E03

Permafrost Research and Monitoring Stations

Northern West Kitikmeot - Slave Geological Province

Report of Field Activities

1995/96

Prepared for

Land Administration

DIAND, NWT Region, Yellowknife

Prepared by

Wolfe, S.A., Terrain Sciences Division

Geological Survey of Canada

SUMMARY

In the summer of 1995, a permafrost research project was initiated in the northern West Kitikmeot - Slave Geological Province through a cooperative agreement between DIAND, Land Administration and Terrain Sciences Division. Utilizing an existing NATMAP project for logistics, a permafrost component was incorporated into the surficial geology program in the Coppermine (86O, east half) and Kikerk Lake (86P) map sheets. This report of activities describes preliminary observations on permafrost and geotechnical conditions based on initial field investigations, and highlights the monitoring sites installed for permafrost and climatic monitoring. The report further outlines future research needs and presents a preliminary proposal for 1996-97.

Based on the surficial mapping, till blankets and veneers are the most common surficial sediments. Glaciofluvial deposits are also common and serve as potential aggregate resources. Permafrost features associated with these units include mudboils and well developed solifluction lobes on till. Coarse grained glaciofluvial and deltaic deposits typically contain large ice-wedge polygons with wide and deeply incised troughs. These features may be the result of partial or complete meltout of underlying wedge ice or could signify the presence of massive ground ice at depth resulting in a widening of the troughs through creep deformation of the underlying ice. Marine blanket deposits comprised of clayey silt cover much of the coastal plain and are typically ice-rich in the upper 1.5 m with small retrogressive thaw flowslides. These permafrost features and processes have numerous implications with respect to potential development in the region, stemming from the active slope processes and potentially thaw-sensitive materials. Results from the permafrost and climate monitoring stations, to be released at a later date, will provide seasonal temperatures in permafrost and active layers on a variety of terrains, and may assist in determining the susceptibility of the terrain to thermal disturbance.

INTRODUCTION

Ongoing geological exploration and development in the central and north Slave Geological Province have resulted in the need for a wide range of baseline information. In response, Land Administration (DIAND) and Terrain Sciences Division (GSC) has initiated a cooperative permafrost research initiative in the West Kitikmeot - Slave Geological Province. This project is another step towards filling the geoscience information gaps in the West Kitikmeot/Slave Region, and complements the surficial geology National Mapping (NATMAP) Program that is currently providing regional data on surficial materials. A permafrost component was incorporated into the 1995 surficial mapping in two 1:250 000 map areas covering Coppermine (86O, east half) and Kikerk Lake (86P) (study area 1 in Fig. 1). Permafrost and terrain information is particularly relevant in this area because of increasing prospects for development, including a proposed a winter road and marine port facility along the Coronation Gulf coast (Fig. 2).

METHODS

Permafrost and terrain information was gathered in association with the surficial mapping, through helicopter-assisted traverses and interpretation of 1:60 000 airphotos. Permafrost features, observations on bedrock weathering, terrain disturbance and drainage were described (as per Table 1) in addition to the surficial geology and sediment composition at approximately 240 till and surficial sediment sample locations (Fig. 2). Sediment samples were taken for grain size analysis, moisture content and basic engineering properties. Till samples were collected predominantly from pits dug in mudboils at depths of 0.2 to 0.9 m and additional samples were collected at the base of these pits if frozen ground was encountered. Approximately 30 samples of surface water, snow, icing ice, wedge ice and ice-rich sediments were collected for isotopic and geochemical analysis. A CRREL corer was used to obtain samples to a depth of 2 m and associated sediments were collected for analyses (Plates 1 and 2). Six air temperature and near surface ground temperature monitoring stations were installed within the map area

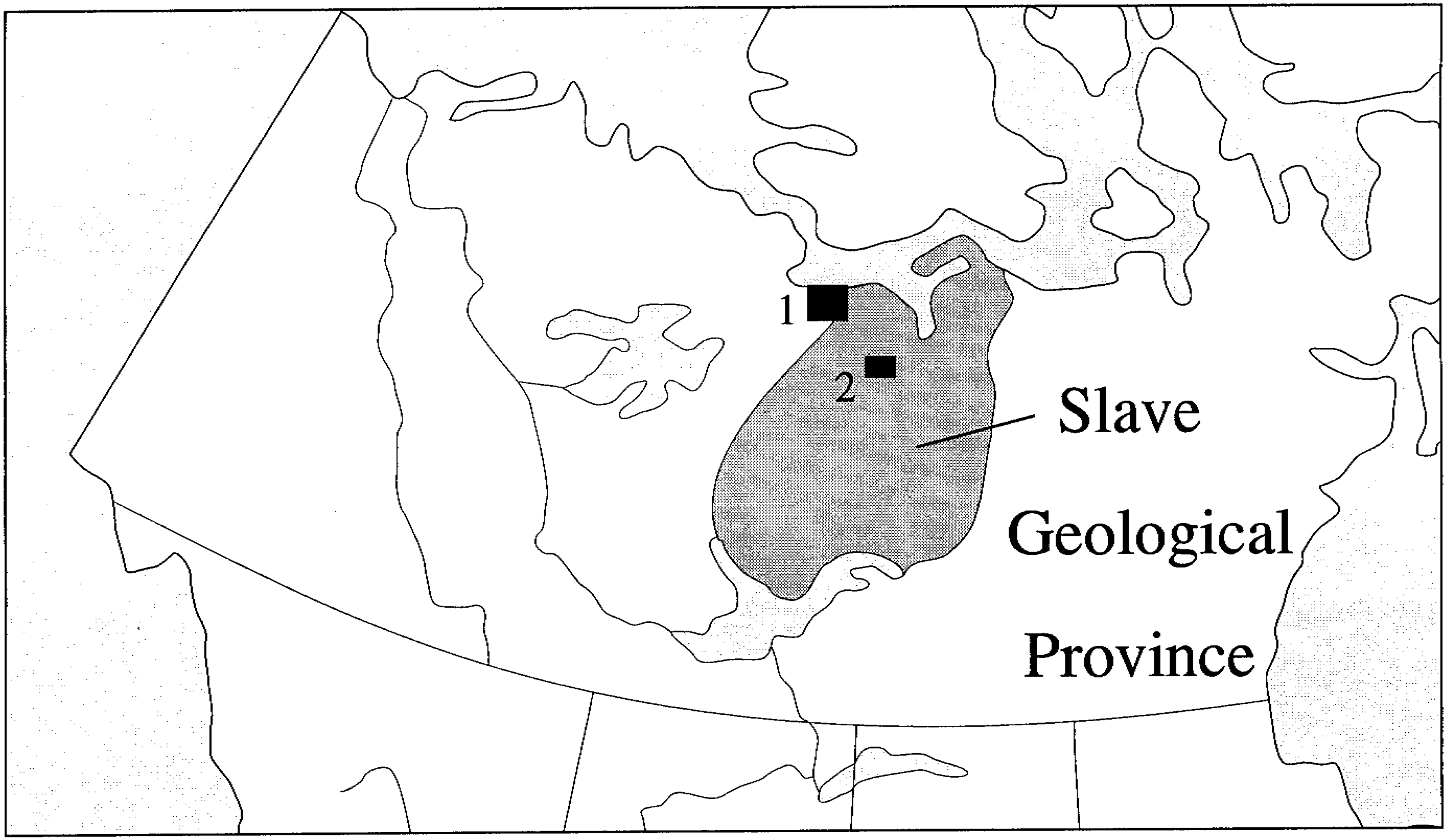

Figure 1. Location of Slave Geological Province and study areas. 1) 1995/96 study area; 2) 1996/97 study area.

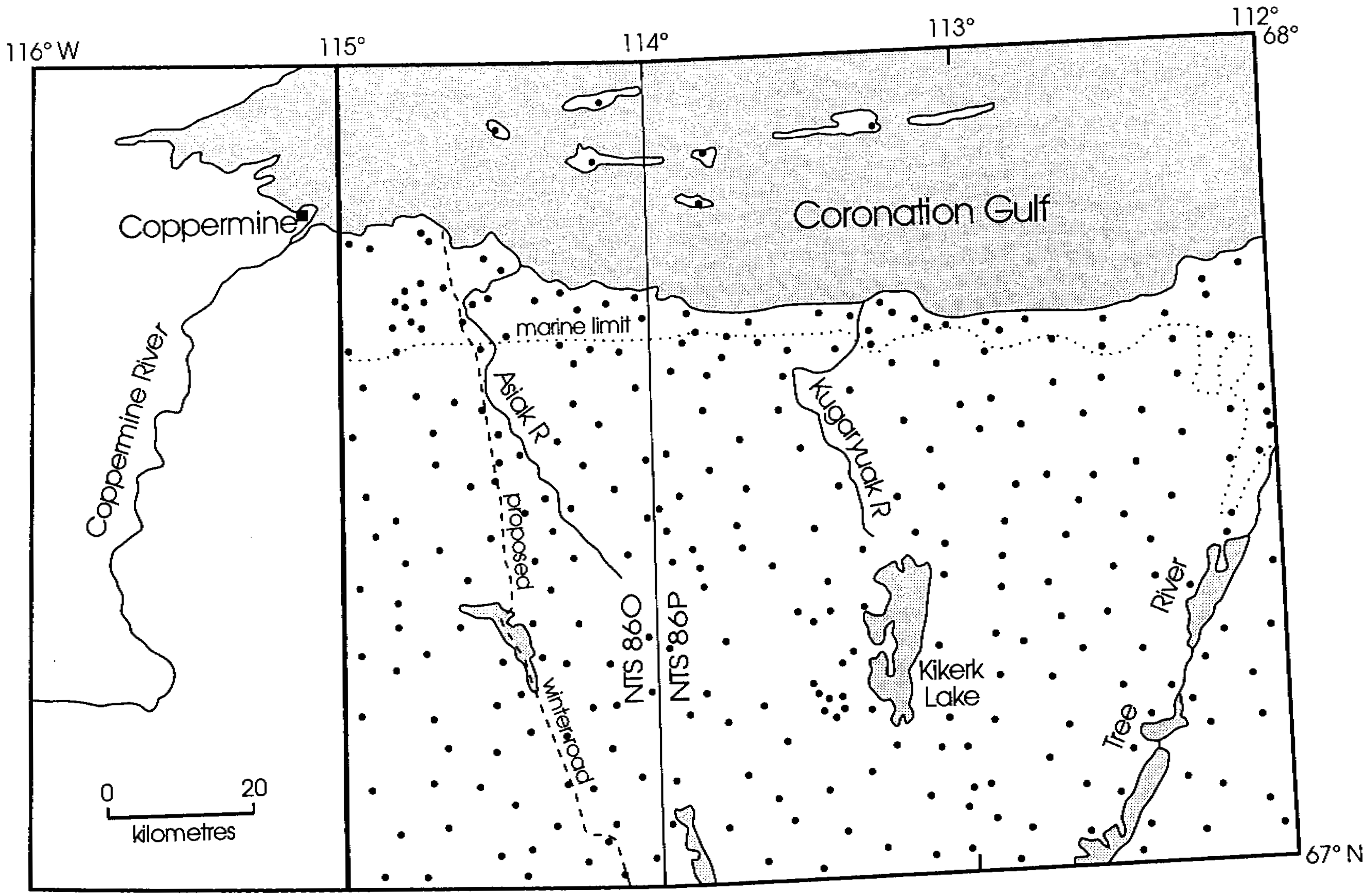

Figure 2. Location of sediment samples and site descriptions in the study area. Small dots represent sample/observation sites. Limit of marine submergence and Izok proposed winter road also delineated.

Date: ______________ Station: 95______-________
UTM: __________ __________ Elev: ________

Map Unit Site: ______ Local: ______
Depth to Bedrock Site: ______ Local: ______

Site Description:
Veg. cover/density:

PERMAFROST:
mud boils, polygons, frost-heaving,
frost-shattering, stripes, lobes
description: dimensions, abundance:

TERRAIN DISTURBANCE:
retrogressive thaw flow-slides, thermokarst,
active layer detachments, gullying, slumping
description: dimensions, abundance:

DRAINAGE:
good, moderate, poor, standing water

SLOPE: angle: __________ aspect:________

Sample site:
matrix:
sample depth:
compaction:
stoniness:
shape:
structure/oxidation/cryoturbation:
ice types:
active layer depth:

Striae:
Bedrock:
Erratics:
Photos:

Table 1. Field datasheet for surficial geology and permafrost description.

(Fig. 3) to monitor climatic controls on the active layer and permafrost. Two ground temperature profile stations with seven thermistors were also installed using the jet-drilling method (Judge et al., 1976) to depths of 30 and 19 m, respectively, within marine sediments near the Coronation Gulf (Fig. 3). The ground temperature sites are adjacent to small lakes, each of which is thermally monitored with submersible data loggers.

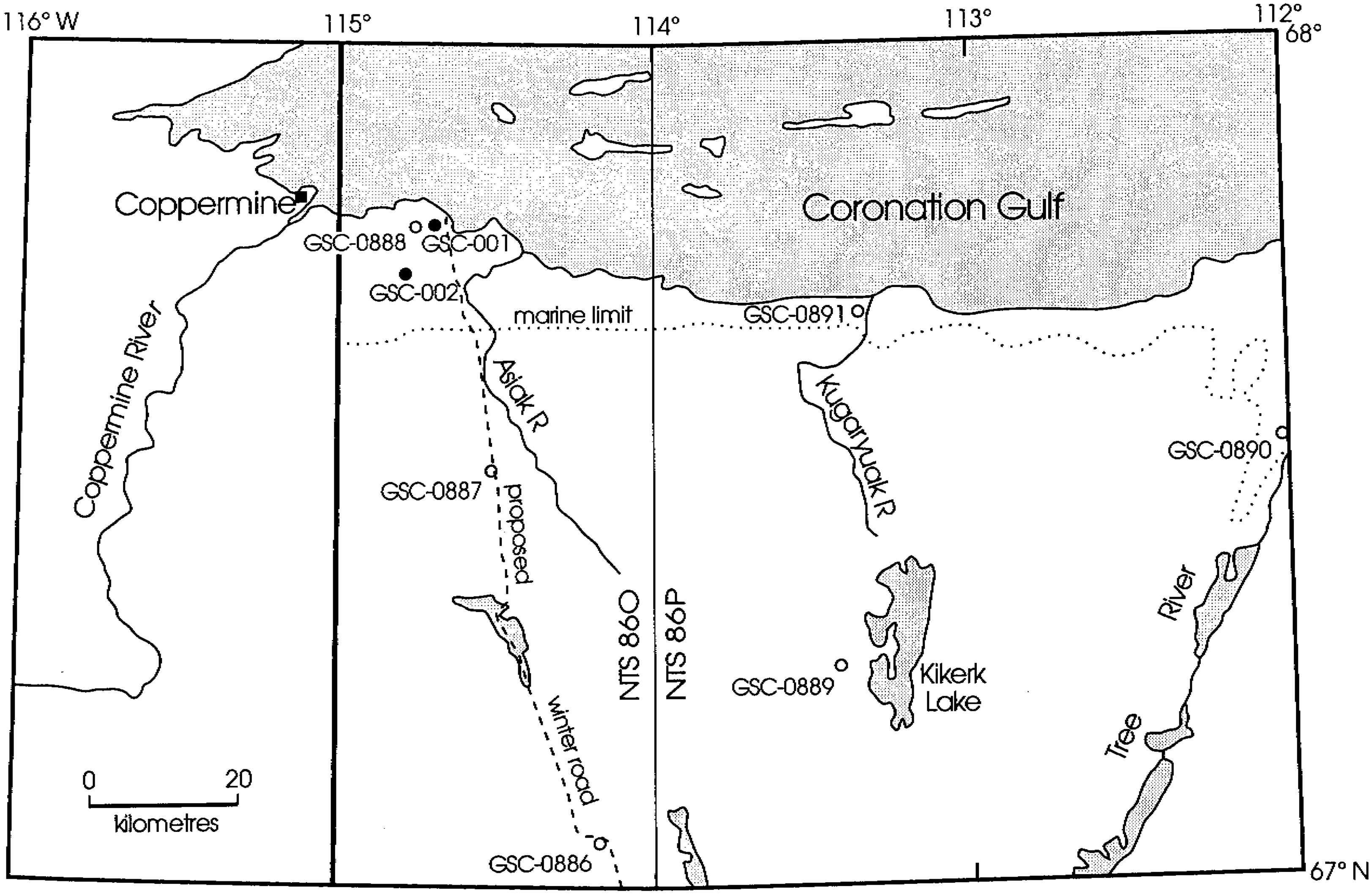

Figure 3. Location of monitoring stations in the study area. Black dots represent ground thermal profile and lakewater monitoring stations; white circles represent air and near surface ground temperature stations.

REGIONAL SETTING

The Coppermine-Kikerk Lake region lies within the zone of continuous permafrost. Climatic data from a weather station at Coppermine (Atmospheric Environment Service, 1982) indicates that the mean annual air temperature is -11.6°C. The mean daily temperature is -30.1°C for January and 9.7°C for July with 4 months (June, July, August, September) having a mean daily temperature >0°C. Total annual precipitation averages 202.3 mm per year, with approximately 50% (100 cm) in the form of snow.

The study area was entirely glaciated by Laurentide Ice during the Late Wisconsin. During deglaciation, coastal regions experienced rapid ice retreat and simultaneous marine incursion across isostatically-depressed terrain. The marine limit, ranges from about 170 m a.s.l. near Coppermine to 210 m a.s.l. in the upper Tree River valley (Fig. 2) and was formed from approximately 11 to 10.2 ka BP respectively (Kerr, 1994). Wood from the base of a thermokarstic depression on a marine delta 32 km southwest of Coppermine suggests that vegetation development began by at least 9150 ± 100 BP (Geurts, 1985). This date is comparable to, but slightly younger than, the onset of the early Holocene warm period which initiated extensive mass wasting in the MacKenzie Delta region to the west between 9500 and 10 000 BP (MacKay and Dallimore, 1992). However, the timing and potential terrain impacts of an early Holocene Warm period in the Coppermine-Kikerk Lake region are presently unknown.

SURFICIAL SEDIMENTS AND PERMAFROST FEATURES

Tills

Till blankets and veneers are the main surficial sediment south of the limit of marine submergence (Fig. 2) while till veneers, generally <2 m thick, cover large areas containing small bedrock outcrops, and conform to underlying bedrock morphology. Along the western margin of the Kikerk and eastern margin of the Coppermine map areas, there is an extensive area of large, parallel crag and tail and drumlinoid features, some of which are up to 35 km long (Plate 3), separated by zones of bare bedrock, thin till veneer and glaciofluvial outwash deposits.

The tills consists of a matrix-supported diamicton, with a clayey silt to fine sand matrix, exhibiting low to high compaction. Clasts range in size from small pebbles to large boulders, with medium to large pebbles predominating. Subangular to subrounded clasts are most common but some exposures, notably those close to bedrock, may be dominated by angular blocks. Most exposures have between 10 and 30 percent clasts. Matrix grain size varies according to bedrock source; till derived from sedimentary and volcanic rocks is silty whereas granitoid rocks produced a more sandy till.

Frost-action within the active layer results in the widespread occurrence of mudboils in all till units. Mudboils are best developed on till blankets (Plates 3 and 4), frequently occurring as stripes on inclined surfaces. Solifluction lobes are also common and are most pronounced near the base of drumlinoids (Plate 3). Ice wedge polygons are rarely visible on tills, probably due to a thick active layer (>1.0 m) resulting from mudboils and solifluction activity on slopes. However, ice wedges rooted in till may occur in depressions, where peat cover is on the order of 0.25 m thick or greater.

Glaciofluvial sediments

Glaciofluvial sediments consist of eskers, kames and proglacial outwash. Eskers range from small, sinuous ridges a few tens of metres long, to large, more linear features up to 30 km in length. Composition ranges from fine sand to cobbles, and may change rapidly over short distances. Throughout much of the map areas, outwash plains scarred by braided channels and kettle lakes are associated with the esker complexes. Some of these sand and gravel outwash plains cover areas of 8 square kilometres or more. As with eskers, their grain size is variable. Such glaciofluvial deposits are potential resources for large volumes of granular materials.

The presence of permafrost typically results in the formation of ice-wedge polygons in glaciofluvial sediments while mudboils are rarely present in these relatively coarse grained materials. Ice-wedge polygons are exceptionally well developed on most flat-topped outwash deposits despite the thin (<0.2 m) organic cover. Polygons on the order of 30 to 100 m in diameter with troughs up to 2 m deep and raised rims up to 1 m high are common and some troughs reaching over 6 m wide (Plates 5 and 6). Smaller polygons approximately 10 m in diameter, with troughs on the order of 0.3 m deep also occur on outwash sediments. In some areas, both sets of polygons occur together possibly indicating multiple periods of ice wedge growth. Ice wedge polygons are seldomly visible on eskers in the map areas, perhaps due to the narrow and steep-sided nature of these features.

Glaciomarine/marine sediments

Raised glaciomarine and marine sediments are extensive along the coastal lowlands of Coronation Gulf and extend up to 40 km inland in the Tree River valley. These sediments consist primarily of four types: 1) undifferentiated, massive to well stratified silt and clay up to 30 m thick; 2) veneers of similar composition <2 m thick; 3) coarse sand, pebbles and cobbles of littoral origin (raised beaches) (Plate 7); and 4) sand to cobbles forming perched glaciomarine and marine deltas.

Permafrost has extensively affected the marine sediments and mudboils are widespread on marine silts and clays. In many areas along the coast, particularly within the Tree River valley, the fine-grained marine blanket deposits are gullied and bare of vegetation cover (Plate 8). Retrogressive thaw flowslides are common along streams in these areas, with active slides typically >10 m in diameter and headwalls 1-2 m high (Plate 9). As with till, ice wedge polygons are rarely visible on fine-grained marine deposits, probably due to mudboil and solifluction activity. Ice-wedge polygons are common on most raised beach and sandy littoral sediments (Plate 7) while mudboils are rare. Where littoral sediments form laterally extensive veneers over marine silts or clays, tundra ponds and low centre polygons are common (Plate 10). As with the outwash plains, large ice-wedge polygons in excess of 30 m diameter with deeply incised troughs are found on the coarse glaciomarine/marine deltaic deposits.

Organic sediments

Organic sediments consist of peat formed by the accumulation of fibrous, woody and mossy vegetative matter up to 1 m or more in thickness, locally overlain by a dense grass or shrub cover. They occur predominantly in topographic depressions and valley bottoms with poor drainage, but are most noticeable below marine limit where they overlie fine-grained marine sediments. Ice-wedge polygons are common in organic sediments, and are rooted in the underlying till, glaciofluvial or marine deposits. Frozen ground was encountered at depths as shallow as 0.13 m below the surface in peat in late summer.

Alluvial sediments

Alluvial sediments comprise gravel to silt size sediment deposited by modern streams and rivers and are occasionally associated with icings. These coarse-grained alluvial sediments often form stripes and sorted circles within perennially active stream beds. In one instance meltout of ground ice, covered by a veneer of alluvial gravels, was observed in a flowing streambed (Plate 11). The ice was approximately 70 cm thick and appeared to have grown in-situ over the winter months. Meltout of the ice and subsequent collapse of overlying gravels resulted in a pattern of sorted circles and stripes, oriented with the flow of water.

BEDROCK WEATHERING

The bedrock geology of the Kikerk Lake and Coppermine map sheets have been described by Hoffman and Hall (1993) and Jackson (1994). Differences in weathering and susceptibility to frost-shattering were noted between rock types. Granitic outcrops show low to moderate evidence of frost shattering or heaving, depending on the joint pattern; most frost shattering was concentrated as haloes around the edges of outcrops. Argillites are typically extensively frost-shattered and heaved especially near base of slopes. The frost-heaved argillites are most pronounced downslope of ponded water and/or in close proximity to perennial springs (Plate 12). Dolomites are somewhat less frost-shattered, breaking into large blocks along joints. These blocks rotate outward on shallow slopes, and steep terrain is susceptible to small rockfalls. Solution weathering is ubiquitous in the dolomites where pits and more resistant, intercalated chert layers and lenses have relief up to 5 cm. Basalts and sills are not extensively shattered or heaved but may exhibit large talus slopes along the edges of palisades (located near the coast and along the eastern portion of Kikerk Lake map area) and contain grussified zones which appear to be more common on bedrock once submerged by the postglacial sea.

PERMAFROST CONSTRAINTS AND HAZARDS

Should engineered structures, transportation right of ways, or borrow pits be developed in the region, several permafrost constraints or hazards could exist, stemming from the presence of thaw-sensitive material and active periglacial processes within various terrain units.

The fine grained marine sediments are probably the most sensitive to permafrost degradation. These silty sediments are typically ice-rich in the upper 1.5 m, and lenses of ice up to 1.0 m thick are present (Plates 2 and 13). The presence of ice-rich sediments results in thaw-sensitive slopes, particularly along the Tree River valley and coastal plains (Rampton and Thomas, 1993). The deposits are saline, with salinities of 5 to 20 ppt in the upper 1.5 m and likely continuing at depth. The thickness of these deposits is variable and may exceed 30 m. Ice-rich silty marine sediments also occur beneath veneers of sandy littoral sediments. Removal or disturbance of the overlying littoral sediments would likely induce melting and slumping of the ice-rich sediments.

Ice wedge polygons are present on most flat-topped coarse grained deposits including littoral sediments, marine deltas, alluvial terraces, outwash, kames, and in most areas with an organic mat at least 0.3 m thick (Plate 14). In Coppermine, removal of the organic cover for granular resources has resulted in moderate thermokarst activity in littoral and alluvial sediments (Plate 15). However, the implications drawn from the presence of ice-wedges on the glaciofluvial units must be interpreted with caution. Ice-wedge troughs on many marine deltas, outwash and kame deposits can be exceedingly large; the largest, >2 m deep and up to 6 m wide (Plates 5 and 6. The enormity of these features suggests that slumping and infilling has occurred. This may be due to partial or complete meltout of ice. Meltout could well be attributed to an early Holocene warm period, although this constrains the initial ice-wedge growth to a time period no more than 2000 years, and possibly much less, prior to the onset of warming. Alternatively, the large ice-wedge troughs may due to the presence of buried massive ground ice within the glaciofluvial sediments. In this case, creep deformation of the massive ground ice as described by Dallimore et al. (1995) may be responsible for the widening and deepening of the overlying ice-wedge troughs. These over-deepened wedges can also occur in conjunction with a set of smaller ice-wedges. Certainly, granular deposits associated with the features must be investigated for potential ground ice prior to removal of aggregates.

Mudboils and solifluction lobes are common on till and marine blanket deposits (Plates 3 and 4). These deposits show considerable sediment translocation, dependent upon slope angle, with lobes 10 to 30 m long protruding over rock or littoral sediment. It is clear that significant sediment translocation has occurred since deglaciation, although the rate of downslope has probably varied.

Fine-grained sediments and organic accumulations limit the depth of the active layer. Active layers are shallowest over fine-grained marine and till deposits where peat accumulations exceed 0.3 m. In these areas, the active layer is commonly restricted to a depth of 0.2 to 0.4 m. Mudboils and gullying restrict vegetation growth on some marine silts and clays (Plate 8). Preliminary investigations show that active layer thicknesses are typically only 0.6 m or less on these deposits. In comparison, active layer thicknesses on mudboils in sandy tills are on the order of 1.0 m. Esker, outwash and beach deposits commonly have thick active layers, due to the coarse sediment and poor organic accumulations. Littoral and outwash sands with 0.1 m to 0.15 m of organic cover have active layers on the order of 0.7 m thick while those on unvegetated gravels are in excess of 1.3 m thick. Results from the thermal monitoring stations to be released at a later date will provide seasonal temperatures in permafrost and active layers on a variety of terrains, and assist in determining the susceptibility of the terrain to thermal disturbance.

TEMPERATURE MONITORING STATIONS

Six air temperature and near surface ground temperature monitoring stations were installed within the map area (Fig. 3) to monitor climatic controls on the active layer and permafrost. Thermistors recording near surface temperatures were placed 25 mm below the ground. In addition, programmed thermistors recording air temperatures were placed within Gill-type radiation shields at heights of 1.5 m using masts similar to those described by Nixon and Taylor (1994). Table 2 summarizes the locations and specifications of each station and Plates 16 to 20 show the climate stations set up in the field.

Two ground temperature profile stations, each with seven thermistors, were installed using the jet-drilling method to depths of 30 and 19 m, respectively (Plates 22 to 24), within marine sediments near the Coronation Gulf (Fig. 3). Temperatures from these stations are continuously recorded on programmable dataloggers. While permafrost is continuous in this area, it has only recently aggraded into the sediments as a result of isostatic uplift. Marine regression continues today, with permafrost aggrading into newly exposed sediments along the present coastline. The ground thermal regime along the marine coast can be expected to vary with the time since emergence. Data collected from these sites will provide useful information on the ground thermal regime in this area. Due to the thermal disturbance created by the drilling procedure, it is expected that it make take several years for the temperatures to return to equilibrium conditions with the surrounding environment. The ground temperature sites are adjacent to small lakes, each of which is thermally monitored with submersible data loggers. Data from these sites will provide information concerning the thermal effect of small lakes on the surrounding permafrost. Table 3 summarizes the location and specifications of each station.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-0886	SE section of 86O/1; gf outwash with polygons near Izok road	622130 E 7439689 N Zone 11	25-07-95	Air temp. 1.5 m.	#0886; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17575; 4.8 hr int; 360 days
GSC-0887	NE corner of 86O/7; till blanket on Izok road	606600 E 7487863 N Zone 11	31-07-95	Air temp. 1.5 m.	#0887; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17593; 4.8 hr int; 360 days
				Ground temp. 3.0 m S of tower; -2.5 cm.	#17492; 4.8 hr int; 360 days
GSC-0888	E of Napaktoktok R; littoral veneer adjacent to small lake	595147 E 7521150 N Zone 11	31-07-95	Air temp. 1.5 m.	#0888; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17597; 4.8 hr int; 360 days
GSC-0889	W of Kikerk Lake; gf outwash with polygons	394596 E 7459378 N Zone 12	25-07-95	Air temp. 1.5 m.	#0889; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17520; 4.8 hr int; 360 days
GSC-0890	Tree River Valley; marine clay with willow	457453 E 7491248 N Zone 12	27-07-95	Air temp. 1.5 m	#0890; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#17592; 4.8 hr int; 360 days
GSC-0891	Mouth of Kugaryuak R; alluvial delta with polygons	402688 E 7510722 N Zone 12	27-07-95	Air temp. 1.5 m	#0891; 6:00 hr int.; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#17595; 4.8 hr int; 360 days

Table 2. Air temperature and near surface ground temperature stations.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-001	E of Napaktoktok R; littoral veneer adjacent to small lake and GSC-0888	595143 E 7521155 N Zone 11	10-08-95	HT278: 0.5, 2.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 m	RBR XL-800 #2572; 6:00 hr int; 366 days
			11-08-95	Submerged in ~2.5 m of water	RBR XL-100 #3190; 6:00 hr int; 366 days
GSC-002	E of Napaktoktok R; marine silts adjacent to small lake GSC-0888	592116 E 7513697 N Zone 11	11-08-95	HT288: 0; 0.3; 3.3; 8.3; 11.8; 15.3; 18.3 m	RBR XL-800 #3449; 6:00 hr int; 366 days
			12-08-95	Submerged in ~2.0 m of water	RBR XL-100 #3453; 6:00 hr int; 366 days

Table 3. Ground temperature and lake bottom temperature stations.

FUTURE RESEARCH NEEDS

Follow-up Activities

As a continuation of the permafrost research program in the Coppermine and Kikerk Lake map sheets, geotechnical analyses of sediment samples and isotopic and geochemical composition of ice and surface waters will be reported on when laboratory analyses are completed. The geotechnical data will complement the baseline environmental data collected as a part of the till sampling program carried out under the NATMAP program. Data collected on surface water and ice samples will provide a background dataset for determining the origin of ground ice in other settings, as well as providing information on the potential for saline porewaters in the immediate area. Finally, surficial geology, permafrost and geotechnical data collected along the Izok proposed winter road will be reported on as it becomes available.

Preliminary Proposal for 1996/97

New research

The research and monitoring program undertaken in the Coppermine and Kikerk Lake map areas in 1995/96 is a highly successful endeavour providing much needed permafrost and geotechnical data in the northern West Kitikmeot - Slave Geological Province. The success of the regional program is, in part, due to the logistical linking between the permafrost research program and the surficial geology mapping of the area.

In 1996/97, it is proposed that summer field investigations be undertaken to provide permafrost information throughout the 76E N1/2 map sheet (study area 2 in Fig. 1), encompassing the Lupin minesite, and to provide permafrost and geotechnical data along the Lupin winter road extension to the Izok proposed minesite. The area is approximately 300 km SE of the proposed port facility at the Coronation Gulf coast, at the southerly end of the Izok proposed winter road. This project complements the permafrost information gathered in 1995/96, and places the data collected in the Coppermine and Kikerk Lake areas into a more regional context.

The proposed project would be undertaken from mid-July to mid-August, 1996 in conjunction with surficial geology mapping to be undertaken in the area. During this period surficial sediments will be documented for permafrost-related phenomena and terrain disturbance. In particular, glaciofluvial deposits will be examined for morphology indicative of potential occurrences of massive ground ice. Ice wedge polygons on outwash deposits will be compared to those in the Coppermine and Kikerk Lake areas to determine if the large ice-wedge polygons are a regional phenomena. Surface waters and ground ice samples will be collected with the goal of constructing a regional dataset.

As inland areas are typified by till and glaciofluvial sediments over bedrock, deploying ground temperature cables within permafrost by means of the jet-drilling technique would be impractical and is not recommended for the 1996/97 season. In these areas, ground temperature data can be more readily obtained from instrumented boreholes drilled during winter geotechnical activities. Presently, some ground temperature and climatic information is available from the Lupin minesite. Climatic information in this region could be supplemented by two air temperature and near surface ground temperature stations deployed between the Lupin mine and the Izok proposed mine and north of the Izok site. These stations would require regular annual checks, to retrieve the data and redeploy loggers. This could be performed by DIAND, GSC other qualified personnel.

Continued monitoring

As a part of the monitoring program initiated in the Coppermine and Kikerk Lake map areas in 1995/96, it is proposed that data from the various temperature stations deployed in 1995 be retrieved in the summer of 1996. This may be accomplished after the permafrost research program is completed in the Lupin-Izok area in order to take logistical advantage of a helicopter in the area.

Logistical and Funding Requirements

The proposed permafrost research program in the Lupin-Izok area will not only provide regional geoscience information in the Slave Geological Province, but will do so in a financially prudent manner by taking advantage of other programs conducted in the area. The GSC can provide logistical support for the permafrost program, if undertaken in conjunction with their surficial geology mapping of the area. In addition, Terrain Sciences Division has applied for 35 hours of helicopter support from PCSP to be directed specifically to this project. Given the preceeding level of support, an additional $20 K would be required for instrumentation, fuel, accomodation and shipping to cover the project. At the request of DIAND, Land Adminstration a detailed budget can be prepared for the 1996/97 season.

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Plate 1. CRREL coring of ice-wedge polygons rooted in till.

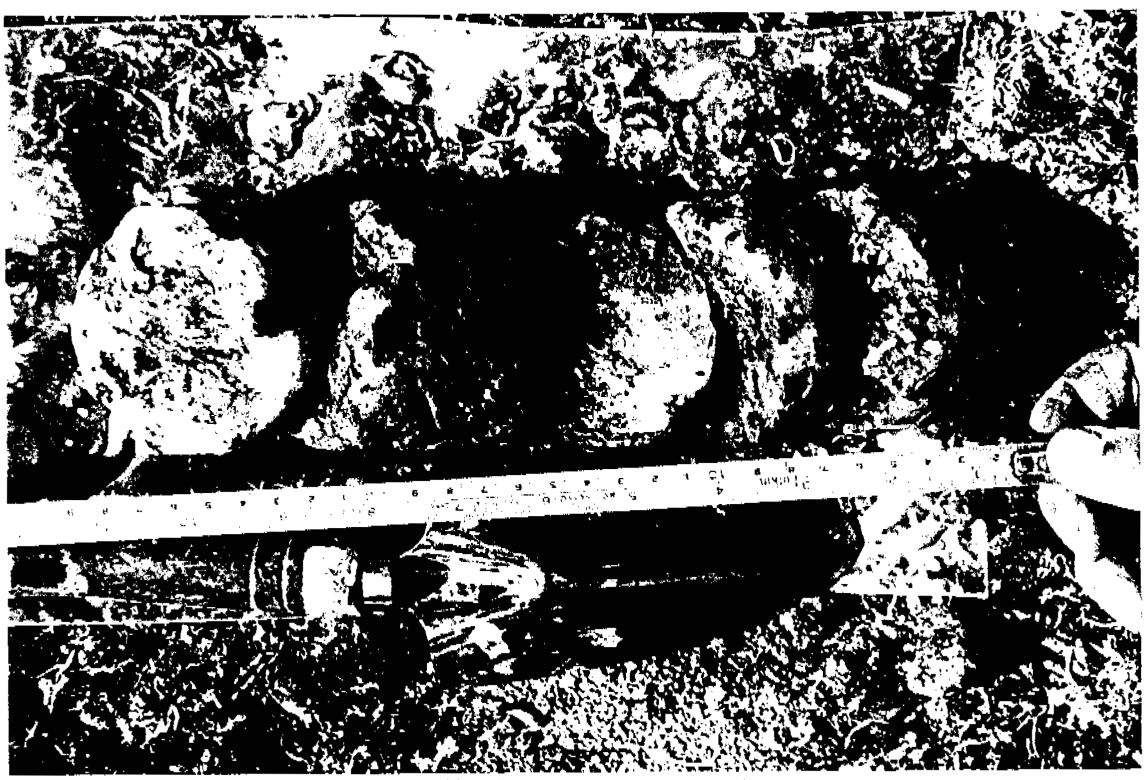

Plate 2. Ice with silt inclusions, obtained from marine blanket deposits southeast of GSC-002 monitored site.

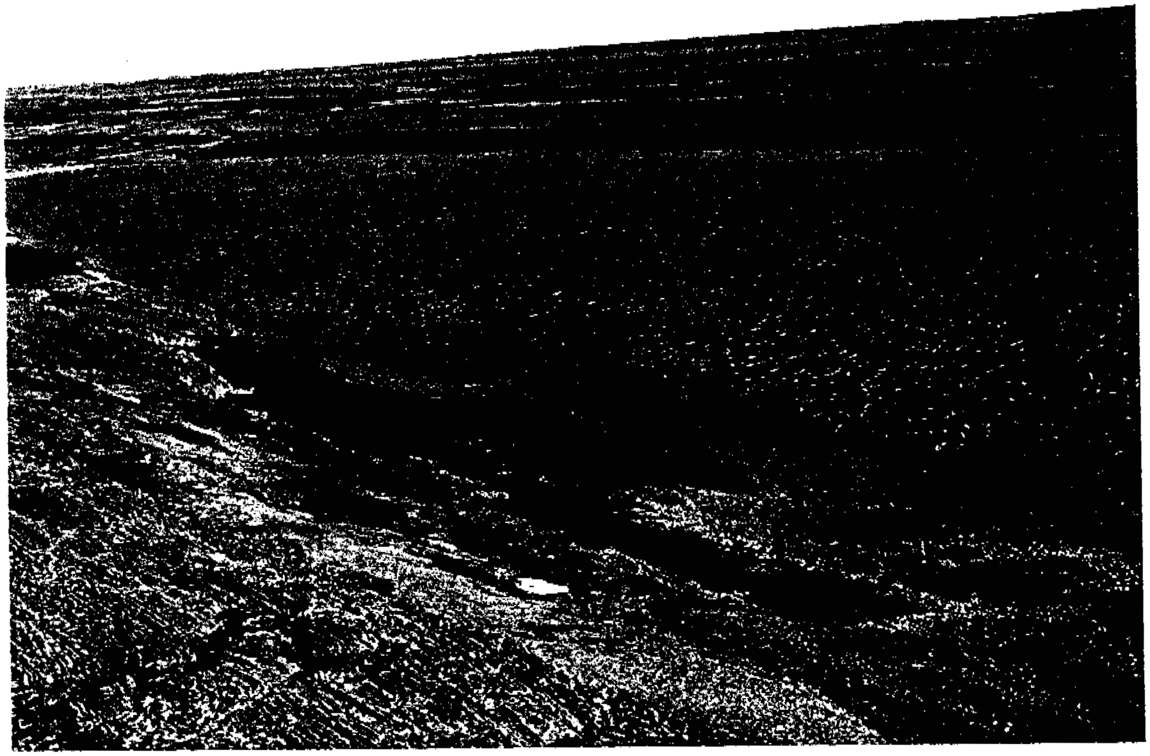

Plate 3. Large drumlinoid feature consisting of till blanket (right) with solifluction lobes advancing over washed till veneer (foreground).

Plate 4. Till blanket with unvegetated mudboils (stripes) on surface and small outcrop in distance..

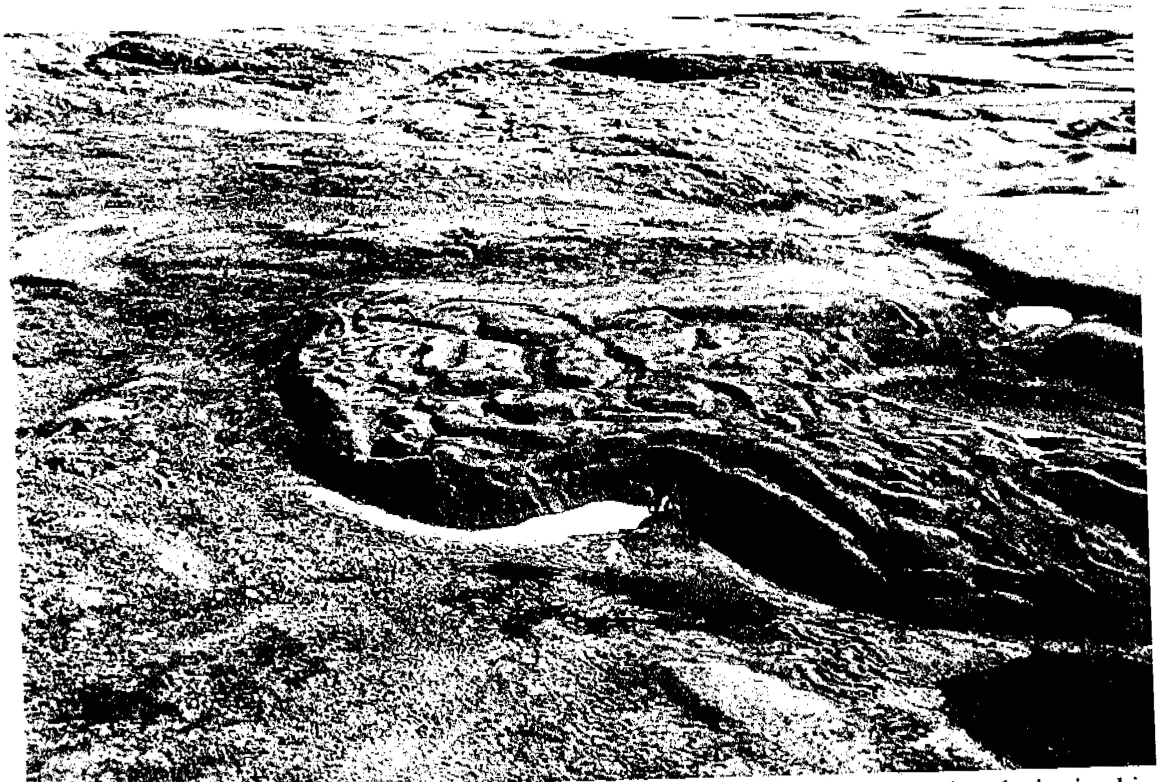

Plate 5. Glaciofluvial outwash complex near the Kugaryuak River. Note deeply incised ice wedge polygons and kettled (hummocky) outwash plain in centre and relatively featureless plain to the right.

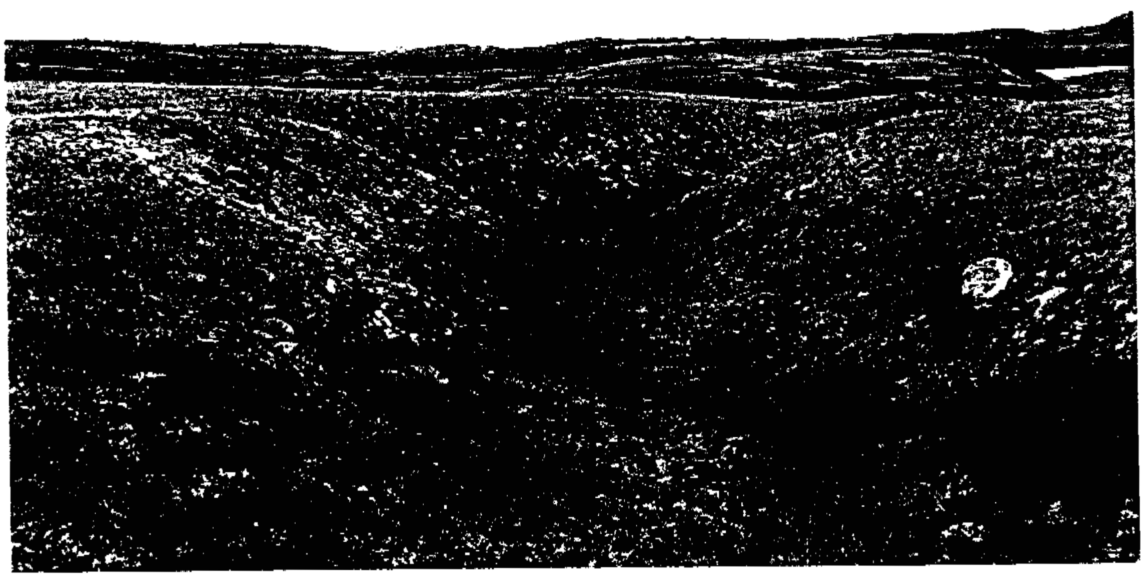

Plate 6. Deeply incised ice-wedge trough in glaciofluvial outwash.

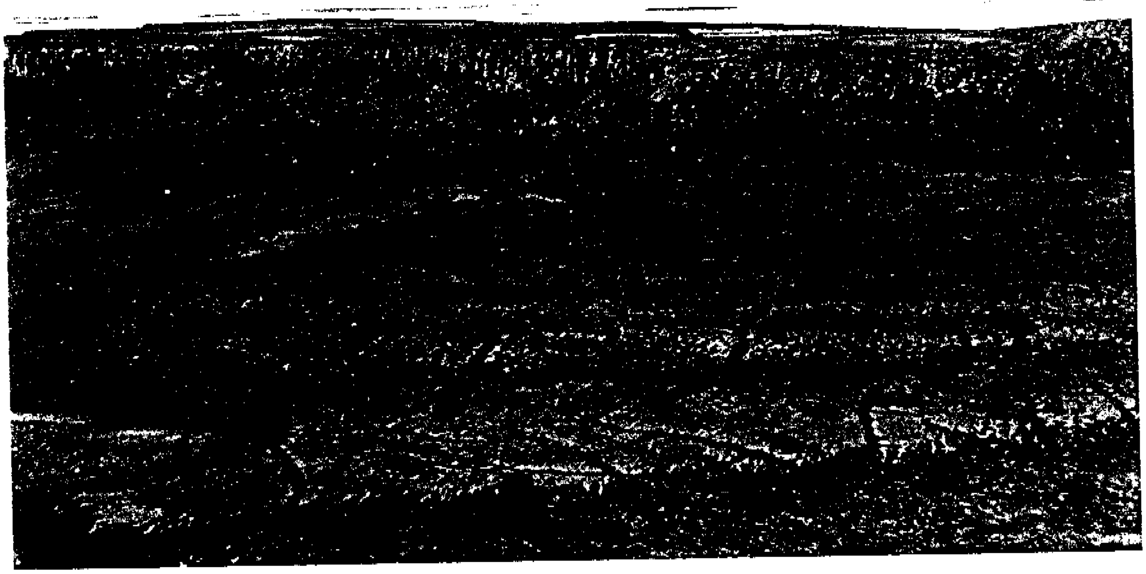

Plate 7. Raised marine beaches 7 km east of the mouth of the Kugaryuak River, Coronation Gulf. Note ice-wedge polygons cross cutting beach ridges.

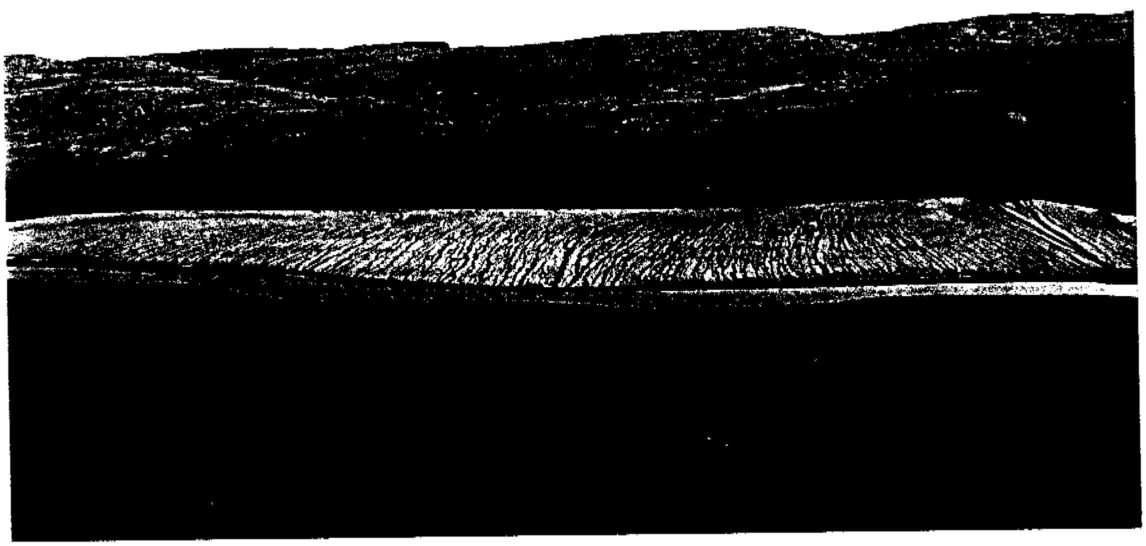

Plate 8. Silty clay marine sediments in the Tree River valley. Slope processes keep surface bare of vegetation.

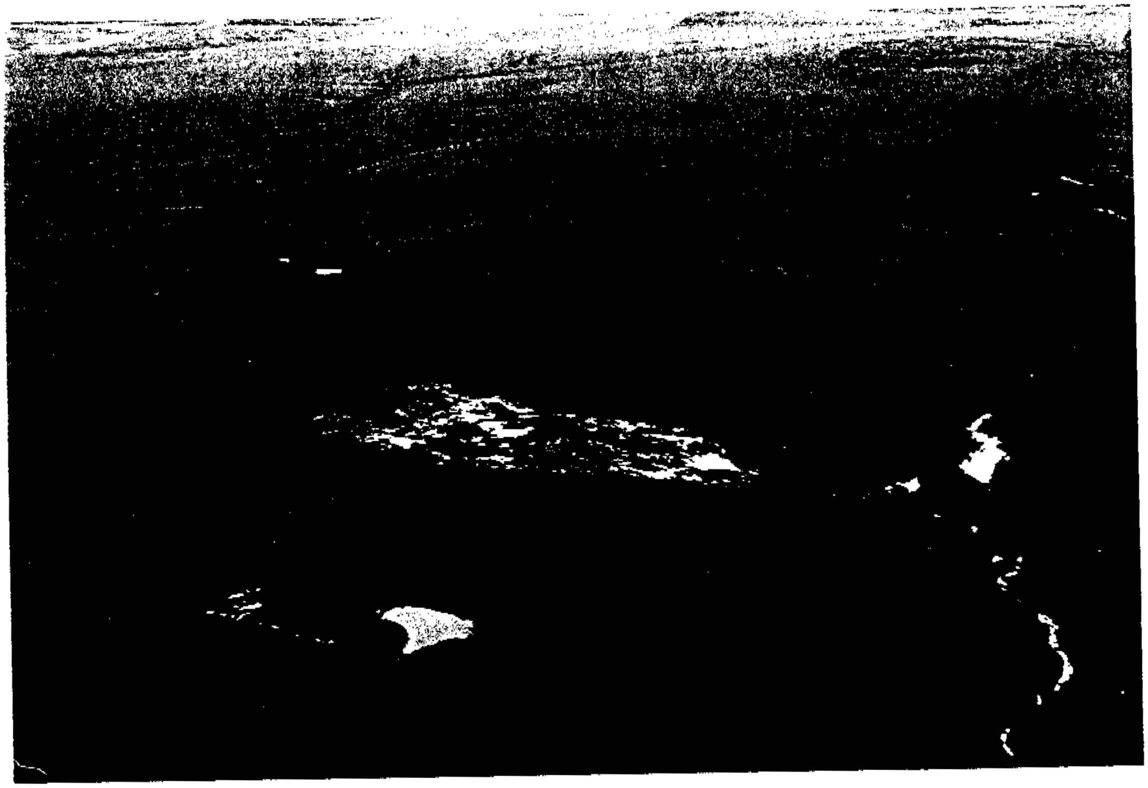

Plate 9. Small thawslide east of Coppermine on silty-clayey marine sediments.

Plate 10. Checkerboard pattern of ice-wedge polygons on littoral sediments near mouth of the Asiak River.

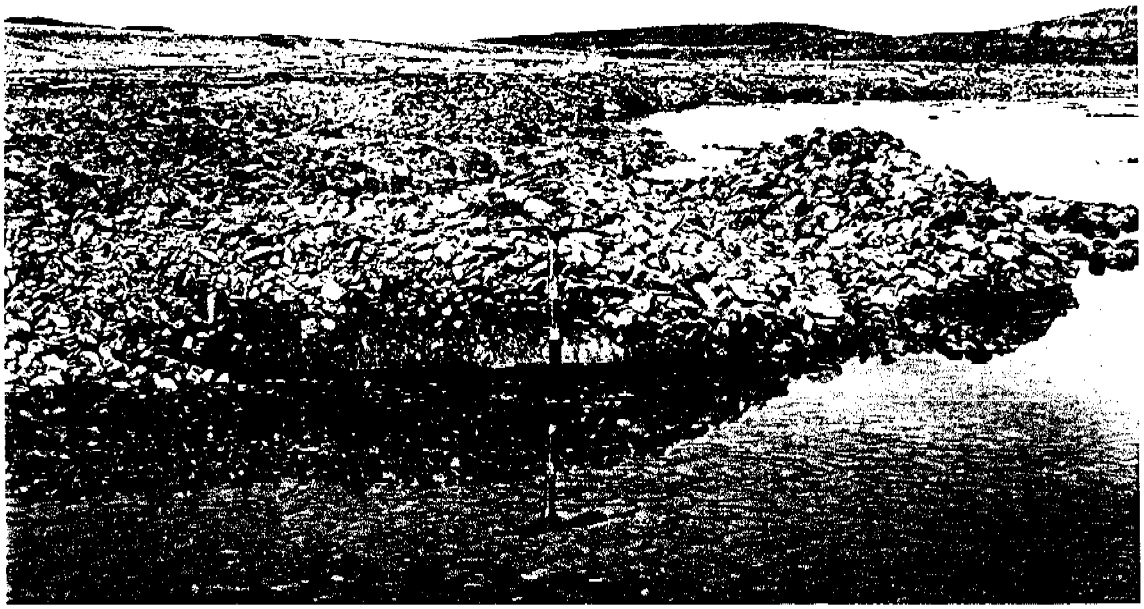

Plate 11. Ground ice covered by a veneer of alluvial gravels. Ice appears to have grown in-situ. Meltout of is creating a pattern of sorted circles and stripes in the gravels.

Plate 12. Frost heaved argillites downslope from small lake (not in picture). Note spring issuing from base of slope and draining into lake in distance.

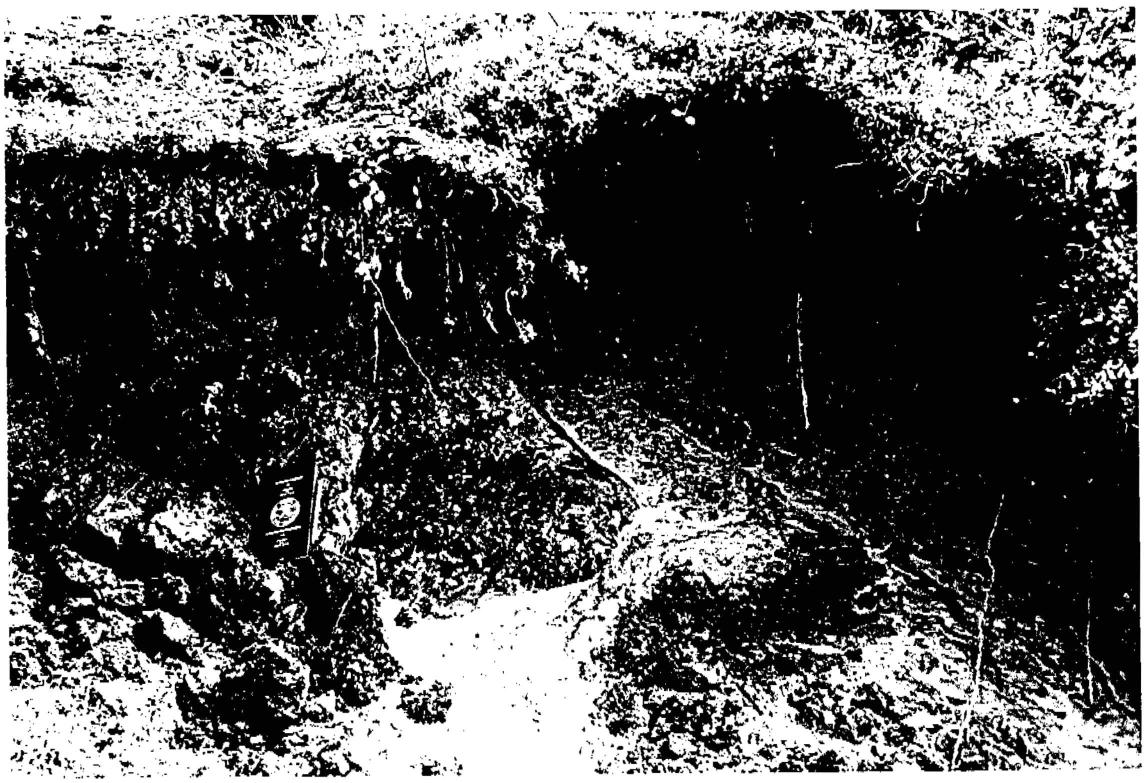

Plate 13. Ground ice in silty marine sediments. Ice contains suspended inclusions of marine sediments and small bubble-rich pockets.

Plate 14. Cross-section of ice wedge in littoral sediments.

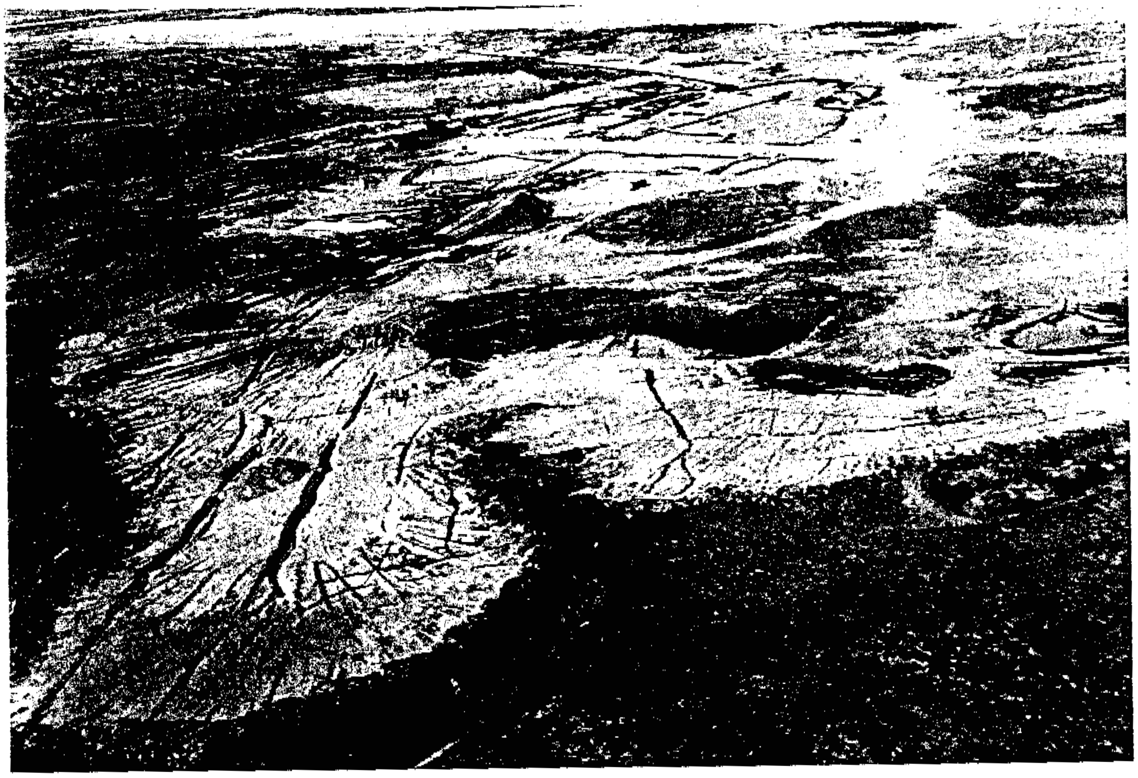

Plate 15. Thermokarst development and ponding resulting from removal of organic cover for granular resources south of the Coppermine airport.

Plate 16. Station GSC-0886 located at SE section of 86O/1 near the Izok winter road on glaciofluvial outwash with ice-wedge polygons. Proposed winter road would traverse lake in backgound. Station is set up on a proposed granular resource.

Plate 17. Station GSC-0887 located in NE corner of 86O/7 near Izok proposed winter road on a till blanket deposit.

Plate 18. Station GSC-0888 located east of the Napaktoktok River adjacent to small lake. Sediments are a littoral veneer over marine silts. Lake in background and ground temperatures are being thermally monitored (GSC-001).

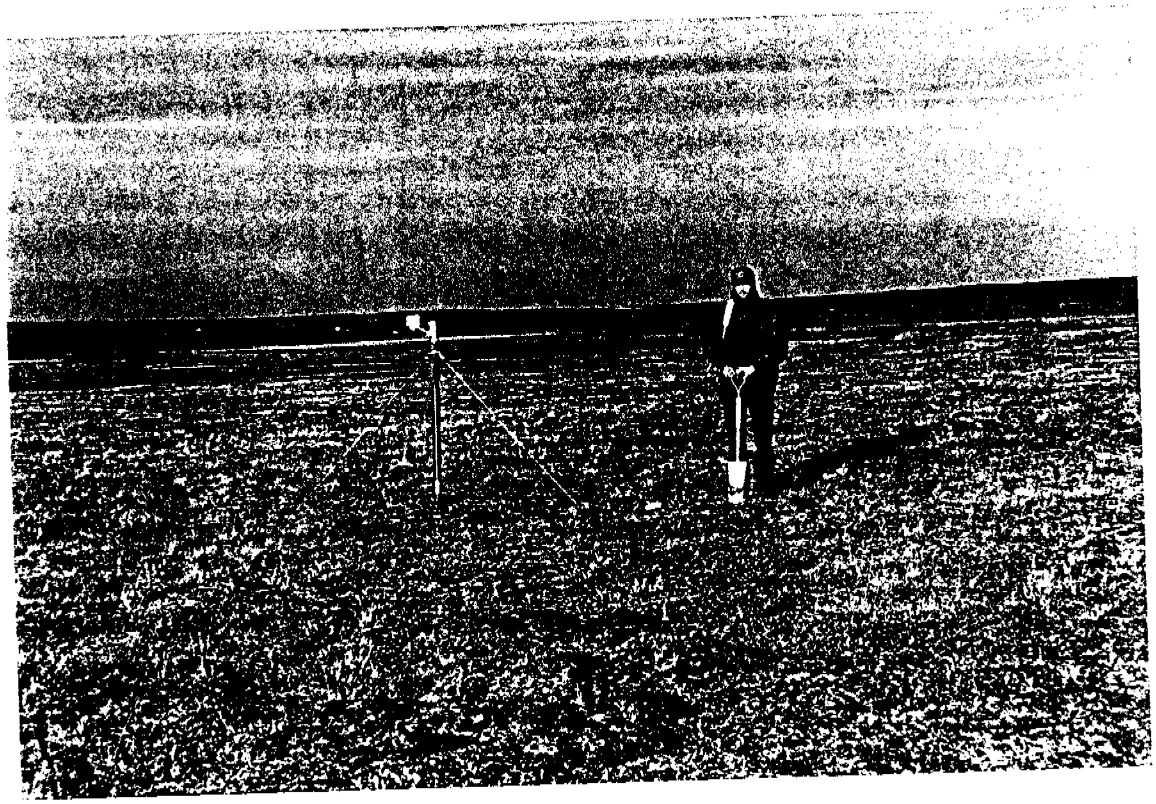

Plate 19. Station GSC-0889 located west of Kikerk Lake on glaciofluvial outwash with ice-wedge polygons.

Plate 20. Station GSC-0890 located in the Tree River Valley on marine clays with willow shrub vegetation.

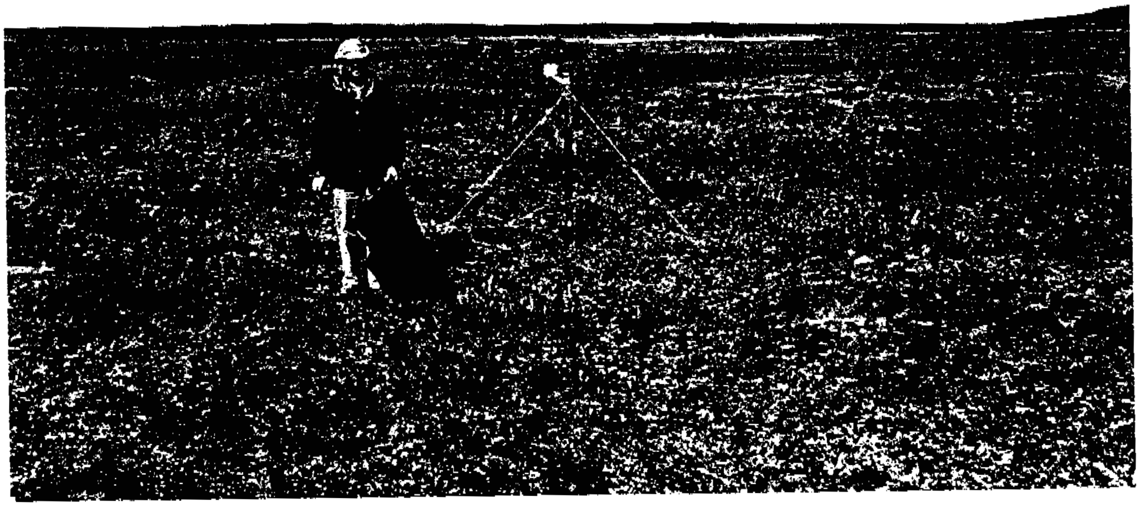

Plate 21. Station GSC-0891 located at mouth of the Kugaryuak River on an alluvial delta with ice-wedge polygons. Station is approximately 100 m from the coastline.

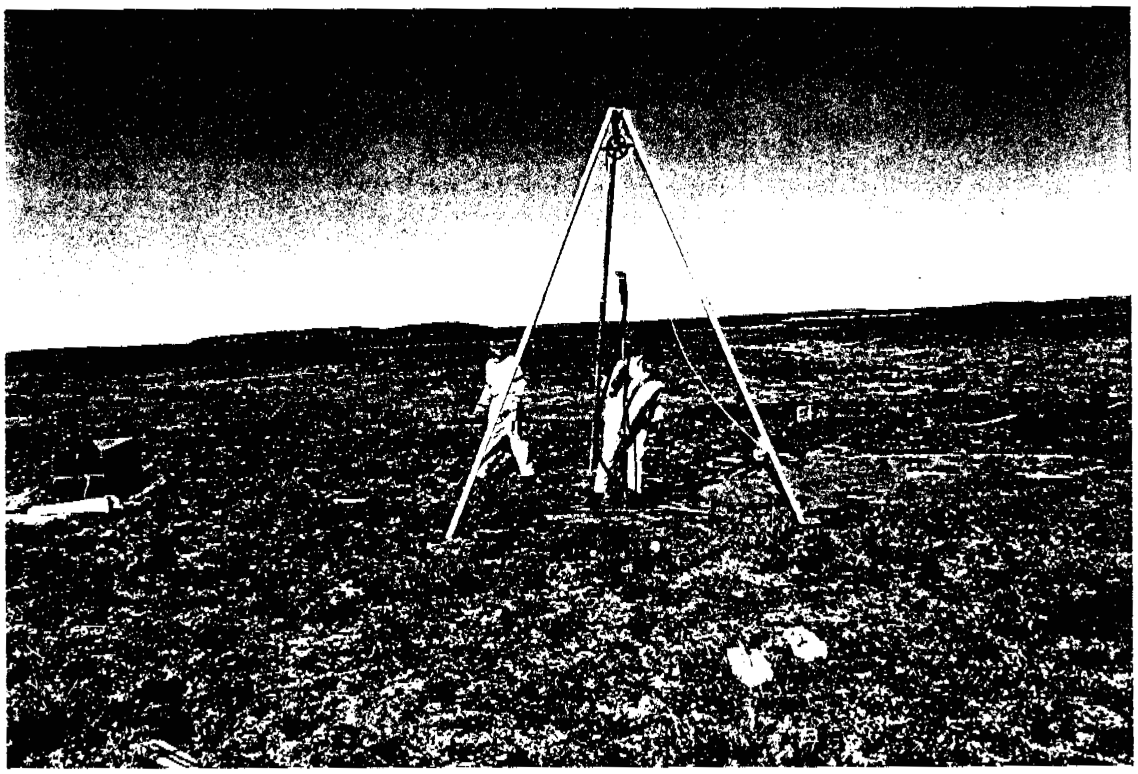

Plate 22. Jet-drilling at site GSC-001.

Plate 23. Permafrost monitoring site GSC-001 after drilling and restoration. Lake in backgorund is being thermally monitored.

Plate 24. Permafrost monitoring site GSC-002 after drilling and restoration. Lake in background is being thermally monitored.