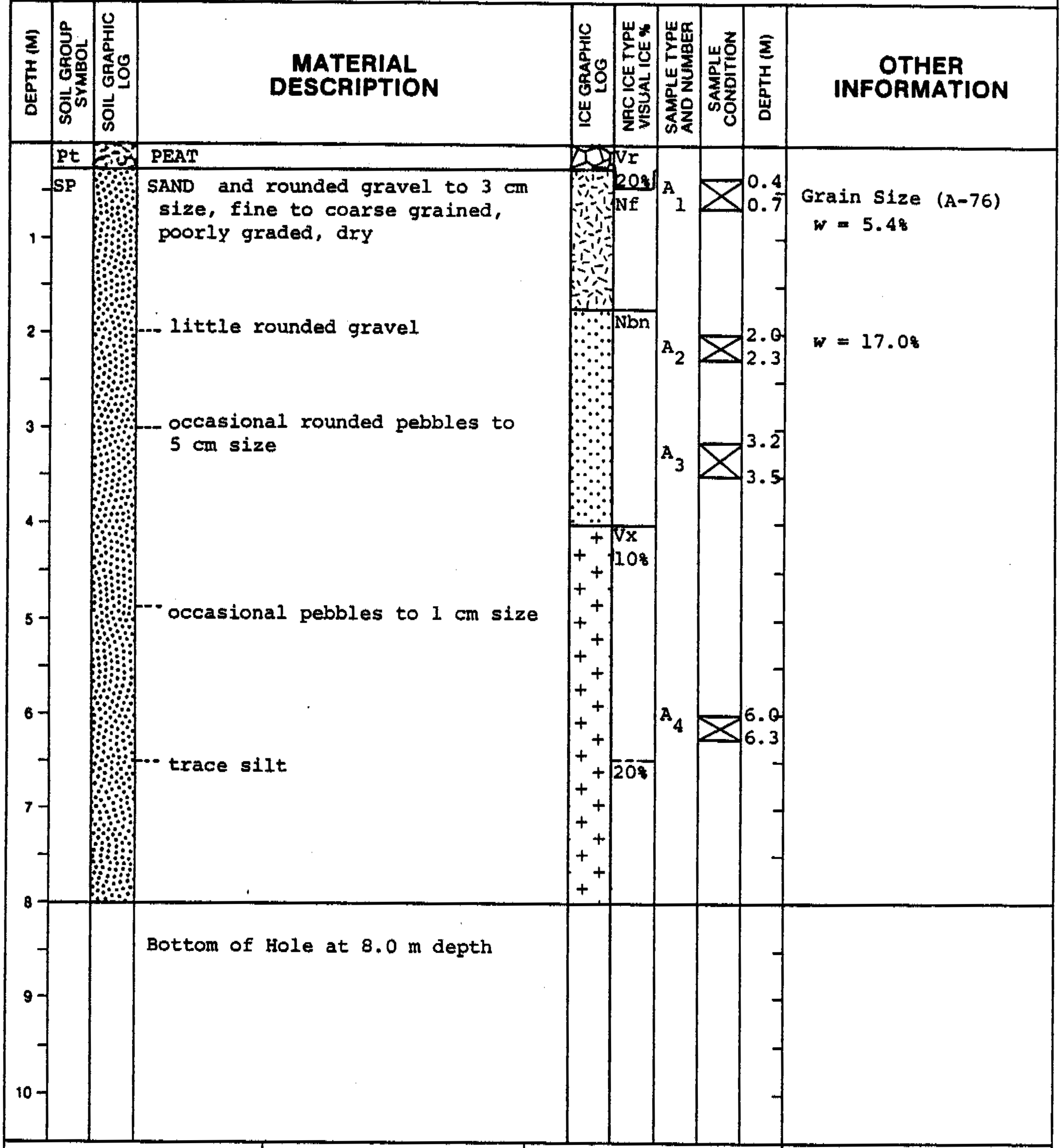
TEST HOLE NO.
28

TEST HOLE LOG 28 a



SOIL GROUP SYMBOL	MATERIAL DESCRIPTION	NRC ICE TYPE VISUAL ICE %	SAMPLE TYPE AND NUMBER	SAMPLE CONDITION	DEPTH (M)	OTHER INFORMATION
Pt	PEAT	Vr				
SP	SAND and rounded gravel to 3 cm size, fine to coarse grained, poorly graded, dry	20% Nf	A 1	☒	0.4 0.7	Grain Size (A-76) w = 5.4%
	little rounded gravel	Nbn	A_2	☒	2.0 2.3	w = 17.0%
	occasional rounded pebbles to 5 cm size		A_3	☒	3.2 3.5	
		Vx 10%				
	occasional pebbles to 1 cm size					
			A_4	☒	6.0 6.3	
	trace silt	20%				
	Bottom of Hole at 8.0 m depth					

DATE: 80.01.25	LOGGED BY: A.C.	DRWN BY: C.G.	CHKD BY: N.H.

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TEST HOLE NO.
28a

APPENDIX B

DATA COLLECTION SITES

Source 160/161 C

Site 1

The high east west trending ridge which separates Source C into two areas. A 0.5 metre deep shovel pit in the centre of this ridge intersected stratified sand and gravel. Sample 1 collected from this pit.

Site 2

The low area in the centre of the north pit. This is just above water level in the pond and the aggregate is wet. The shovel pit is about 0.5 metres deep and intersected stratified sands with silt beds. The active layer is in excess of 1.5 metres.

Site 3

A one meter section on the north side of the thermokarst pond [north pit]. This is about 1.5 metres above water level. The aggregate is dominantly stratified sand with few pebbles. The sand is wet.

Site 4

The same high ridge as Site 1. This is a good 2 metre section with 1.3 metres of fine pebbly gravel overlying sand but it is not possible to be certain how continuous the gravel is. The high mounds south of this site and closer to the lake are dominantly sand. The aggregate in this area is dry.

Site 5

On the east side of the thermokarst pond that occupies the southwest part of Source C. The pond is substantially more extensive than it was in 1985 and appears to be expanding rapidly. There are fresh tension cracks and collapse structures on this side of the pond. There is at least one metre of gravel exposed in a good section just above the pond. There is a small plateau of undisturbed material to the east of this but it dips off into a low wet area and potential to extract more material is limited.

Site 6

In the southeast part of Source C on the north side of the pond. This is a section on the south side of the hill which lies east of Source C. This is not a good section and it is difficult to expose fresh material. There is, however, in excess of one metre of gravel exposed on this slope. There is some lateral variation and 6 metres west of this site sand is exposed at surface. There is gravel below this sand but it is uncertain if this is a lower gravel bed or material that has slumped from above.

Site 7

On the east side of the north pit [Source C]. There is in excess of one metre of gravel exposed in a good section. There is significant lateral and vertical variation from sand with pebbles to pebbly sand to gravel. As at other sites along this slope it is high and dry and there appears to be good gravel. The sample was taken from the section

Site 18

On the east side of the north pit. This is a section with in excess of 1 metre of gravel. Sample collected from section.

Site 19

On the east side of the north pit. This is a section with in excess of 1 metre of gravel. Sample collected from section.

Water depth measurements in the thermokarst ponds

P3----2.6 metres

P4----2.5 metres

P5----1.5 metres

Source 160/161 E

Site 8

This is in the east part of the borrow pit near Lake E. Surface topography is rugged with flat topped hills and wedge shaped troughs. The depth of the troughs is 3-4 metres. Shape and distribution of the depressions would suggest that they reflect melt of ice wedges in an ice polygon network.

Up to two metres of section is exposed at several sites. The material exposed in the slopes is stratified sand and granular sand with some pebbly sections. There is some lateral and vertical variation and gravel beds are present throughout this area. However the aggregate in this area is dominantly sand. This is consistent with the exploration borehole in this area.

Sample 8 is of bedded sand

The active layer is unknown due to difficulties penetrating gravel beds in the sand but exceeds 1.5 metres.

Site 9

This is along the southeast margin of the pit. There is about 1.5 metres of poorly exposed section and it is difficult to determine how much of this is slump. The material appears to be interbedded sand and gravel at the top with more sand at the base of the section. As at site 8 it is dominantly sand

Site 10

Site 10 is at the extreme south end of the pit. There is not as much thermokarst activity here as there is in the centre of the pit or on the east side of the pit. In the base of the pit the active layer is 1.0 to 1.2 metres. The aggregate in this low is dominantly sand.

Sample 10 is collected from a section which is dominantly gravel.

The surface material along this south and southeast flank of the pit is generally pebbly gravel. Sections and pits indicate that this is a capping of less than 0.7 metres over sand. There is one good section, just above the pond and between Sites 9 and 10, with in excess of 2 metres of interbedded sand and gravel. It is difficult to expose fresh material on this slope and therefore the amount of gravel is uncertain.

Site 11

This is a two metre high plateau at the west side of the largest pond and just south of the ridge which separates the pond from the lake. There is a one metre section of bedded sands and gravels. It is difficult to expose a fresh section but there appears to be 0.6 metres of gravel.

The depth of the active layer is unknown due to difficulties probing through gravel

Sample 11 is collected in a shovel pit.

Site 12

This is a section on the extreme west end of the borrow pit, The total section exposed is about 2.5 metres but only the top 0.6 metres is fresh material. The aggregate is bedded sand and gravel, dominantly gravel. There may be some good aggregate here but it is close to the edge of the hill and 15 metres further to the west is low ground. Extractable aggregate may be limited.

Water depth measurements in the thermokarst ponds

P2----2.5 metres

Source 160/161 F

Site 15

On the west side of the north pit in a linear depression on the edge of the area of extraction and at the edge of the push pile of organic material.

The active layer is 1.5 metres in the borrow pit.

Site 16

Sample of gravel taken at the base of the south pit.

Site 17

South pit--0.5 metres of gravel overlying sand

The active layer is 1.6 metres in the borrow pit

Source 160/161 G

The surface of the borrow pit is 2 to 3 metres above water level in the pond.

In the more southerly part of the pit the active layer is 1.3 metres. In the north part of the pit the active layer is 1.65 m.

Water depth measurements in the thermokarst ponds

P1----2.1 metres

Source 160/161 H

Site 13

Sample taken from the side of the trench in the south pit at Source H

The active layer is 1.2 metres in area with minor organics at surface

Source 160/161 North

Site 20

On the west side of the east pond. The borrow pit is flat topped with deep water filled depressions. The flat areas area appear to be the base of the pit and all depressions are assumed to reflect post extraction collapse. Depth from top of the slope to water surface is 3 to 3.5 metres. Water depth in the pond is 3.3 metres. The total depth is 6 to 7 metres.

On the margins of the pond there are tension cracks and linear depressions The margins of the pond appear to be actively eroding. Shrubs drowned but still growing in the pond suggest that water level has risen or the bottom of the pond dropped. The shorelines show no sign of a raised water table and the margins are actively eroding.

At a section there is 0.6 metres of gravel over silt with a thin cap of sand over the gravel. The sample is of this gravel.

At a small pond in this area abandoned high water marks suggest that water level has dropped 0.6 to 0.7 metres

Site 21

There has been some drainage from the north side of the pit into the organics in the low area. Erosion associated with this water flow appears to have opened some of the ice wedge polygons.

Site 22

On the east side of the pond. It does not appear that any material has been extracted from the fringe between the borrow pit and Pikiolik Lake but the organics have been slightly disturbed, presumably during extraction activities. In some parts of the fringe most of the organics are gone. Revegetation is taking place in these areas. The active layer along this fringe where there is almost no organics is at 1.2 metres in sand. Further south along this slope there are some organics left on surface and the active layer is at 0.42 metres. The distance from the borrow pit to the break in slope is 12 to 13 metres. This is the only protection between the pond and the lake. It is not possible to determine how far this may erode but there are ice wedge cracks in the fringe and the margin is collapsing in some places.

Site 23

On the southeast side of the borrow pit Bedded sands and gravels. The distance between the borrow pit and the break in slope is less than 5 metres.

Site 24

On the south side of the borrow pit. Distance from the borrow pit to the edge of the slope is 5 metres. There are several depressions in this area that probably reflect the intersections of ice wedges. The depth of two dry linear depressions in this area are 1 to 1.5 metres and 2 to 2.5 metres. Some of these are water filled and show a high level water mark in the pond These ponds have no outlet and depression in water level likely reflects a change in the water table. This in turn may reflect the lowering of the active layer during the thaw season. The distance from present water level to the high water mark is 0.6 metres. This is consistent with the depression of the active layer at other sites in the Tuktoyaktuk region.

Aggregate in this area is sand with a few thin gravel beds In the area where the organics have been disturbed but not completely removed the active layer is 0.68 meters. The active layer in a linear depression is 1.02 metres.

Site 25

The north side of the pit between the two ponds. The area is flat topped with linear depressions. One of these depressions is approximately 2 metres deep. Depth of water is approximately one metre and high water mark is 0.6 metres above present water level.

The active layer on the north side is 0.46 metres in undisturbed ground and 1.1 metres in sand in the borrow pit. Most of the aggregate is sand but the sample is of gravel from a section.

Site 26

On flat ground on the north side of the deposit. This area was opened by 1981. Near the edge of the deposit organics have been stripped back but here does not appear to have been much aggregate removed. This region has changed very little since 1985 and appears to be nearly stable.

In the large central pond water depth is 1.3 metres in the north and 0.7 metres in the south part. Depth from water surface to pit surface is 3 to 4 metres and total depth of this depression is 4 to 5 metres.

Active layer is at about 0.84 metres in sand in disturbed ground with minor organics remaining on surface.

Site 27

At the west end of the borrow pit. Grasses are well established where there is only minor organic material. Active layer at 1.0 metres. Throughout much of this area the active layer is difficult to determine due to problems penetrating thin gravel beds.

Site 28

On the south side of the borrow pit. This part of the deposit has changed very little between 1985 and 1991. There are two channels from the borrow pit to Fresh Water Creek. The water presently flowing through the main outlet is just a trickle and this seeps into the sand above the creek. The depth of the channel is 4 to 4.5 meters. The channel originates at the west pond but there was no surface water flow from this pond in September 1991.

In the west pond high water mark is 0.5 metres above present water level.. Throughout this area the side slopes are fairly stable and the pond may not be expanding.

There are several dry depressions in this area The dry depressions may reflect a low water table near the steep slope to the creek Active layer in one dry pond is 1.8 metres. The active layer with some organics at surface is 0.48 metres

29

The small pit south of the main borrow pit. There are a few depressions that may reflect melt out of ice wedges but they are less than 0.3 metres deep. Grasses are reestablishing in this pit

Water depth measurements in the thermokarst ponds

P6----3.3 metres

P7----1.3 metres

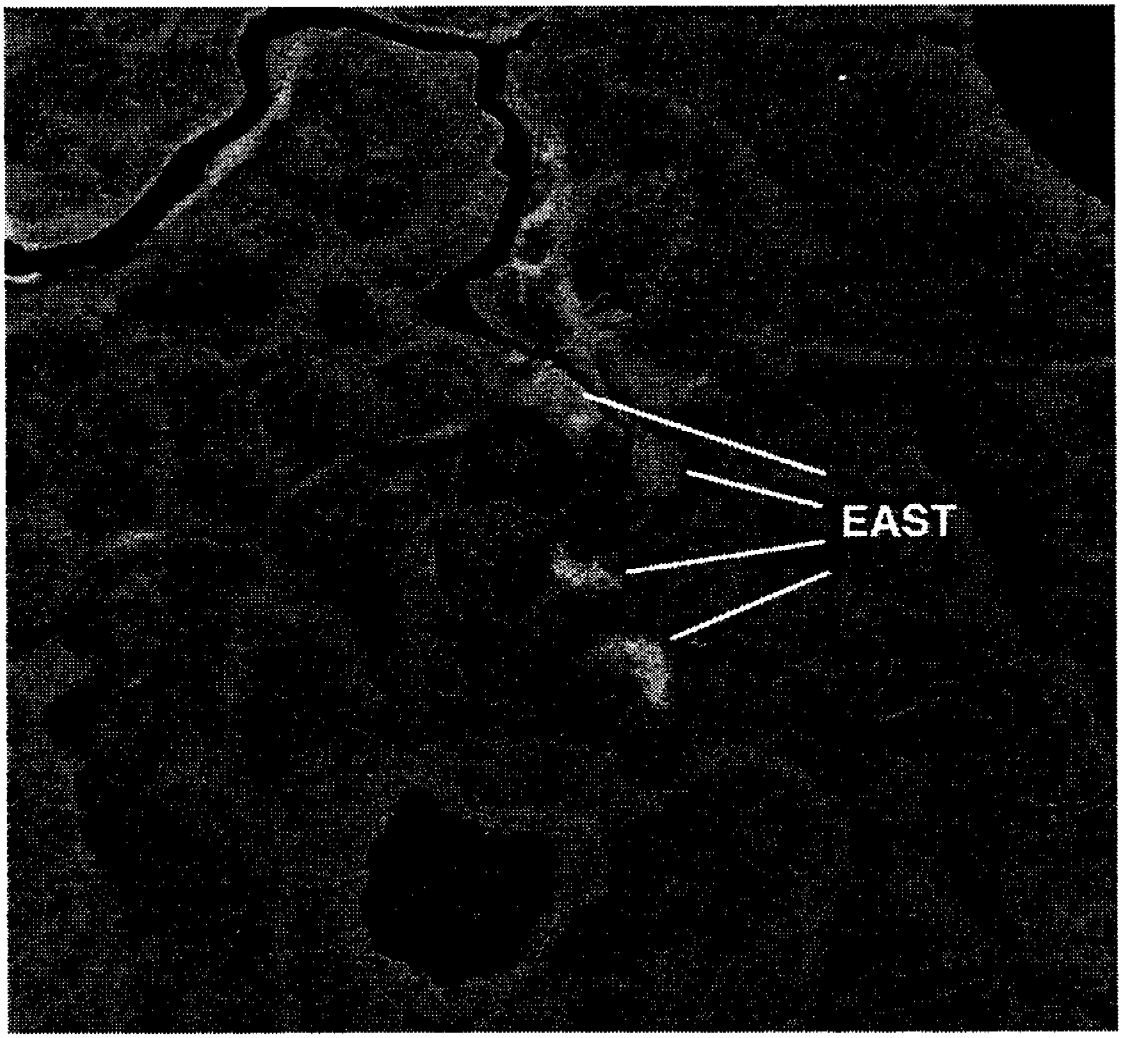
P8----0.7 metres

APPENDIX C

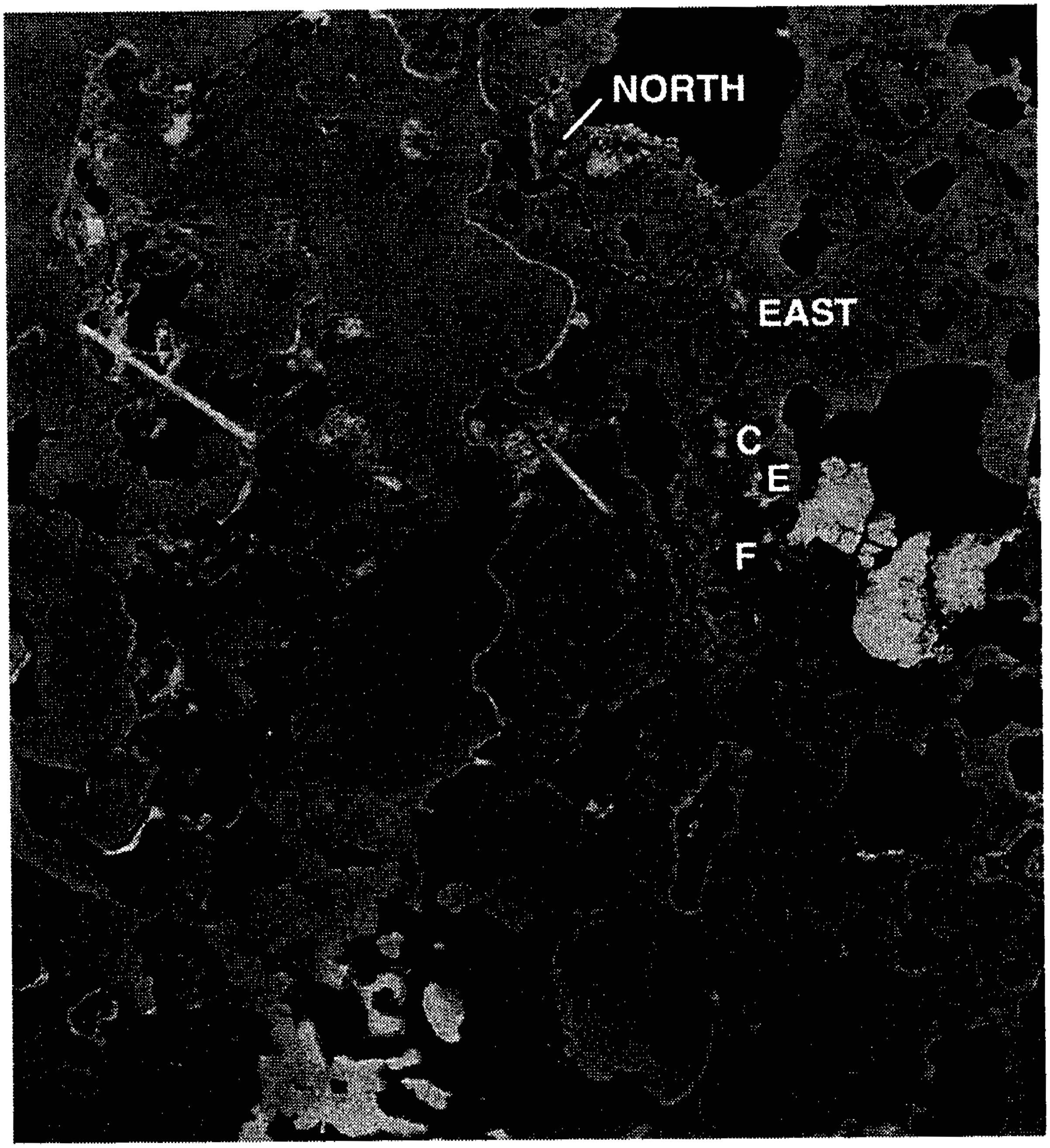
GRAIN SIZE ANALYSIS

APPENDIX D

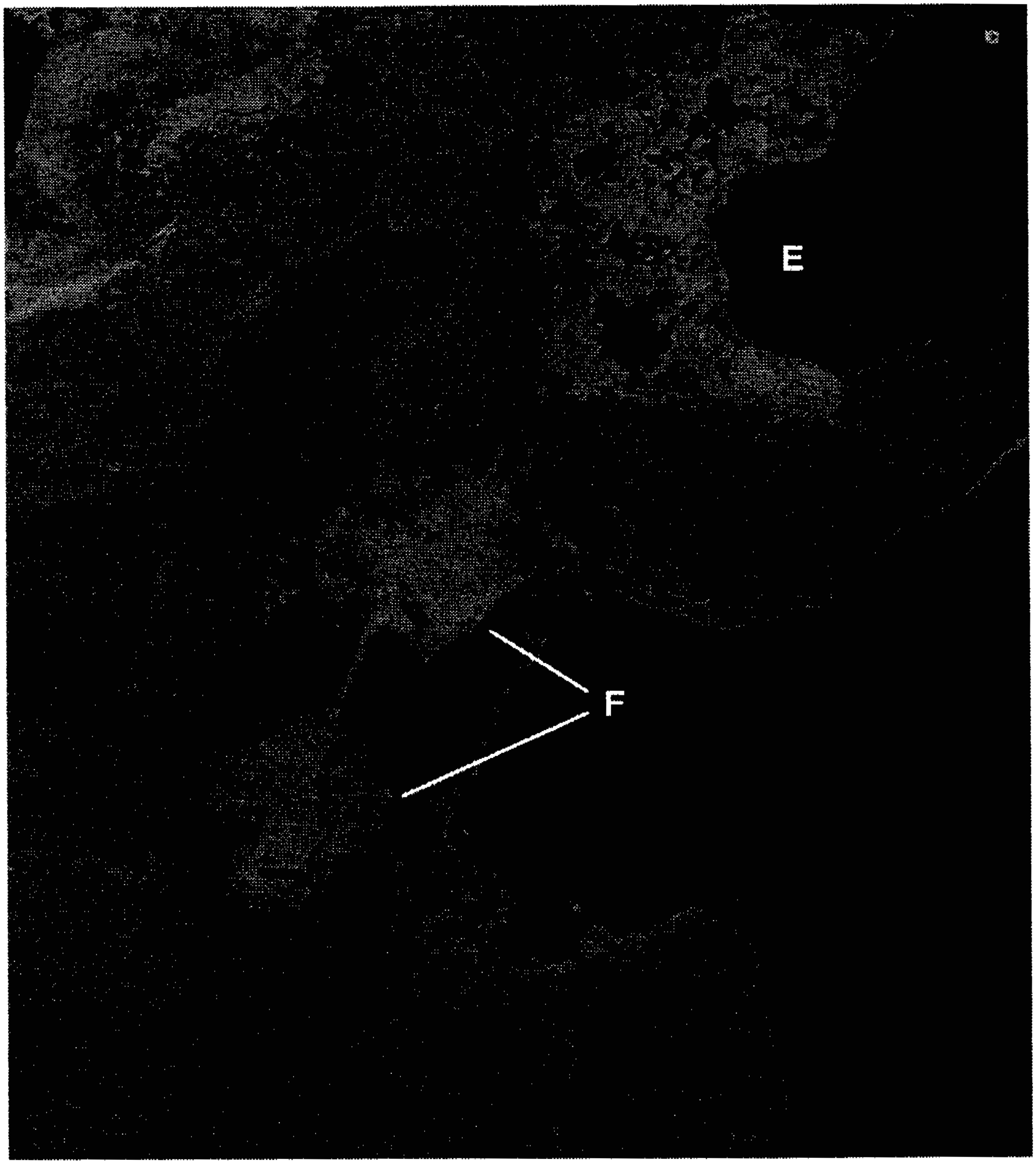
AERIAL PHOTOGRAPHS



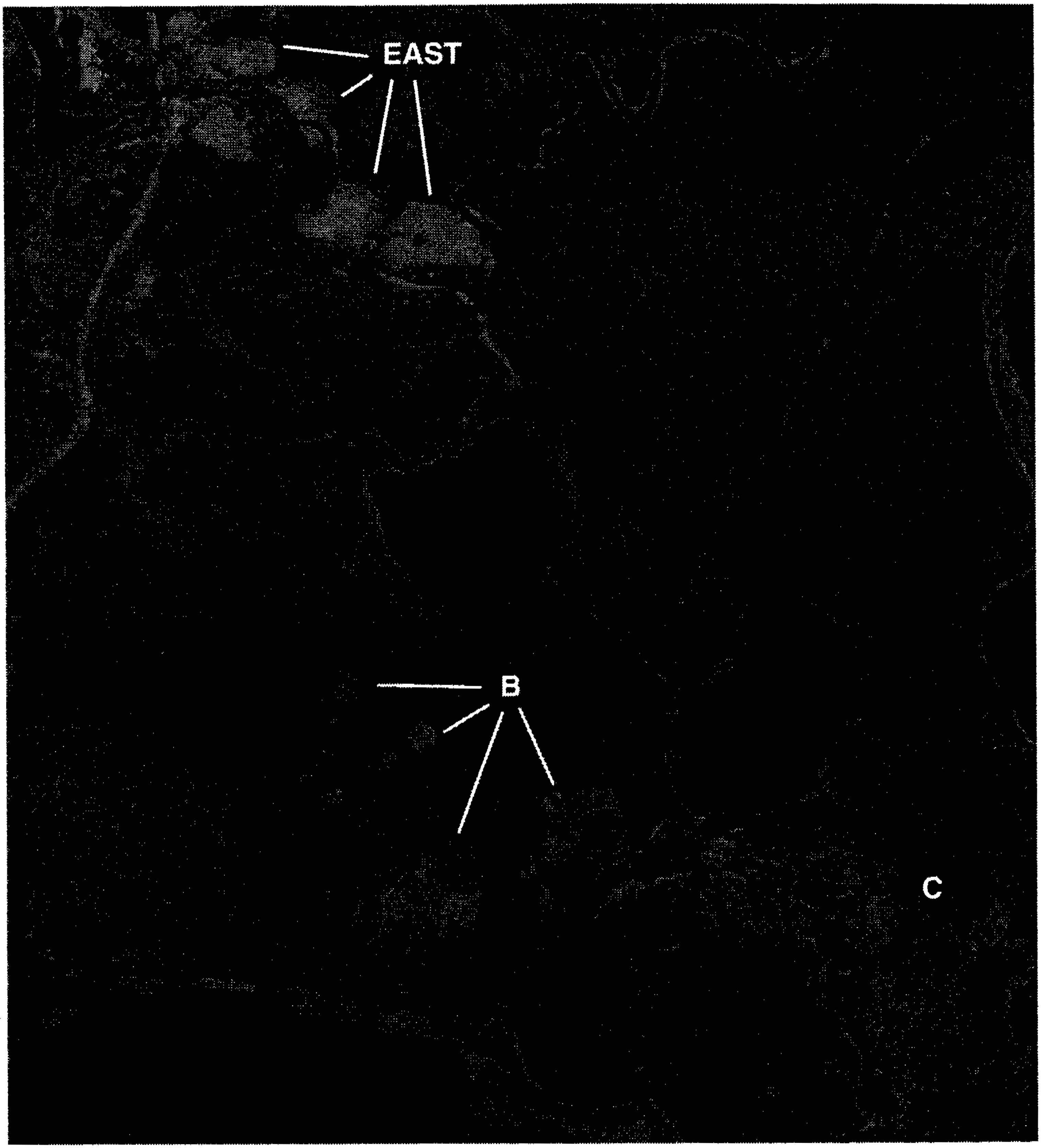
Aerial Photograph A23850-71
Source 160/161
Photograph taken July 1974
Scale 1:5,600



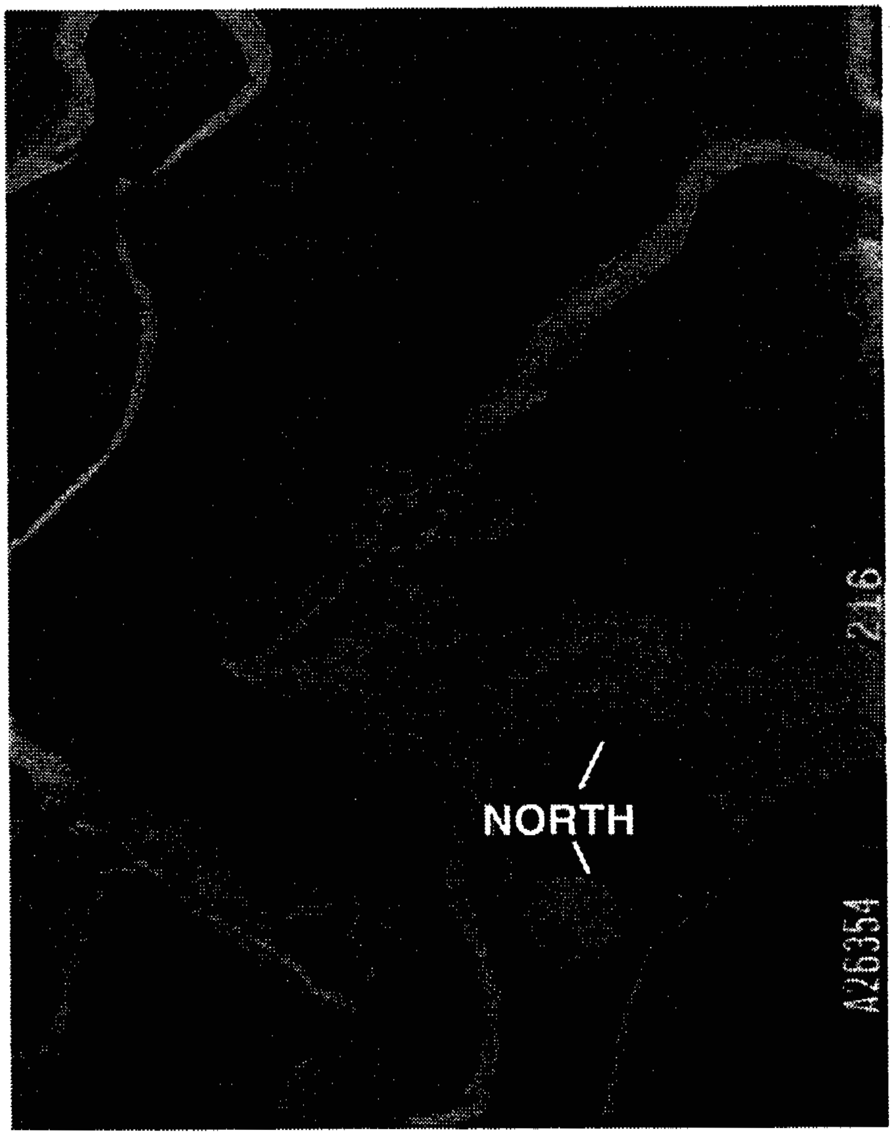
Aerial Photograph A25776-78
Source 160/161
Photograph taken June 1981
Scale 1:50,000



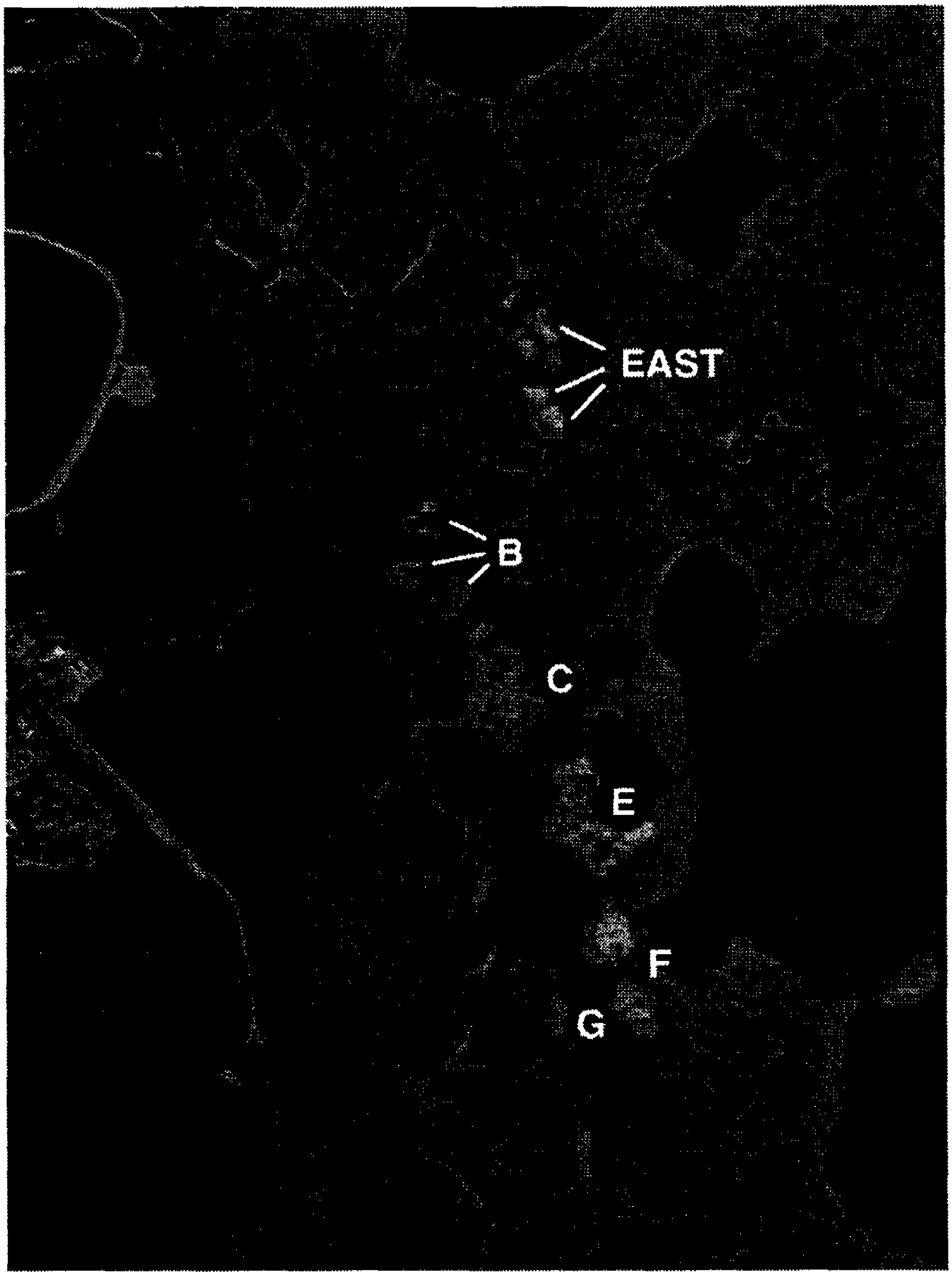
Aerial Photograph A26354-237
Source 160/161
Photograph taken July 1983
Scale 1:5,000



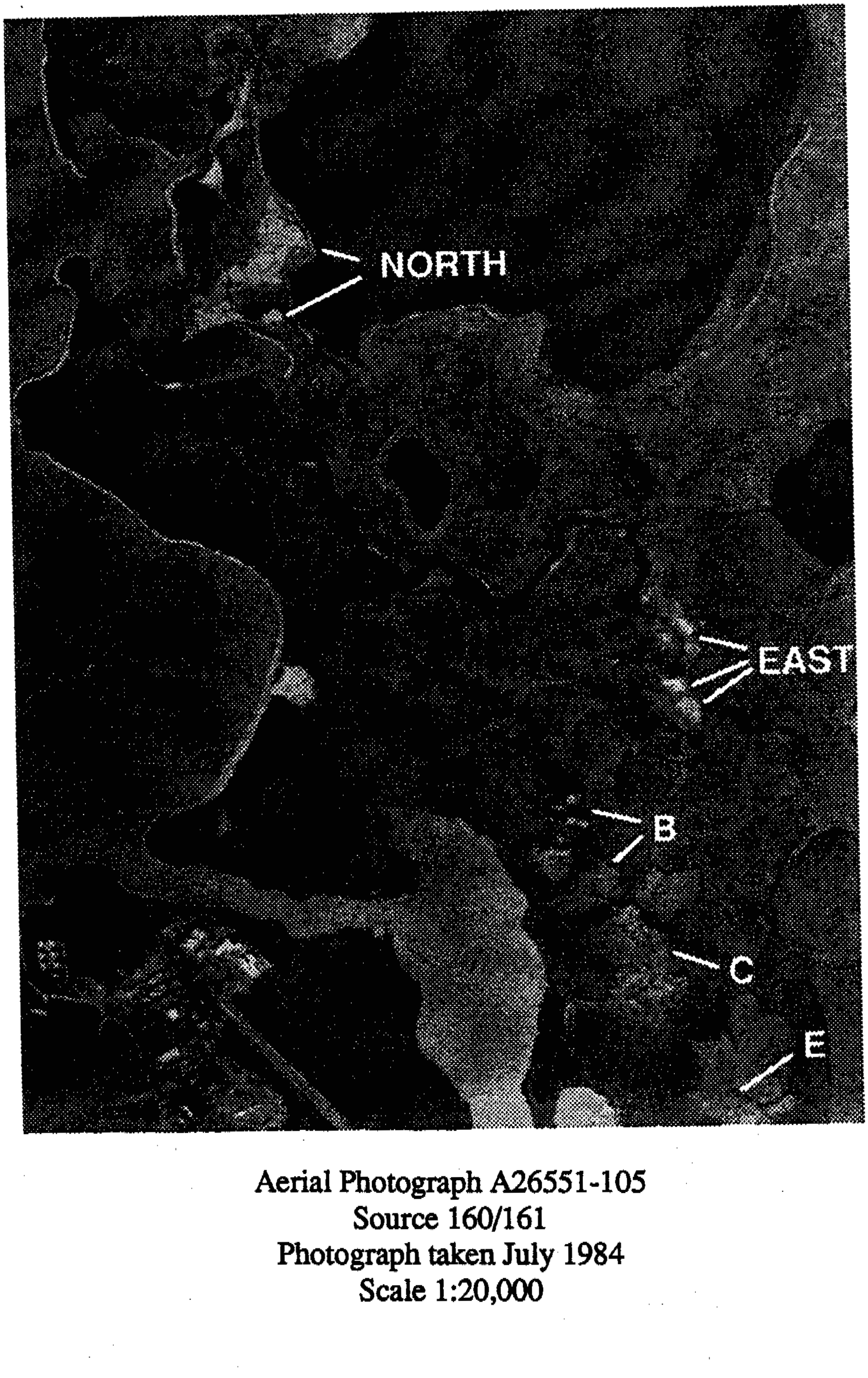
Aerial Photograph A26354-211
Source 160/161
Photograph taken July 1983
Scale 1:5,000



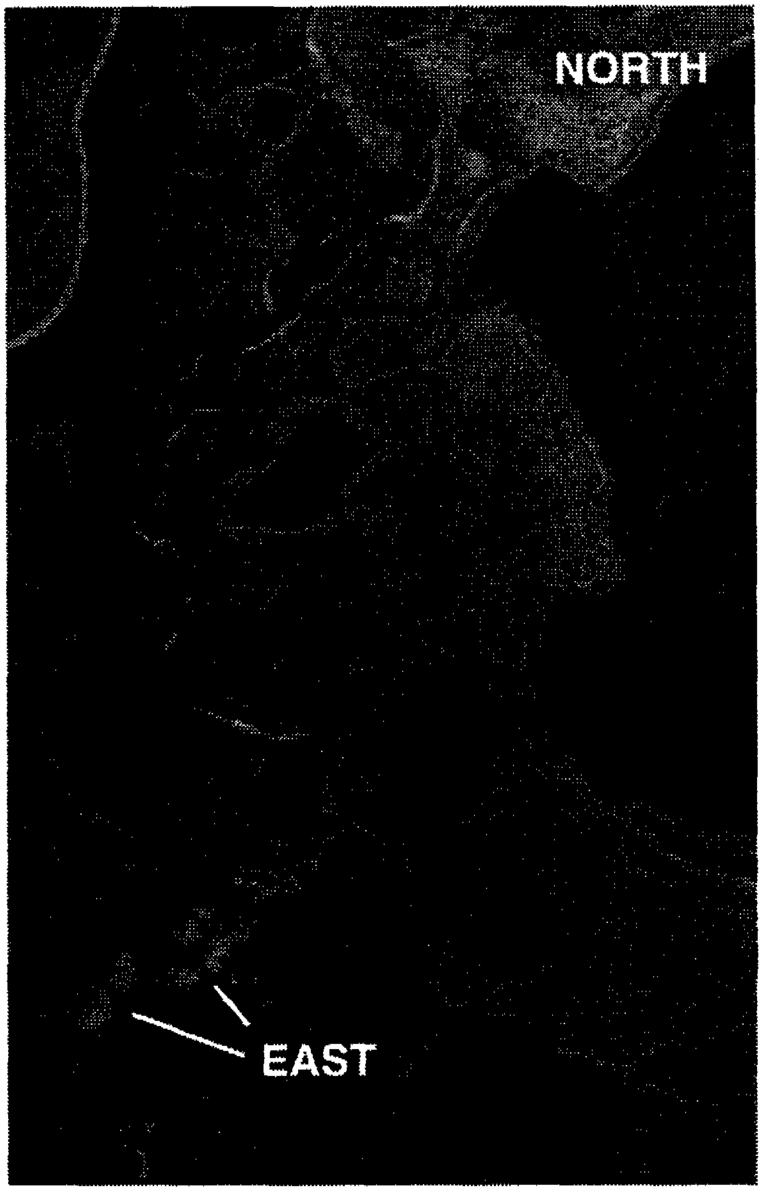
Aerial Photograph A26354-216
Source 160/161
Photograph taken July 1983
Scale 1:5,000



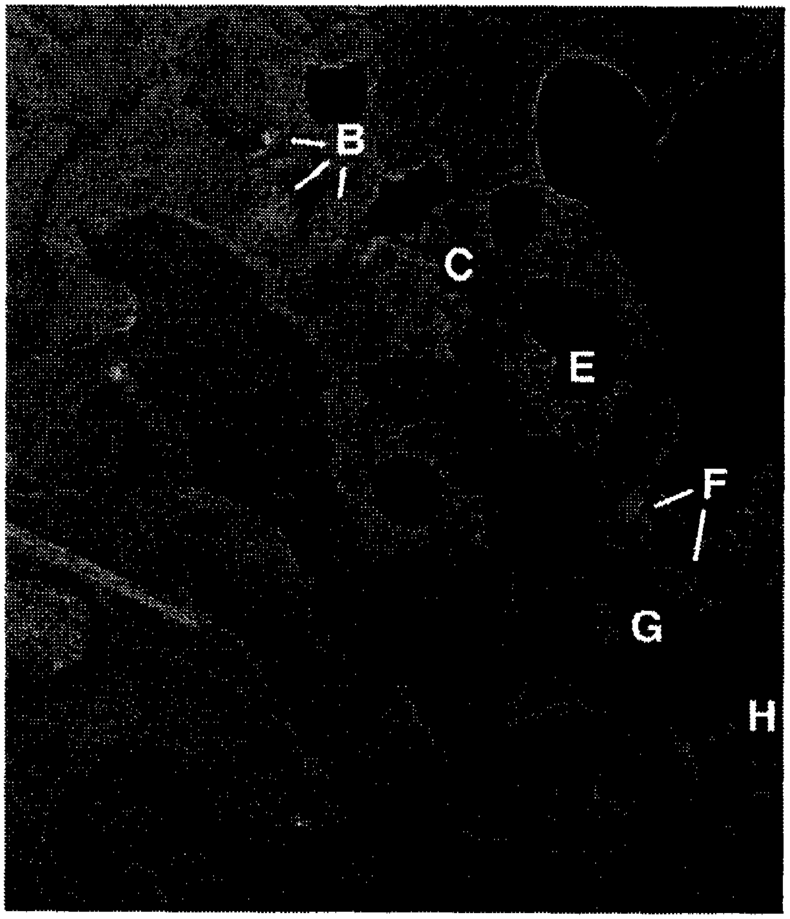
Aerial Photograph A26551-106
Source 160/161
Photograph taken July 1984
Scale 1:20,000



Aerial Photograph A26551-105
Source 160/161
Photograph taken July 1984
Scale 1:20,000



Aerial Photograph A26732-88
Source 160/161
Photograph taken July 1985
Scale 1:15,000



Aerial Photograph A26732-86
Source 160/161
Photograph taken July 1985
Scale 1:15,000

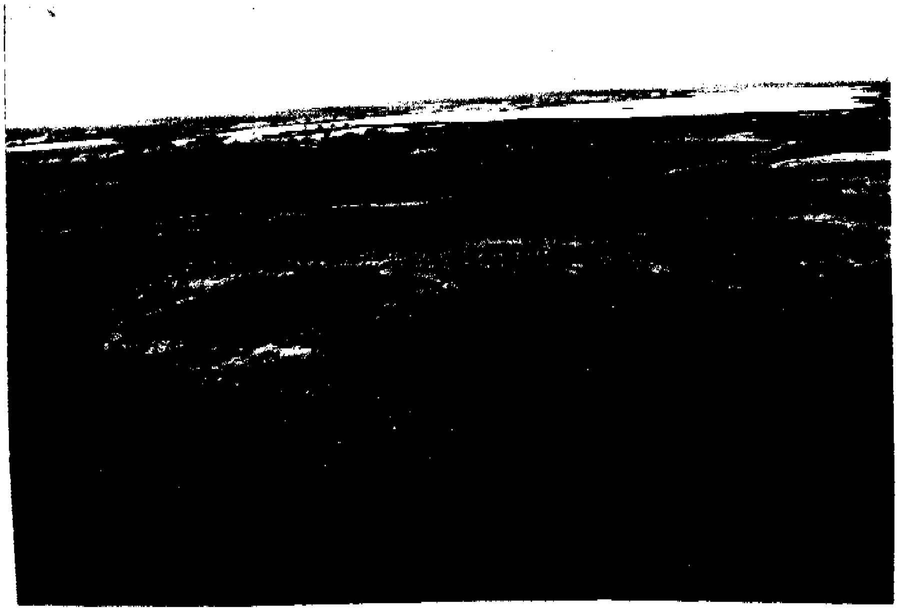
APPENDIX E

HELICOPTER AND GROUND PHOTOGRAPHS

Photograph 1. Aerial view of borrow pits 160/161 C, E, F and G looking west, June, 1991. Kudluk Lake is in the near foreground.

Photograph 2. Aerial view of Fresh Water Creek and borrow pit at 160/161 West, looking northwest, June, 1991.

Photograph 3. Aerial view of borrow pit 160/161C, looking south, September, 1991. The thermokarst ponds, the ridge between the pond and Lake C the ridge in the centre of the pit and the hill on the east side of the pit area shown. Lake C is in the foreground.



Photograph 4. Aerial view of borrow pit 160/161C, looking west, September, 1991. The new vegetation growth on the disturbed organic fringe is visible by its lighter tone.

Photograph 5. Aerial view of borrow pit 160/161E, looking west, September, 1991. The narrow ridge between the thermokarst pond and Lake E is shown in the centre of the photograph. Lake E is to the right in the photograph.

Photograph 6. Aerial view of the southern borrow pit at 160/161F, looking north, September, 1991.. Note the thermokarst ponds and the new vegetation growth on the disturbed organic fringe is shown.

Photograph 7. Aerial view of the northern borrow pit at 160/161F, looking northwest, September, 1991. The new vegetation growth on the disturbed organic fringe is shown. Kudluk Lake is in the right foreground.

Photograph 8. Aerial view of the borrow pit at 160/161G, looking east, September, 1991. The southern borrow pit at 160/161F is visible in the background.

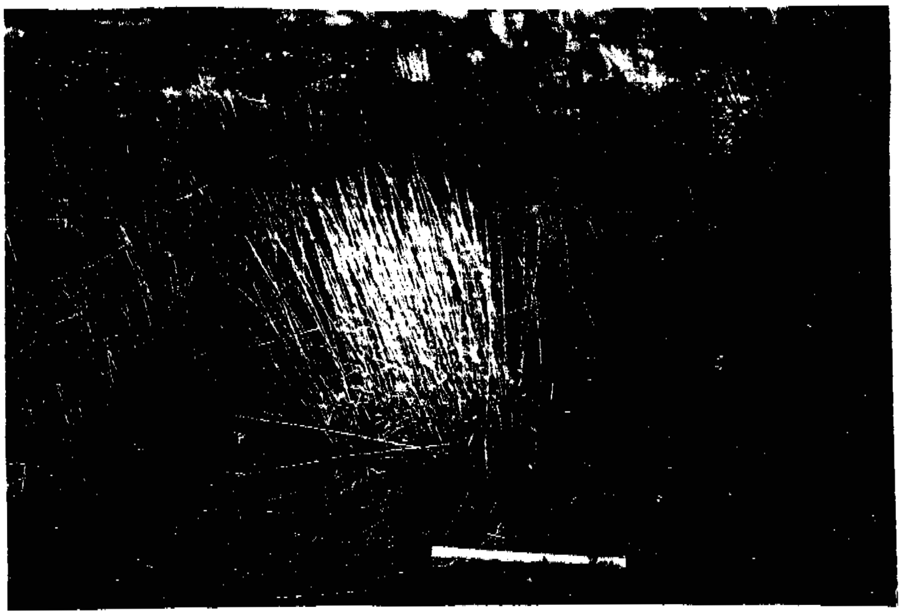
Photograph 9. Aerial view of the borrow pit at 160/161 North, looking south, September, 1991. The two thermokarst ponds are visible. Pikiolik Lake is to the left and Fresh Water Creek to the right.

Photograph 10. Section in coarse granular aggregate on the east side of 160/161 C.

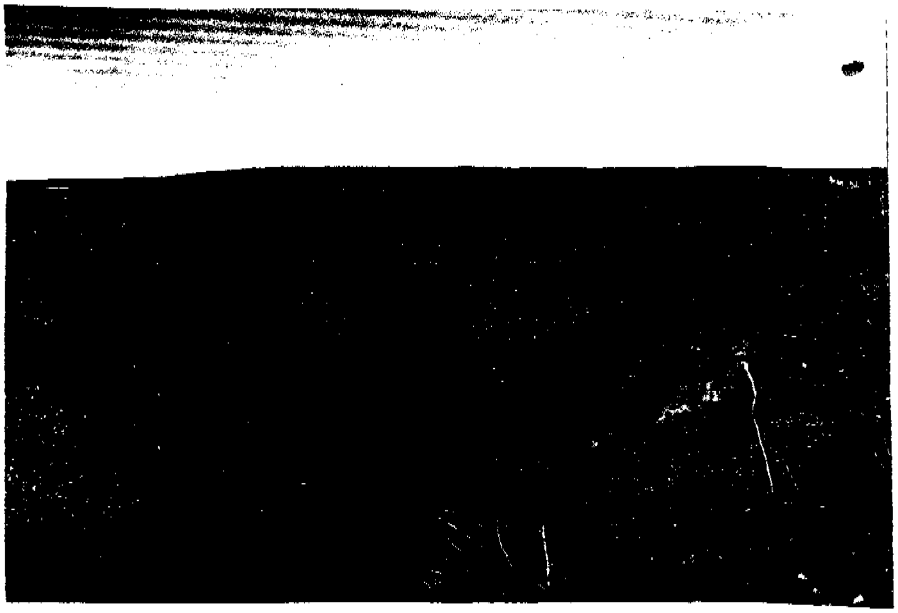
Photograph 11. Section at 160/161 North showing granular aggregate overlying sand. Note shovel for scale.

Photograph 12. Borrow pit 160/161 North showing typical unvegetated surface and linear depression.

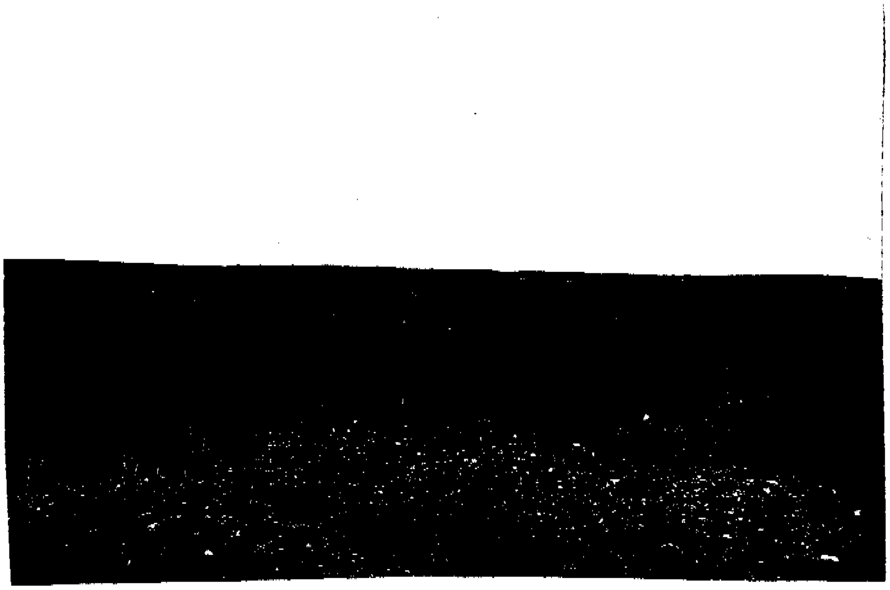
Photograph 13. Typical new vegetation growth along the disturbed fringe of the borrow pit where there are some organics at surface. Unvegetated surface of the borrow pit in the background.



Photograph 14. Close up view of grass that grows in areas disturbed by borrow pit activities. Note shovel for scale.

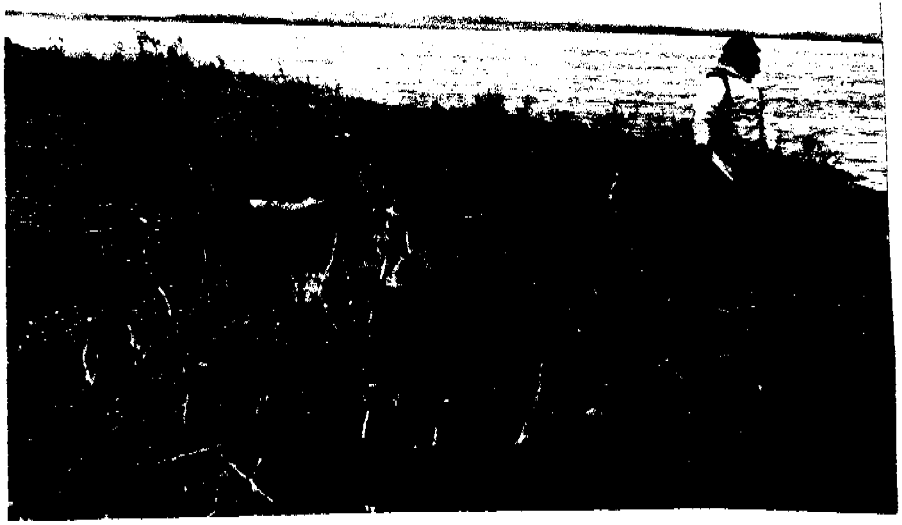


Photograph 15. Deep wedge shaped depression on the east side of 160/161 C. Note person for scale.



Photograph 16. Thermokarst pond at 160/161 E looking north across the narrow ridge to Lake E. Person in the right cente of the photograph for scale.

Photograph 17. Thermokarst depression on the east side of 160/161 North showing drowned vegetation.



Photograph 18. Sparsely vegetated margin between Pikiolik and the borrow pit at 160/161 North.

Photograph 19. Drainage channel from the western thermokarst pond at 160/161 North to Fresh Water Creek. Note person in the upper left of the photograph for scale

APPENDIX F

MAPS AND FIGURES

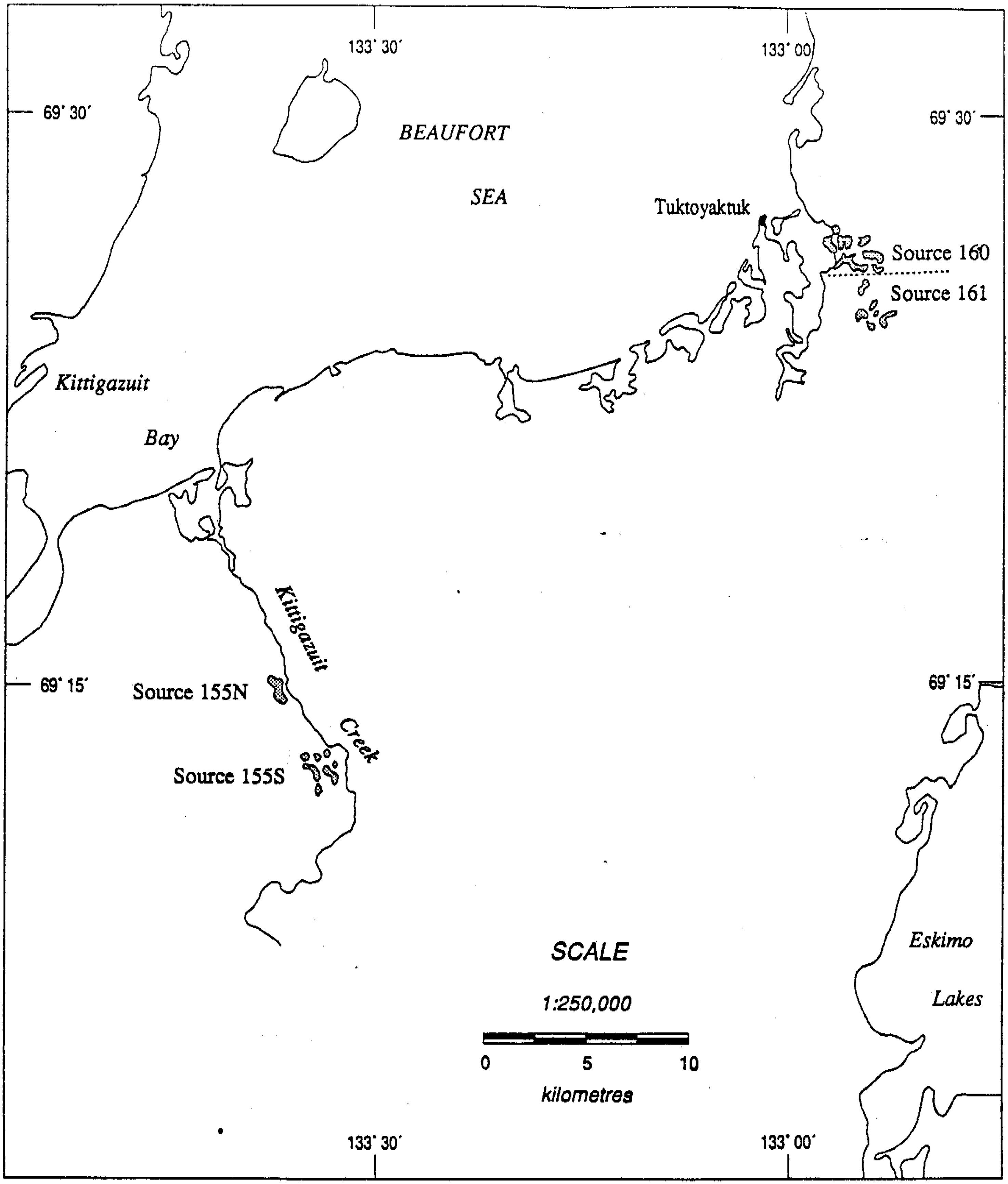


Figure 1. Location map (modified after Hardy 1986)

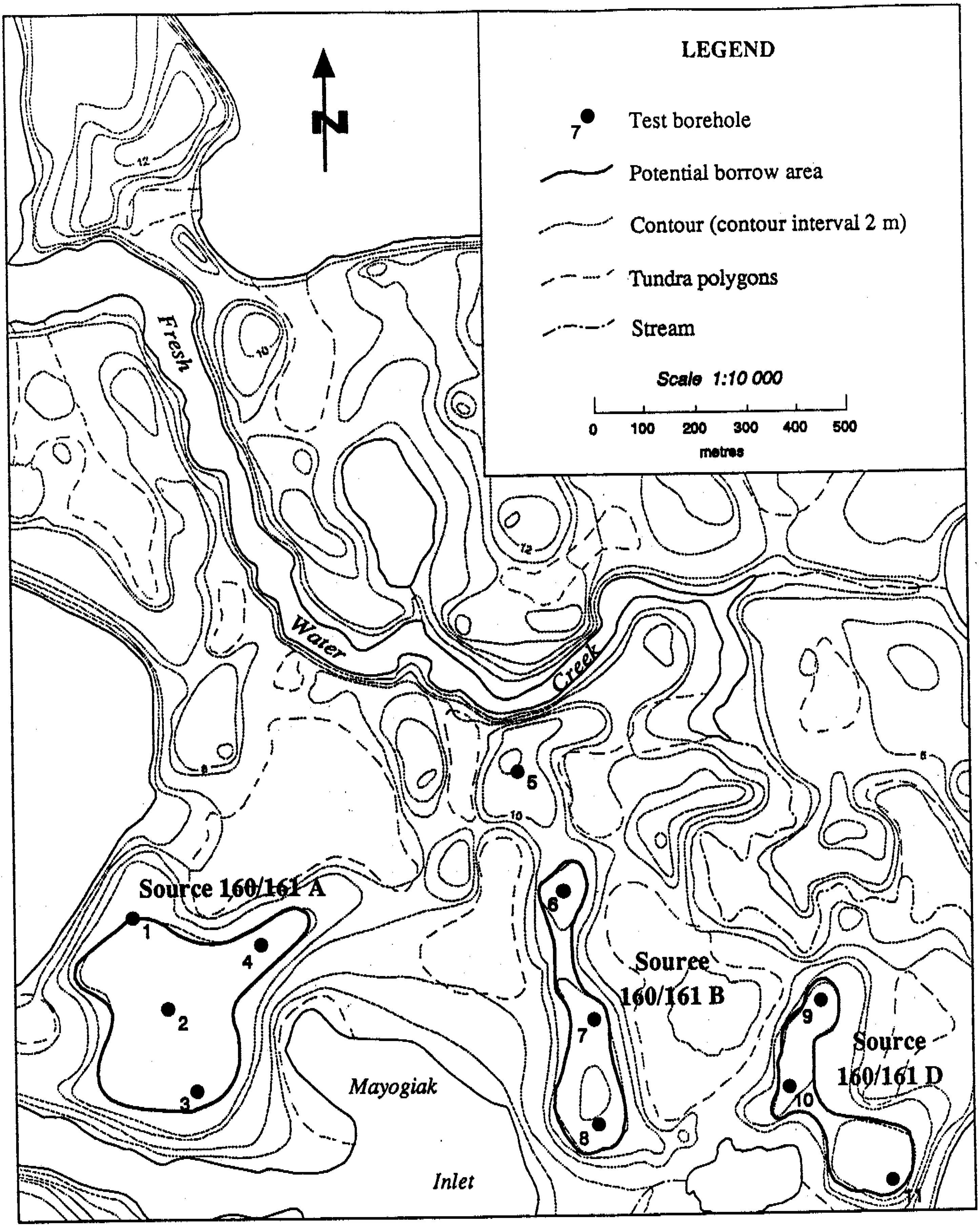


Figure 2 (North): Test boreholes and potential borrow areas. Modified after Hardy (1980).

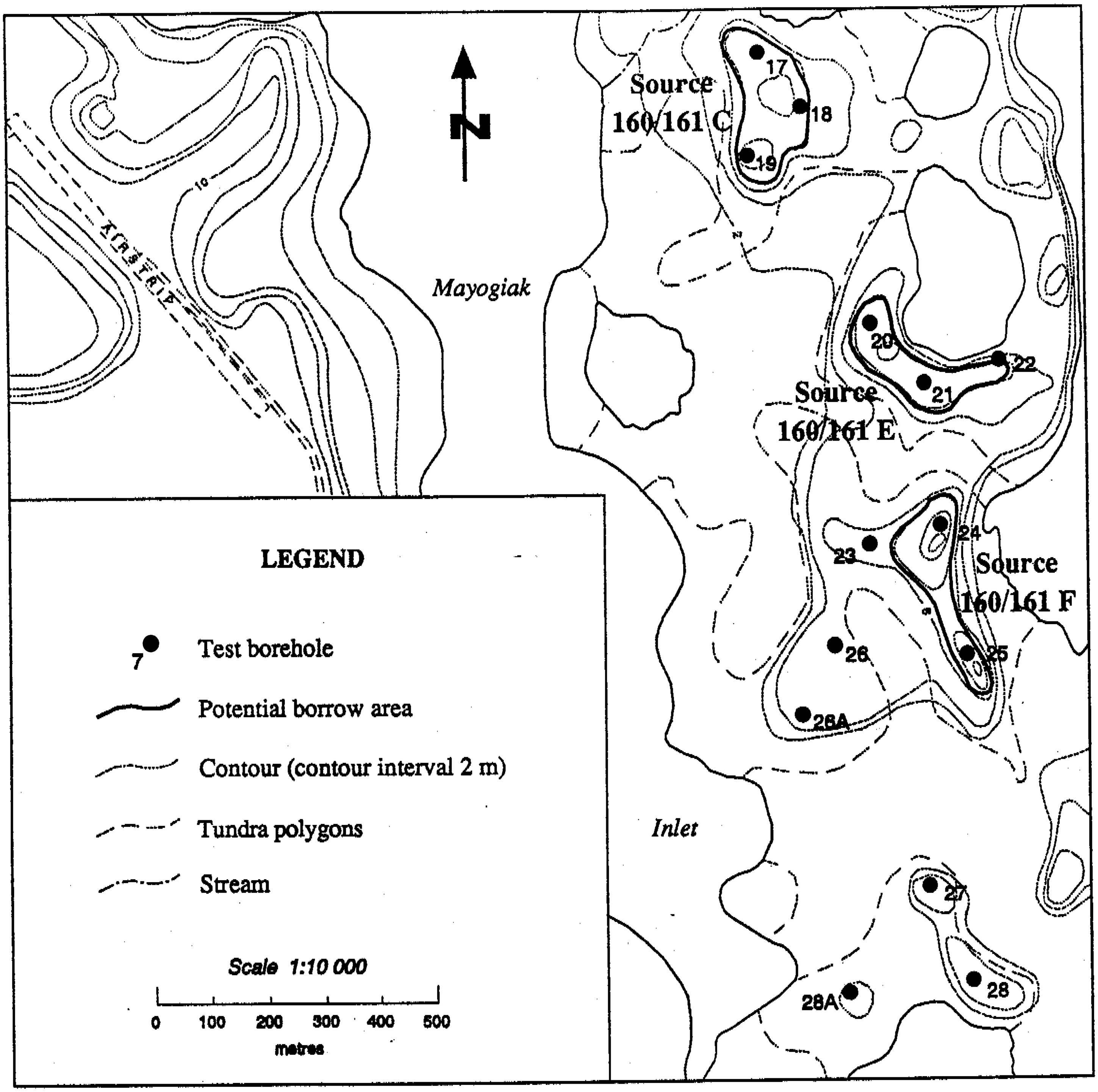


Figure 2 (South): Test boreholes and potential borrow areas. Modified after Hardy (1980).

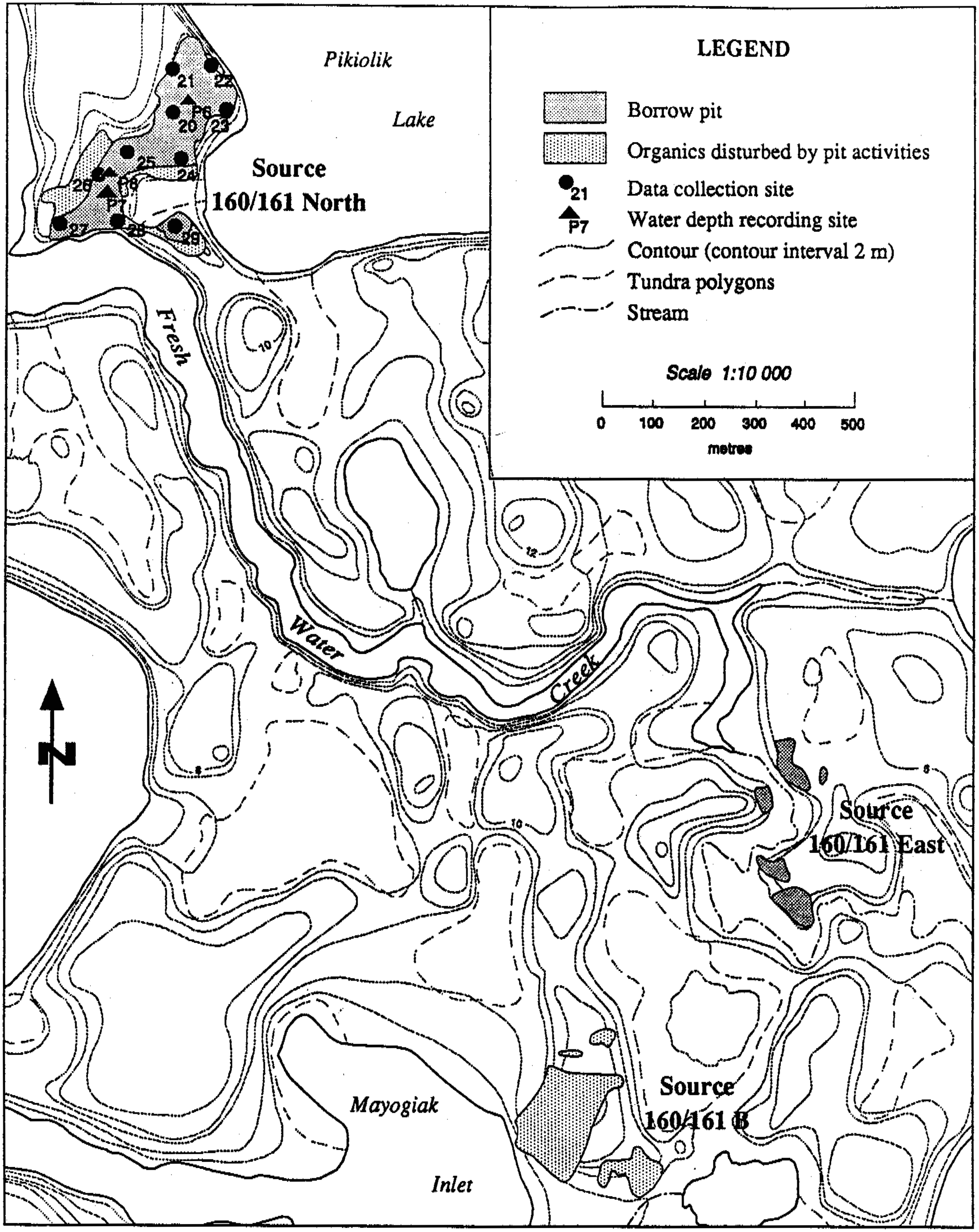


Figure 3 (North): Extent of the borrow pits and of fringe areas disturbed by borrow pit activities based on 1983 and 1985 aerial photographs. Data collection sites and water depth recording sites from 1991 field surveys.

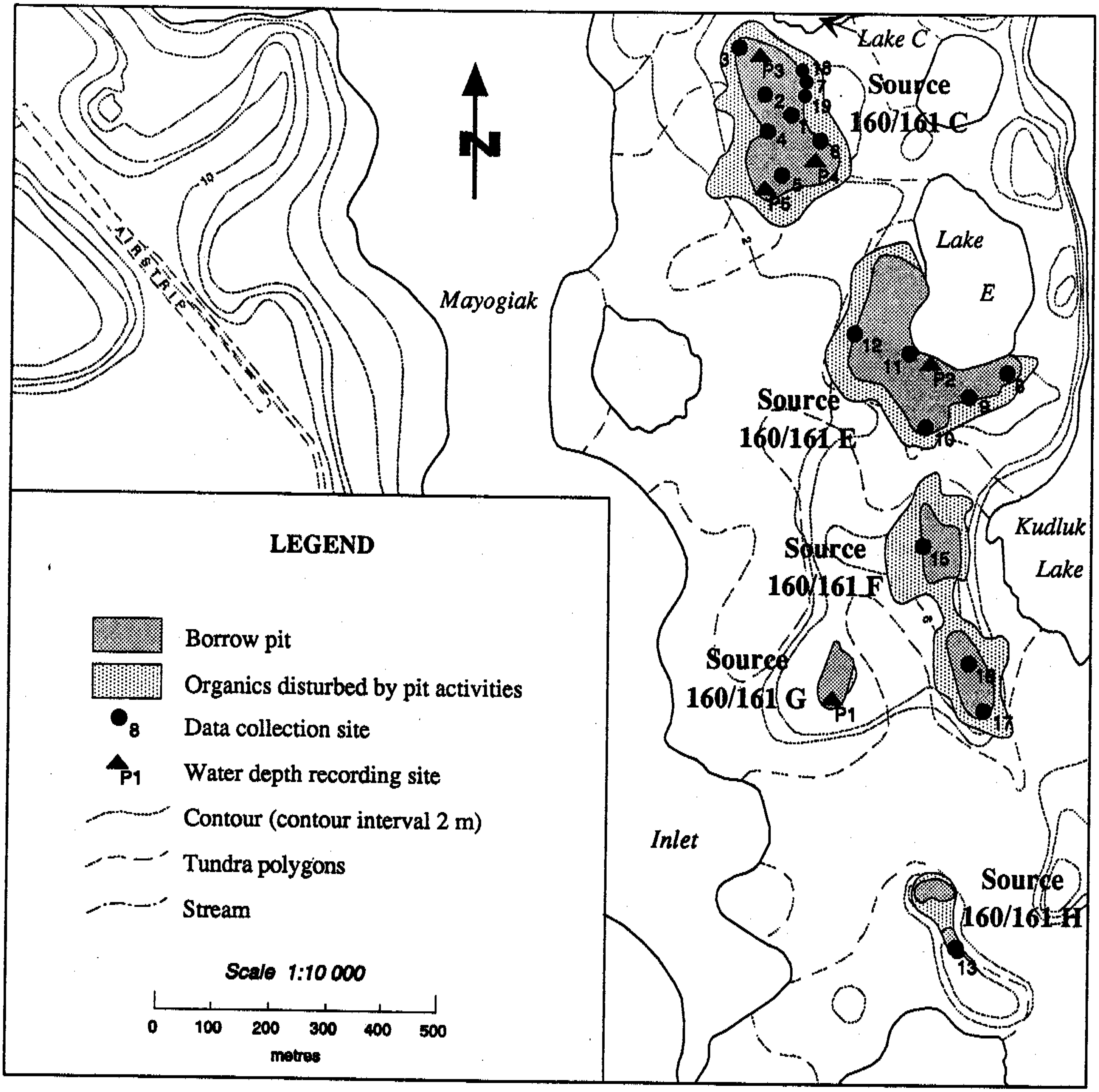


Figure 3 (South): Extent of the borrow pits and of fringe areas disturbed by borrow pit activities based on 1983 and 1985 aerial photographs. Data collection sites and water depth recording sites from 1991 field surveys.