SECTION 7

GUIDELINES FOR MEDIA COMMUNICATIONS

Designated Winter Road Spokesperson PHIL FLAUMITSCH

Alternate Spokesperson ______________________________

The following are statements of Echo Bay Mines Ltd. Winter Road Operations Policy for crisis communications

1 Obey the cardinal rule Tell it all and tell it fast and tell it straight. There is no better or more effective way to stop rumours and calm nerves than to provide accurate information on the crisis as fully and quickly as possible. The flow of information tends to signal that, while things are not in perfect order, there at least are persons somewhere, somehow, reining in the controls In other words, if "they" can report what is happening, "they" know what is happening and in short order will know how to straighten things out

2 Cover all bases and all of the important subjects, to the extent possible Whatever information is available, as long and it does not involve some security or confidential issue, should be made public If a particular area is not detailed, questions will focus on it and make it far more crucial than it may be

3 Provide regular updates to the news media. An exceptionally fluid situation required frequent updates In a crisis situation, there are very few times when there is too much contact with the media and public. Minute by minute accounting builds a trust and confidence Lapses in the information flow will stimulate speculation and heighten anxiety.

GUIDELINES FOR MEDIA COMMUNICATIONS

Additional Guidelines

Do's:

- Refute rumours with fact and logic.
- Release only verified information
- Escort the press at the emergency scene
- Keep a record of all inquiry or news coverage
- Provide equal opportunity to various news media

Don't's:

- Joke or ridicule as a means of refutation
- Speculate on causes of the emergency
- Interfere with legitimate duties of the press
- Attempt to cover up
- Blame anyone for the emergency.

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COMMUNICATIONS

Lupin

Lupin can be contacted by·

Telephone	(403) 429 - 8750
H.F Radio	4765 0 or 4441 0 MHz
Radio Telephone	SR1555

Winter Road

Winter Road Camps & Vehicles

H F Radio	4765 0 or 4441.0 MHz
C.B. Radio	Channel 19
Lockhart Lake Camp	T.B A
Lac De Gras Camp	T B.A.

Yellowknife:

Telephone	(403) 920 - 4835
H.F Radio	4765 0 or 4441 0 MHz
C B Radio	Channel 19

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SECTION 8

EQUIPMENT AVAILABLE FOR RECOVERY ON THE WINTER ROAD

D8 Cats	6
D7 Cats	
Front End Loaders	7
Tractor & Trailers for Gravel Haul	4
Winch Tractors, Lowboys, & Hi-boys	3
Bed Trucks	
Cherry Picker	1
Tractors with Product Pumps and Tankers	30
Rig Matts	6
Vacuum Truck - 80 Barrel	1

All of the above equipment will be located along the winter road at various locations, ie Yellowknife, Lockhart Lake, Lac De Gras and Lupin Mine Site. In addition, all trucks hauling fuel are equipped with rolls of polyethylene.

ECHO BAY MINES LTD.

WINTER ROAD PROJECT

NATIONAL SAFETY CODE
PROCEDURAL FORMAT

ECHO BAY MINES LTD.

All commercial vehicles, transport trucks owned by Echo Bay Mines are subject to all applicable vehicle inspections These units have been historically certified at Western Star North As we only operate on a three (3) month basis, they are certified once each year During Winter Road Operations any work done is normally performed at one of the Winter Road Camps

Rental Units

Leased units All lease units must have a valid VIS Certification before coming on line to our operation Echo Bay Mines personnel also do a walk-around inspection prior to leasing units

Echo Bay Mines requires all driver's to complete Pre-trip/daily inspection sheets before operating their unit This includes each tractor and each trailer unit This information will be checked off on the vehicle safety inspection and condition report forms (attached) These forms are handed in at the Yellowknife Winter Road Shop. Required repairs are attended to A S A P If a safety factor is present, the unit will be parked until corrected All units are to be visually inspected tires, springs, lights, piping, and valves, and braking system, prior to loading at all times

All Units are subject to

Inspections by H D Mechanic

A 3,000 km or 2 round trips Yellowknife to Lupin Mine

B 250 hour service, 10 day interval's

C 500 hour service

See attached forms

Trailer units undergo a thorough mechanical inspection each year prior to Winter Road Operations to avoid major problems during the season

These units are subject to vehicle safety inspection and condition reports as well as the "A" Inspections

(1) all units owned or leased by Echo Bay Mines are assigned unit numbers Make, model, serial number, year and the tire size information are recorded and will be available at the Winter Road Shop in Yellowknife and filed per unit as per N S C Maintenance Program requirements (Vehicle Maintenance Profile)

(2) A record of services, inspections, repairs and maintenance operations will be kept and made available in the form of a maintenance log book at the Yellowknife Winter Road Shop.

(3) Records for commercial vehicle covered by national Safety Codes will be kept at the Yellowknife Winter Road Shop These will include inspection reports, and maintenance that is done in other camps as well Additional information could be obtained from Phil Flaumitsch in Edmonton if required - Winter Road Information

(4) Services (oil changes, grease jobs) are done on a ten day basis. This is to simplify matters - ten days at 24 hours being 240 hours. This work as well as our A/B/C inspections will be performed by a heavy duty mechanic at the Yellowknife Winter Road Shop or one of the camp sites along our road. All information will be gathered at the Winter Road Shop in Yellowknife and recorded and filed as per (1)

MANPOWER - PROFILES:

- Driver profiles will be put together as per J.J. Keller & Associates information package

- Driver applications, abstract's, medical information, Driver's License, etc will be in place at Yellowknife Winter Road Shop. Dangerous goods and/or WHIMS courses are mandatory

All information pertaining to the Driver will be kept in the Driver Profile This includes but is not limited to

- Violation warnings/convictions
- Log book sheets
- Expense receipts
- All certifiable data as listed above.

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MAINTENANCE LOG

MAKE

UNIT– SERIAL NUMBER– MODEL NUMBER– TIRE SIZE–

DATE	DESCRIPTION OF WORK	VEHICLE SAFETY INSPECTION REPORT	INSPECTION A	B	C	WORK ORDER	ODOMETER	SERVICE DUE	P.M OU

ECH ◎ Table of Contents TD.

VEHICLE SAFETY INSPECTION AND CONDITION REPORT

№ 10971

To be completed at the beginning of each trip and at intervals of NO more than 800 kilometres

[illegible] ________	TRACTOR NO ________
[illegible]AGE IN ________	TRAILER NO ________
[illegible]LEAGE OUT ________	TRIP REPORT NO ________

Driver must ✓ items as inspected List those defects for correction in the space provided at bottom of form

1 PRE-TRIP INSPECTION	✓
a ENGINE OIL ANTIFREEZE LEVELS	
b COOLANT LEVEL	
c BELT TENSION	
d FUEL	
2. CHECK (After starting the engine):	✓
a LIGHTS - headlamps tail lamps, turn signals stop lamps	
b BRAKES - Brake adjustment (Maximum slack adjuster travel 1 5 inches) Compressor build up time from 50 to 90 PSI not to exceed 3 minutes Air tanks have been drained tractor protection valve functioning properly, no audible leaks and braking system functioning properly	
HORN - electric and air	
d WINDSHIELD WIPERS	
e STEERING - for excessive play	
f TIRES AND WHEELS SECURE - Wheels are secure Tire tread depth and condition is acceptable	
g WINDSHIELD CONDITION	
h MIRRORS - adjustment	
i SAFETY EQUIPMENT	
j VEHICLE DOCUMENTATION INSURANCE AUTHORITIES ETC	

3 ENROUTE INSPECTION: ROAD CHECK	
To be completed after the first 50 kilometres and at intervals of 160 kilometres thereafter	
a TIRES	
b WHEELS AND LUGS	
c OIL LEAKS	
d FUEL LEAKS	
e CARGO - SECURE	
4 END OF TRIP INSPECTION	
a FUEL UNIT	
b DRAIN AIR TANKS	
c LIGHTS AND LICENSE	
d PARK UNIT IN A SAFE AREA	

OIL ADDED ________

COOLANT ADDED ________

☐ UNIT IS ROADWORTHY

☐ UNIT REQUIRES CORRECTION

Completed form is to be submitted to the Maintenance Department in Edmonton

REMARKS AND REPAIRS REQUIRED (Identify unit number for each remark or repair)

____

____

____

____

____

____

____

[illegible] ABOVE UNIT IS ROADWORTHY   DRIVER'S SIGNATURE ________

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"A" INSPECTION
TRACTORS AND TRAILERS

E 'CHO BAY MINES LTD.

DATE ______________

.ompleted at either the beginning or the end of each trip or every 3000 kms

:d Use (X) for serviceable and (R) for repair action

WORK ORDER NO ______________

TRACTOR		
UNIT NO	ODOMETER	
INSPECTION CHECKPOINTS		COND
LUBRICATE	STEERING	
	KING PINS	
	DRIVE LINE	
CHECK U JOINT WEAR		
CHECK OILS AND TOP UP	MAIN TRANSMISSION	
	AUXILIARY TRANSMISSION	
	FORWARD DIFFERENTIAL	
	REAR DIFFERENTIAL	
REPLACE FAULTY LIGHT BULBS		
RECORD OIL PRESSURE		
DRAIN AIR TANKS COMPLETELY		
:ECK AIR SYSTEM PRESSURE		
CK WIPER BLADE CONDITION		
REPLACE FUEL FILTERS		
INSPECT TIRES FOR WEAR		
INSPECT SPRINGS AND SUSPENSION		
CONFIRM OPERATOR S REPORT		

SERVICEMAN S COMMENTS

TRAILER		
UNIT NO	ODOMETER	
INSPECTION CHECKPOINTS		CC
BRAKE ADJUSTMENT		
OIL LEVEL IN WHEEL BEARINGS		
LIGHTS		
SPRINGS		
KING PIN		
TIRE CHECK		
MUD FLAPS		
LANDING GEAR		
GLAD HANDS		

SERVICEMAN'S COMMENTS:

"ES REPAIRS are to be done as a RESULT of this service inspection, NOT as a part of it
SERVICE parts required such as bulbs or fuel filters are to be written on the UNIT'S WORK ORDER

I detect no defects or deficiencies in this motor vehicle as would be likely to affect the safety of its operation or result in its mechanical breakdown

MECHANIC S SIGNATURE ______________

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ECHO BAY MINES LTD.

"B" INSPECTION

ompleted every 250 hrs or 15,000 kilometres (whichever occurs first)

nd Use (X) for serviceable and (R) for repair action

UNIT NO	ODOMETER	WORK ORDER NO	DATE

INSPECTION CHECKPOINTS		COND	RECOMMENDED ACTION
CONFIRM OPERATOR'S REPORT			
COMPLETE "A" INSPECTION			
CHANGE ENGINE OIL AND FILTERS			
INSPECT CHARGING SYSTEM			
INSPECT STARTING SYSTEM			
AIR INLET PIPING AND RESTRICTIONS			
CHECK AIR COMPRESSOR FILTER			
INSPECT TIRES FOR MATCHING			
INSPECT BRAKE LINING WEAR			
CHECK BRAKE ADJUSTMENT			
INSPECT ALL COMPONENTS FOR FUEL OIL COOLANT			
LEAKS	ENGINE		
	RADIATOR AND HOSES		
	TRANSMISSIONS		
	DIFFERENTIAL(S)		
	FUEL SYSTEM		
	WATER PUMP		
CHECK TURBO OPERATION			
INSPECT MANIFOLDS AND EXHAUST			
CHECK EXHAUST SMOKE			
DIAGNOSE ALL OPERATOR COMPLAINTS OF LOW POWER POOR ACCELERATION, ETC			

INSPECTOR'S COMMENTS

ES REPAIRS are to be done as a RESULT of this inspection, NOT as a part of it
SERVICE parts required such as oil filters are to be written on the UNIT'S WORK ORDER

I detect no defects or deficiencies in this motor vehicle as would be likely to affect the safety of its operation or result in its mechanical breakdown

MECHANIC'S SIGNATURE ____________________

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E

~~HO BAY MINES LTD.

"C" INSPECTION HEAVY TRUCK

ompleted every 500 hrs or 30,000 kilometres (whichever occurs first)

ı Use (X) for serviceable, (R) for repair action, and (–) for not equipped

~~IT NO	ODOMETER	WORK ORDER NO	DATE

1 CHECK VEHICLE HISTORY OF PREVIOUS WORK PERFORMED

INSPECTION CHECKPOINTS	CONC
COMPLETE "B" INSPECTION	
DRAIN CRANKCASE AND REFILL WITH ____	
GREASE CHASSIS	
APPLY NEXT SERVICE STICKER	

2. THE FOLLOWING ITEMS ARE TO BE CHECKED.

INSPECTION CHECKPOINTS	COND	INSPECTION CHECKPOINTS	CONI
AIR CLEANER ELEMENT		SHOCKS, SUSPENSION, SPRINGS	
POWER STEERING FLUID LEVEL		DRIVELINE AND U JOINTS	
POWER STEERING HOSE (CONDITION)		DIFFERENTIAL LUBRICANT LEVEL	
RADIATOR COOLANT LEVEL		TRANSMISSION LUBRICANT LEVEL (ALLISON HOT)	
~~LANT STRENGTH MINIMUM ~~ner –34°F (–30°C) Winter –40°F (–40°C)		TRANSMISSION AND DIFFERENTIAL BREATHER	
		TIRES (CONDITION AND INFLATION)	
~~DIATOR AND HEATER HOSE (CONDITION)		WINDSHIELD WIPER (OPERATION AND CONDITION)	
BUG SCREEN AND SHUTTER (OPERATION)		GLASS AND MIRROR (CONDITION)	
BATTERY ELECTROLYTE LEVEL		ALL LIGHTS (OPERATION AND CONDITION)	
BATTERY TERMINALS AND MOUNTS		REFLECTOR (CONDITION)	
FAN BELT (CONDITION AND TENSION)		MUD FLAP (CONDITION)	
BRAKE (ADJUSTMENT)		CHECK LUBRICANT LEVELS	
DRAIN AIR TANKS		GREASE ALL MISC. ATTACHED EQUIPMENT	
EMERGENCY BRAKE (OPERATION)		START ENGINE, RUN, SHUT OFF & CHECK FOR OIL LEAKS	
CLUTCH PEDAL (ADJUSTMENT)		RECHECK OIL LEVEL	

INSPECTOR S COMMENTS:

NOTES: REPAIRS are to be done as a RESULT of this inspection, not as a part of it
SERVICE parts required such as oil filters are to be written on the UNIT'S WORK ORDER

. detect no defects or deficiencies in this motor vehicle as would be likely to affect the safety of its operation or result in its mechanical breakdown

MECHANIC'S SIGNATURE ____

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PENALTIES FOR INFRACTIONS OF RULES OF THE ROAD

a. **Exceeding of speed limits:**

- i First offence - three (3) day suspension without pay,
- ii Second offence - seven (7) day suspension without pay,
- iii. Third offence - the driver will be banned form driving on the Winter Ice Road for the remainder of the haul season
- iv Accident resulting from speeding the driver will be banned from driving on the Winter Ice Road for the remainder of the haul season

b. **Alcohol and Drugs:**

- i Immediate dismissal and the driver will be permanently banned from driving on the Winter Ice Road and will not be permitted to continue or complete the trip

c. **Vehicle separation infractions:**

- i First offence - written warning
- ii Second offence - three (3) day suspension without pay;
- iii Third offence - seven (7) day suspension without pay;
- iv Fourth offence - the driver will be banned from driving on the road for the remainder of the haul season.

d. **Interference with road maintenance activities:**

- i. First offence - written offence;
- ii. Second offence - the driver will be banned from driving on the Winter Ice Road for the remainder of the haul season

e. **Ignoring a road closure posting:**

- i First offence - seven (7) day suspension without pay;
- ii Second offence - the driver will be banned from driving on the Winter Ice Road for the remainder of the haul season.

f. Non-reporting of fuel or chemical spills:

i First offence - seven (7) day suspension without pay,

ii. Second offence - will be subject to immediate dismissal

f.1. Fuel or chemical spills caused by driver neglect:

i Driver will be subject to immediate dismissal

g. Failure to observe required rest period:

i First offence - warning,

ii Second offence - three (3) day suspension without pay;

iii Third offence - seven (7) day suspension without pay,

iv Fourth offence - the driver will be banned from driving on the Winter Ice Road for the remainder of the haul season

h. Refusal to stop when requested to do so:

Immediate dismissal

i. N.S.C. Regulation: **Pre-trip/daily vehicle inspection and proper log book recording will be completed in accordance with applicable regulation. Failure to do so will result in:**

i. First offence - written warning

ii Second offence - three (3) day suspension without pay,

iii Third offence - immediate dismissal.

DRIVER INSTRUCTIONS

1 You will report directly to the Lockhart Dispatcher

2 You are to report all servicing and repairs required on your vehicle

3. you are not to overnight in Yellowknife unless broken down, or in excess of hours of service

4 Your loads will be set by the Dispatcher located at Lockhart Lake Camp
You must have a "fill slip" to load at the Petro Canada Plant This slip will be provided by the Dispatcher You must receive instructions from the Petro Canada Loader, the first time you load

5 Your speed limit will be set and posted by the Road Superintendent and enforced through the Road Patrol

6 You may have emergency repairs carried out at·
   a. Lupin Mine Site or Road Camps
   b All major repair work will be carried out in the Yellowknife Shop

7 You are to run with at least one other truck at all times It may be a haul contractor's truck, a lease truck, or the other Echo Bay Mines Ltd units

8 You are responsible for ensuring you have adequate winter clothing to temperatures of -50 degrees F, a good sleeping bag and emergency rations (rations may obtained from either Camp

9 You are to ensure that you have sufficient fuel in you running tanks at all times (it gets cold when a truck stops if sitting in a storm.)
In addition, the following fuel management is to be carried out:
   a Fuel tanks are to be full when leaving Yellowknife Northbound and all unit's are to be topped up at Lockhart lake Camp on Northbound leg
   b All units have access to fuel and Lac De Gras and Lupin if necessary, due to weather or unforeseen circumstances

10 Prior to loading units must be visually inspected according to N S C regulations and recorded per the "Driver Visual Inspection Form" (This includes springs, tires, lights, brakes, oil/fuel leaks, etc .)

11 You are comply with the rules and regulations of the National Safety Code (N S C)

RULES OF THE ROAD FOR HAUL VEHICLES

i All vehicles are subject to search by Echo Bay at any time while on the Winter Ice Road, and at either of the road camps

ii All speed limits will be set and monitored by Echo Bay and will be passed to haul contractor's representatives on the Winter Ice Road, or posted, or both.

iii All alcohol and drugs are prohibited on the Winter Ice Road, at the road camps and at Lupin.

iv Vehicle separation is critical to the safety and success of the haul operation and vehicles are not permitted to run alone A minimum of two (2) units must be together at all times A minimum separation of one-half (1/2) kilometre between vehicles is mandatory

v Road maintenance takes precedence over all other activities and interference with road maintenance is therefore prohibited.

vi Road closure will be set up by Echo Bay, as required at its sole discretion, with such closures being posted at each road camp, Lupin and at Yellowknife Shop

vii Fuel and chemical spills must be immediately reported to Echo Bay Dispatch at Lockhart Lake Camp, who in turn will notify the Environmental Protection Agency through the "Spill Line" (Phone 403-920-8130, Fax 403-873-6924)

viii. Drivers are required to rest a minimum of eight (8) hours in any twenty-four (24) hour period, and in accordance with N S.C. Regulations

ix All drivers must stop when requested to do so by Echo Bay or haul contractor's personnel

ECHO BAY MINES LTD.
WINTER ROAD - B TRAIN
SAFETY PROGRAM

All Echo Bay Mines Ltd. Winter Road/B Train Personnel will be issued a copy of rules and regulations pertaining to the safe conduct and operations of the Winter Road A signed acknowledgement of review/familiarity will be submitted to the employer by the employee (Copy of rules and regulations enclosed).

Two emergency response units will be maintained and located along the Winter Road route One unit to be located at Lockhart Lake Camp Facility and one unit to be located at the Lac De Gras Camp Facility

Eleven Winter Road personnel will be trained (by Echo Bay Mines - Lupin Safety Department) to perform emergency response and recovery duties. Trained individuals will be located at all pertinent facilities (Yellowknife, Lockhart Lake, Lac De Gras, Lupin and Edmonton).

The registered Echo Bay Mines "Oil and Toxic Spill Contingency Plan" will be in place and carried out in accordance to the plan (Copy Attached)

Echo Bay Winter Road:

Floyd Richardson - Phone: (403) 920-4835 Yellowknife Shop
(403) 963-6145 Home

Alternate Contacts:

Phil Flaumitsch - Winter Road Superintendent
Phone (403) 429-5831 Edmonton Office
(403) 962-6721 Home

Andy Hamel - Winter Road Dispatcher
Phone (403) 429-5838 Edmonton Office
(403) 986-0122 Home

Winter Road Camps:

Phone (403) 429-5888 Lac De Gras

(403) T.B.A Lockhart Lake

Lupin Mine Site:

Phone (403) 429-8750 Main Switchboard

Phone: (403) 429-8764 Weather Station (24 Hour)

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DISTANCE YELLOWKNIFE – LUPIN

		KM	MILES
Yellowknife To:		0	0
Tibbit Lake		70	43
South Gordon Lake		121	75
North Gordon Lake		164	102
South Brown Lake		178	111
North Brown Lake		185	115
South Drybones Lake		212	132
North Drybones Lake		222	138
Lockhart Camp	7 HRS	238	148
North Lockhart Lake		248	154
South Warbuton Bay		250	155
North Warbuton Bay		259	161
Portage Bay		298	185
North McKay Lake		383	238
Lac De Gras Camp	5 HRS	407	253
North Lac De Gras Lake		430	267
North Lac Sauvage Lake		451	280
South Hardy Lake		470	292
South Pallet Lake		491	305
North Pallet Lake		520	323
South Contwoyto Lake		523	325
Lupin Camp	7 HRS	637	396

08-Nov-91

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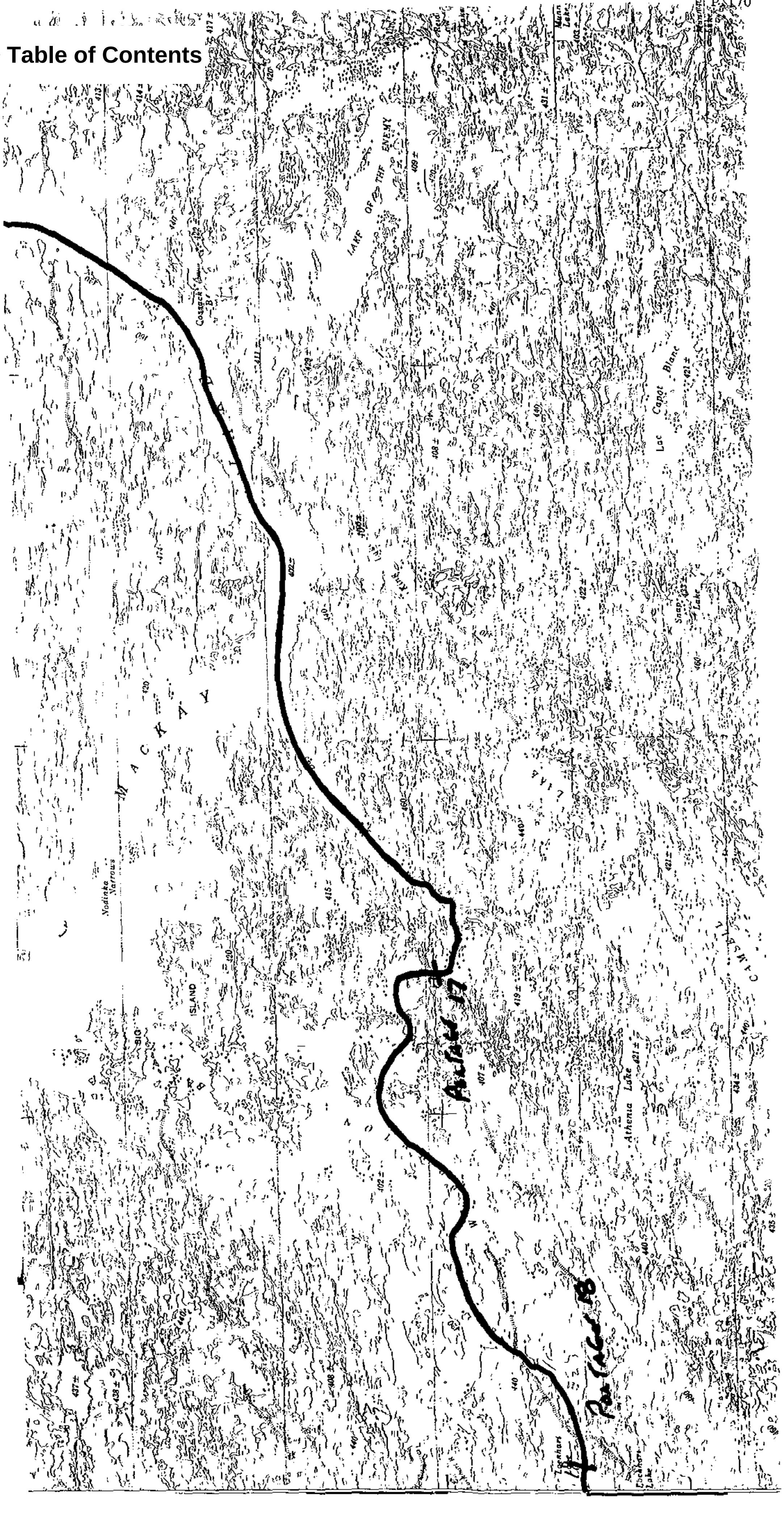

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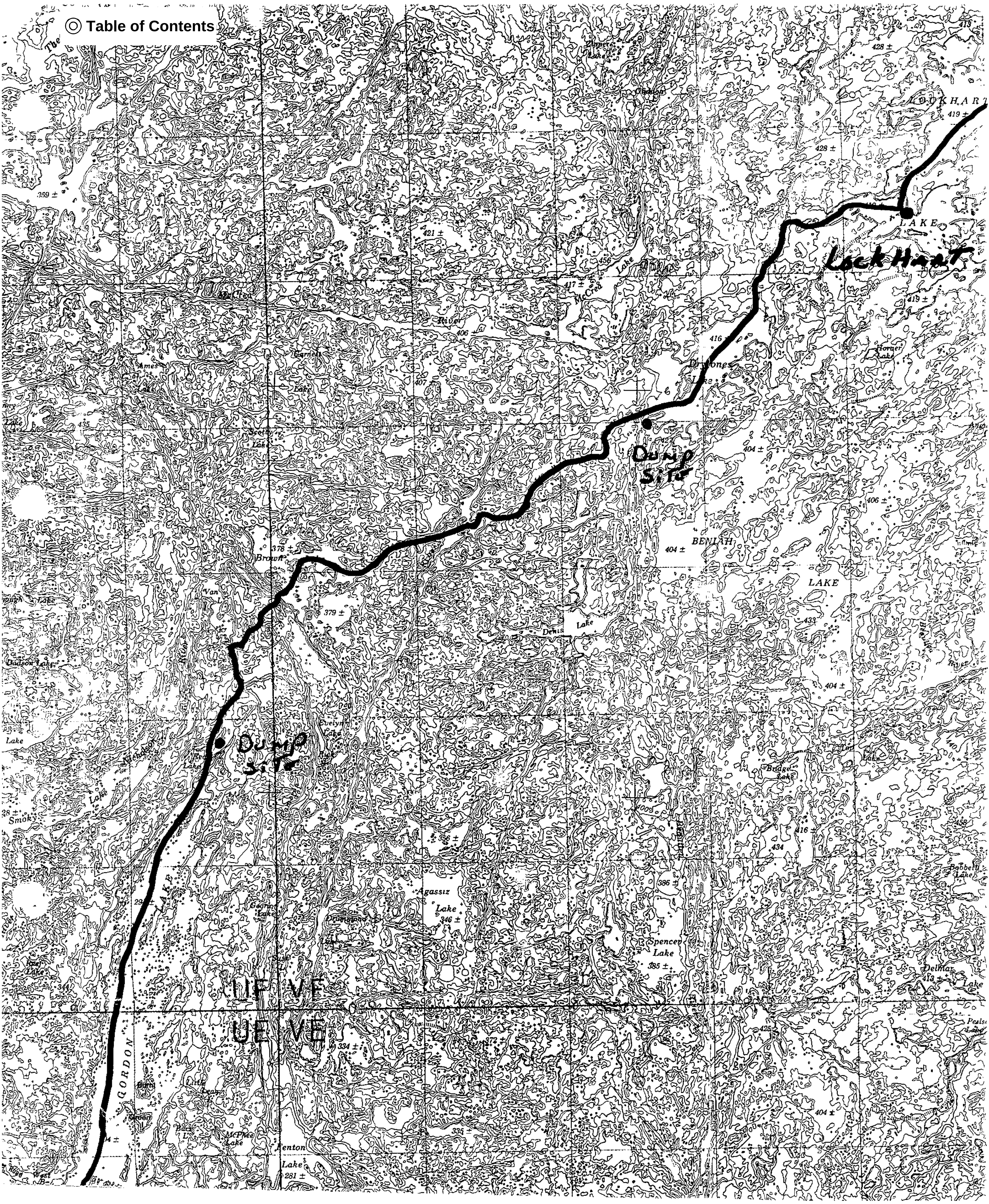

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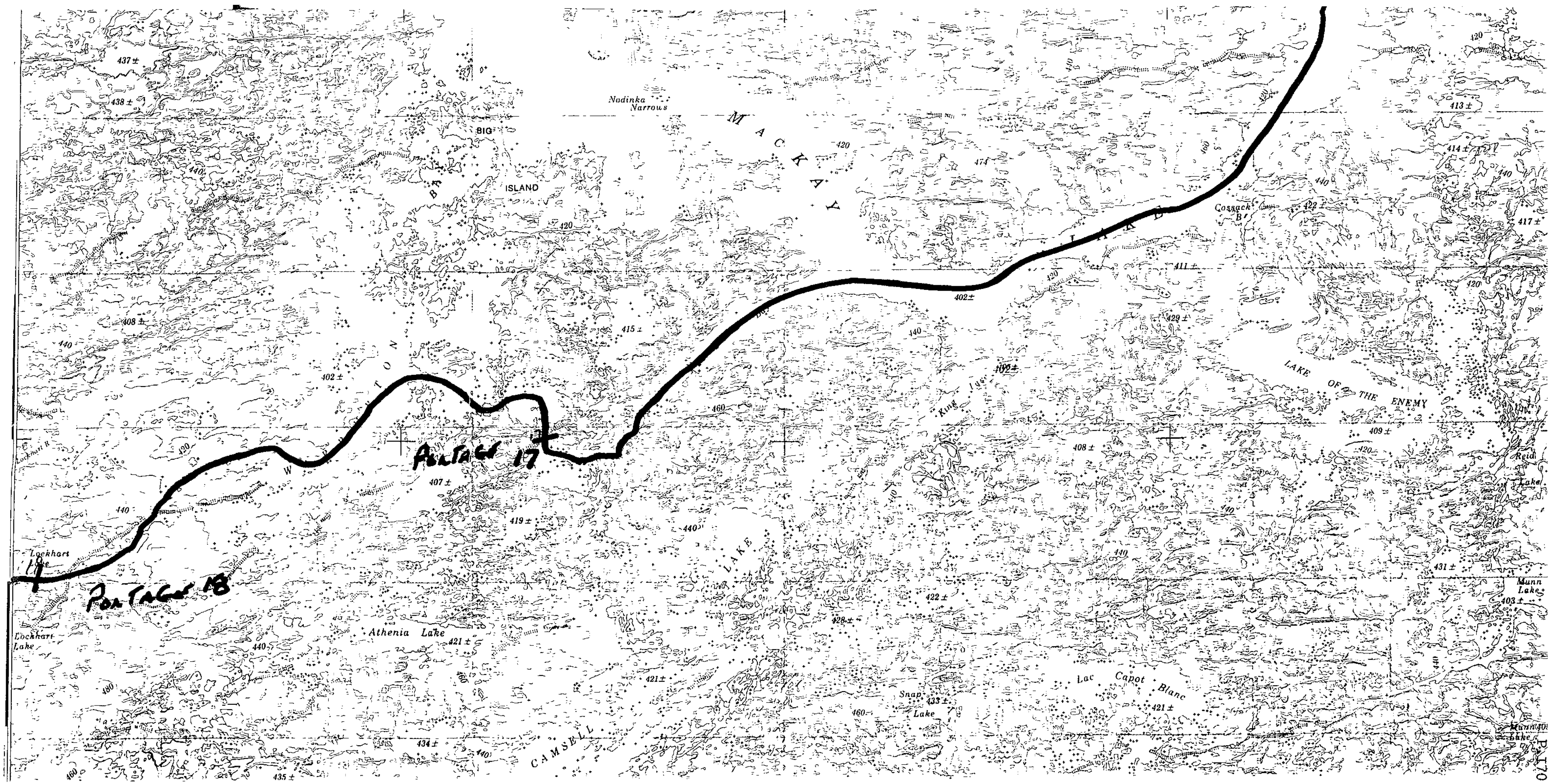

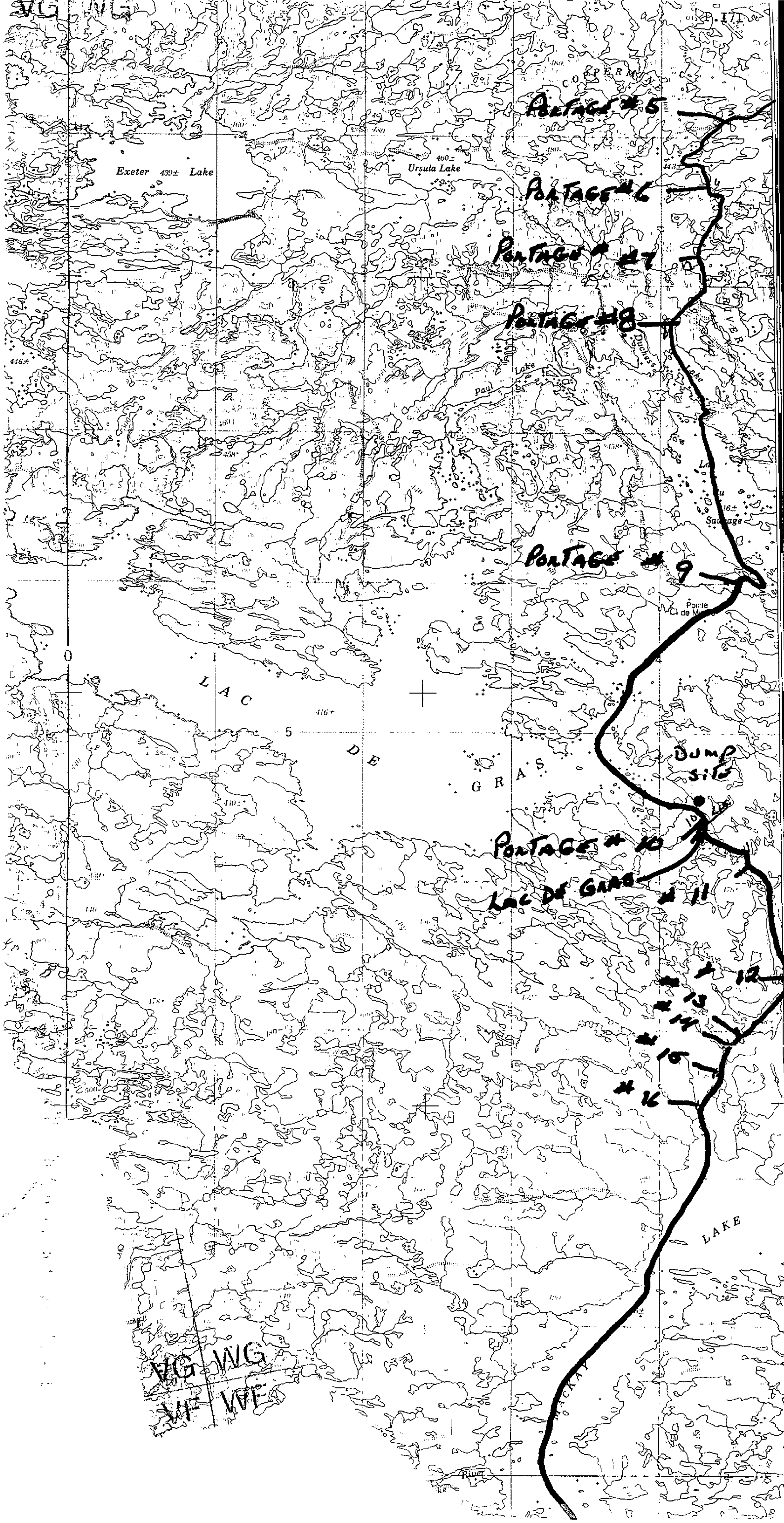

PORTAGE #5
PORTAGE #6
PORTAGE #7
PORTAGE #8
PORTAGE #9
DUMP SITE
PORTAGE #10
LAC DE GRAS #11
#12
#13
#14
#15
#16
Exeter 439± Lake
Ursula Lake
Paul Lake
LAC DE GRAS
416±
RIVER
LAKE
River
VG WG
VF WF

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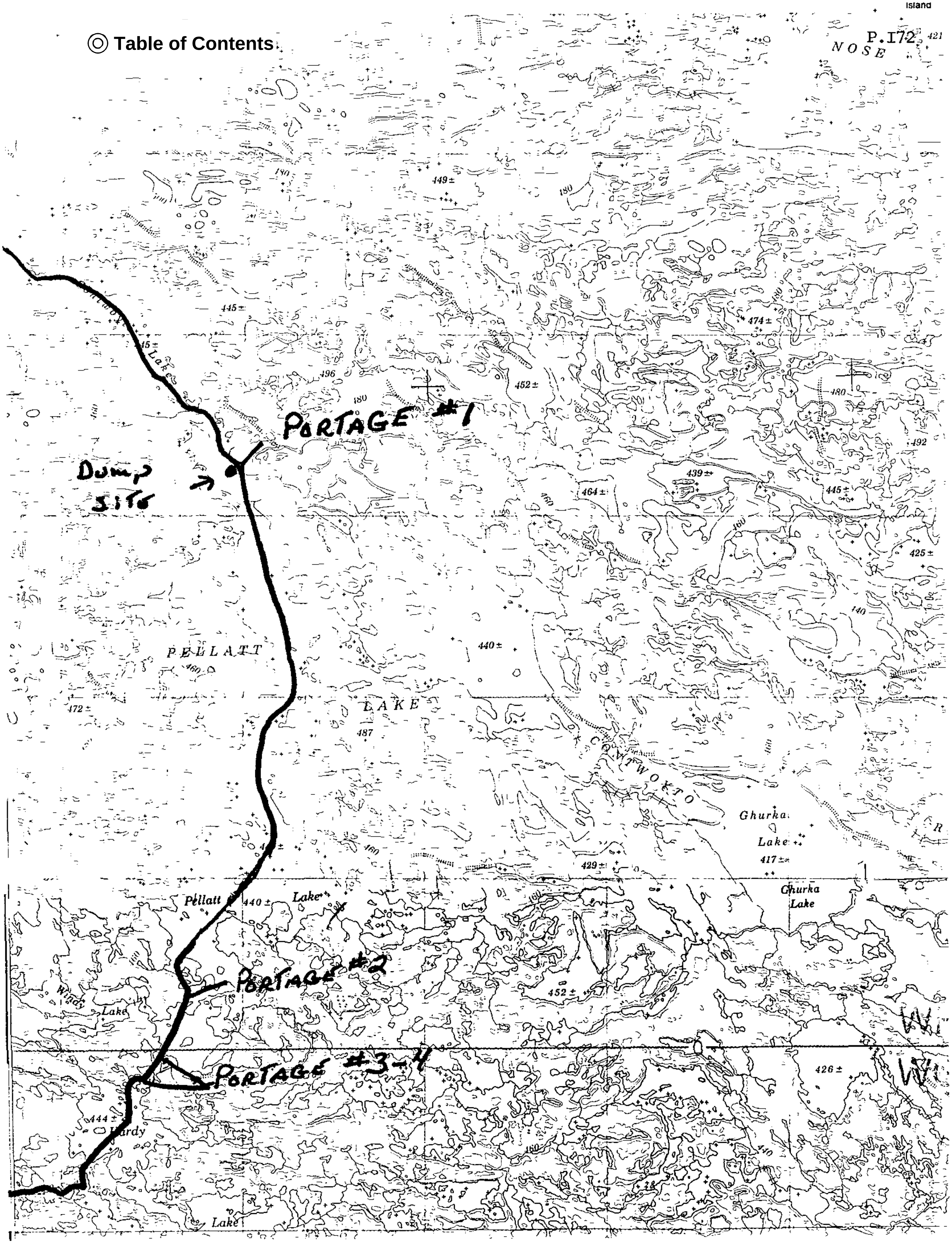

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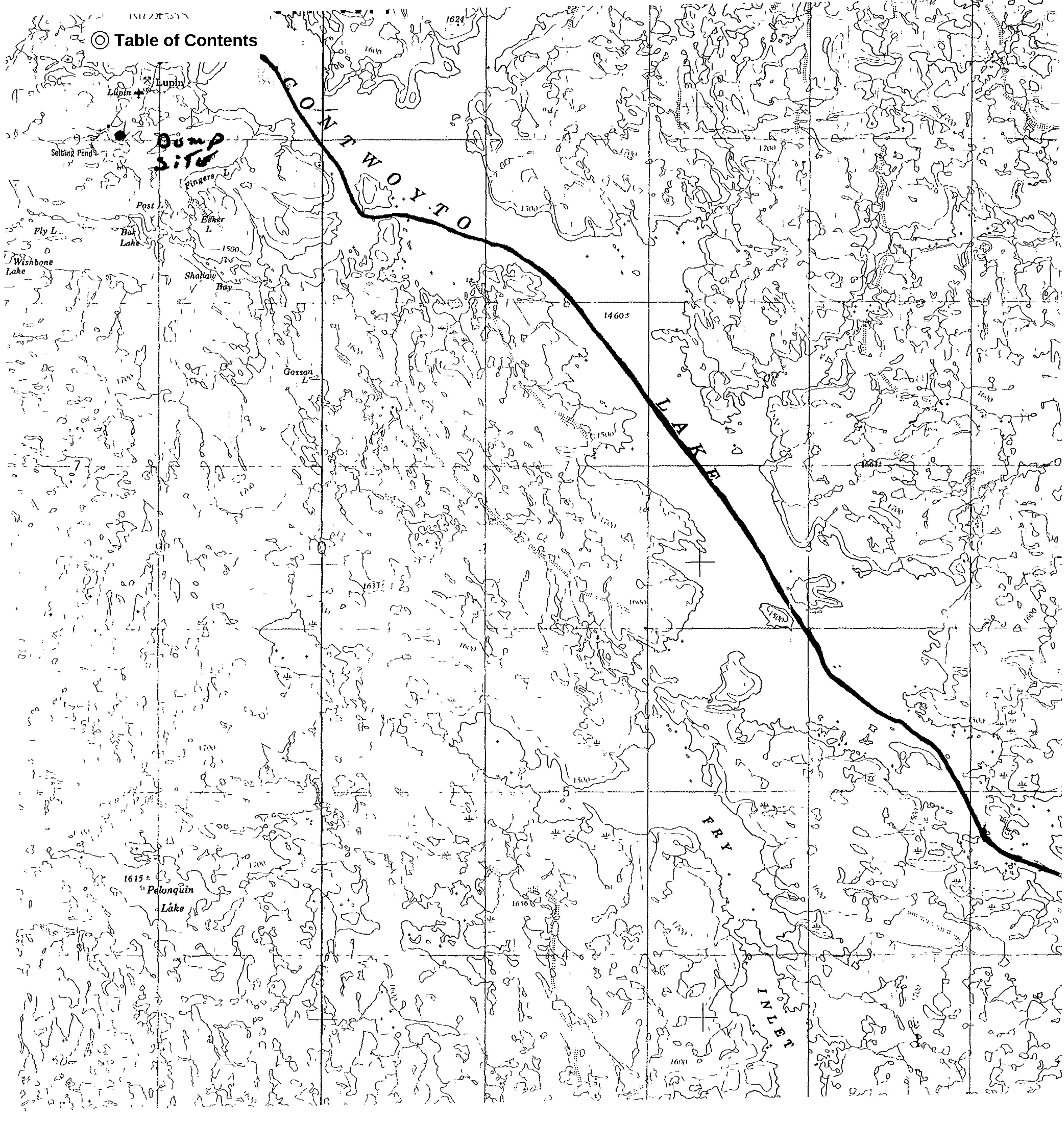

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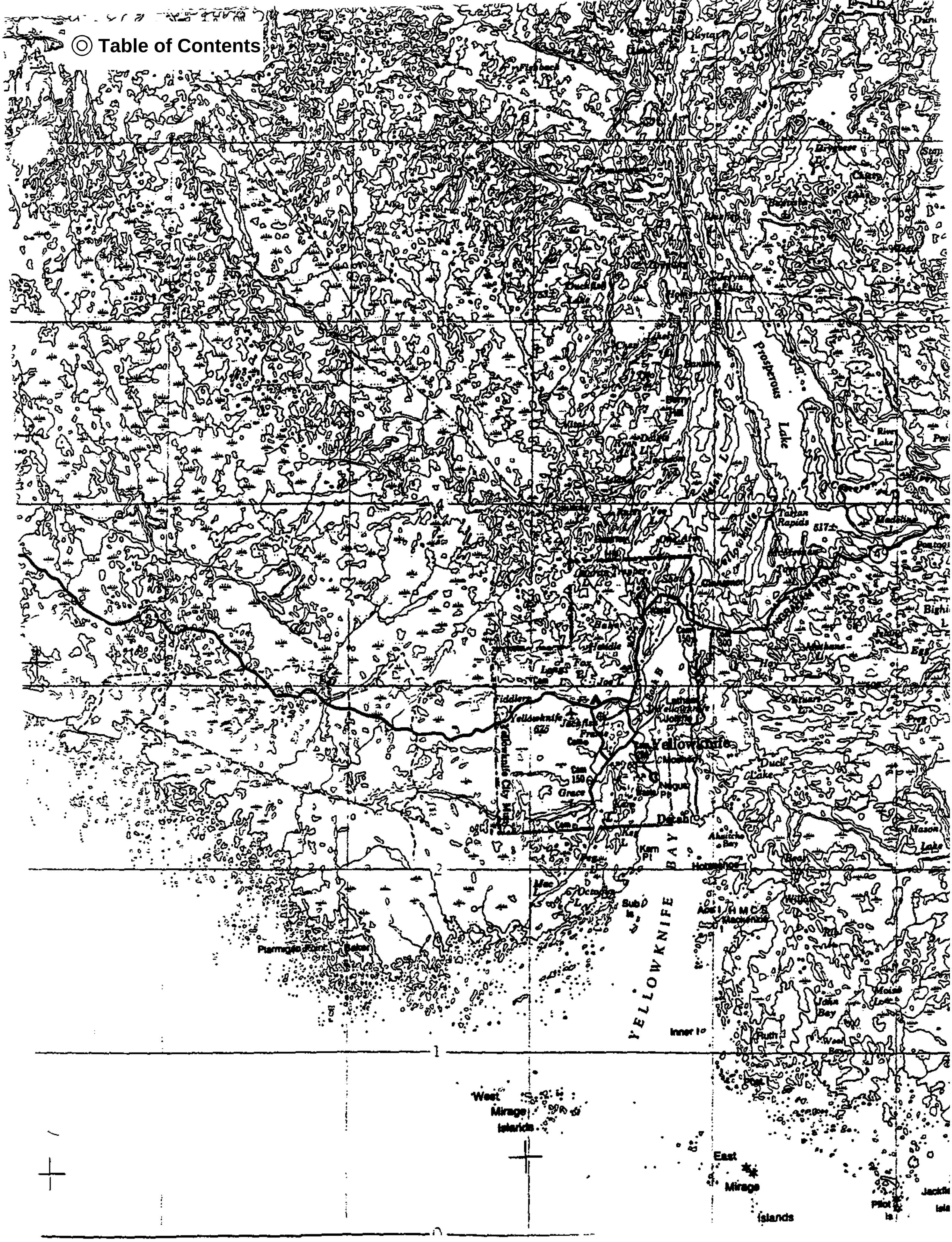

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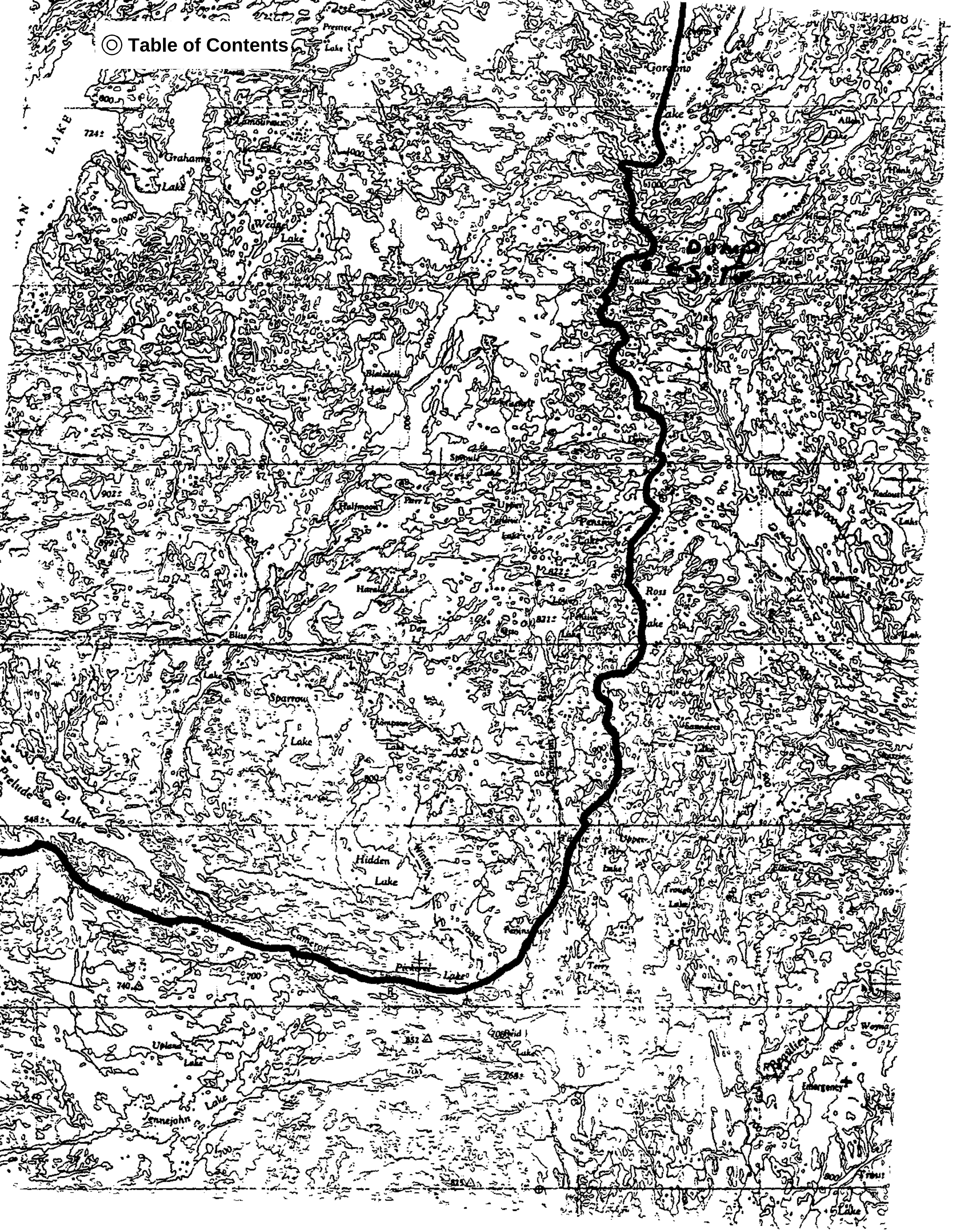

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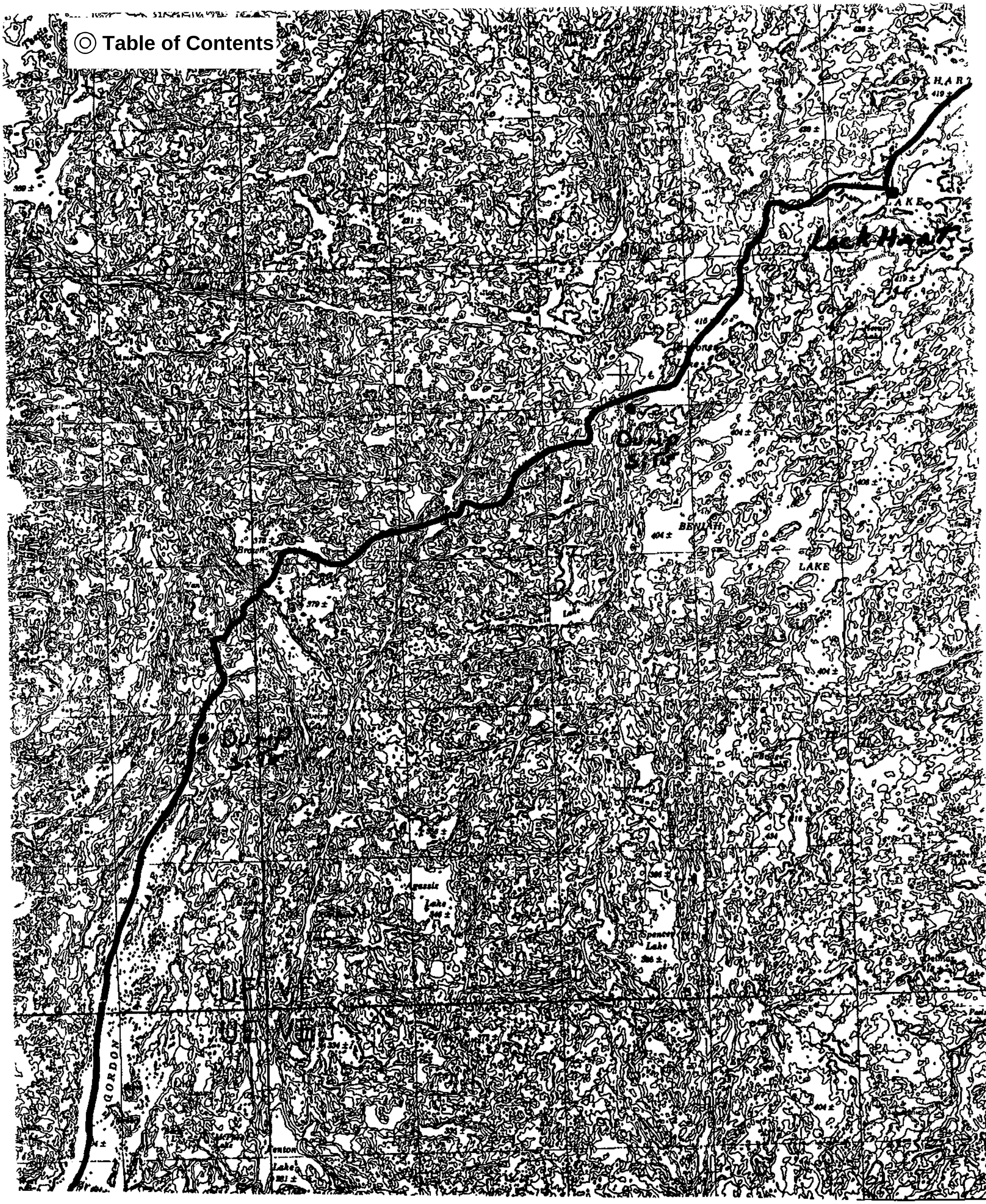

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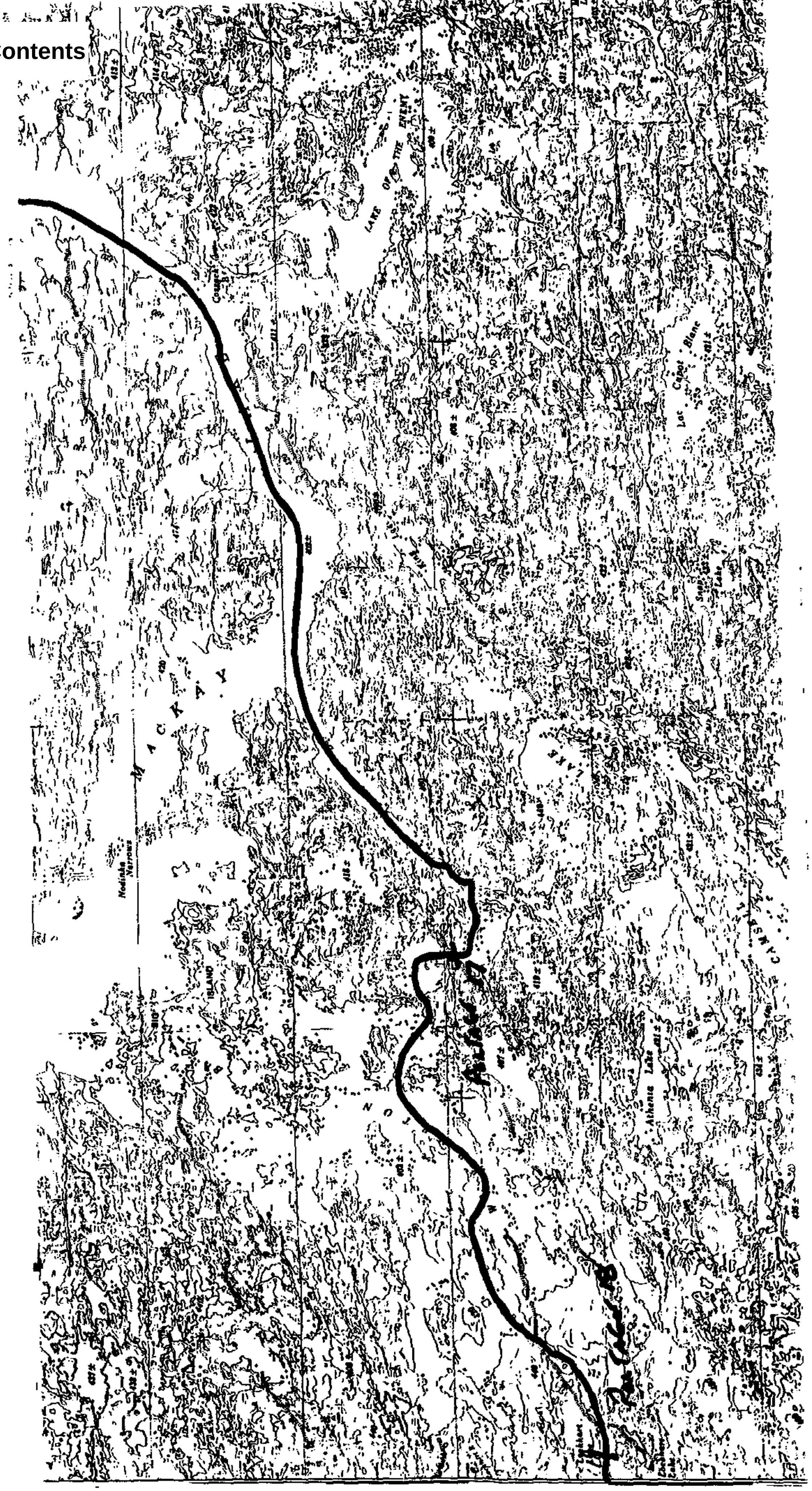

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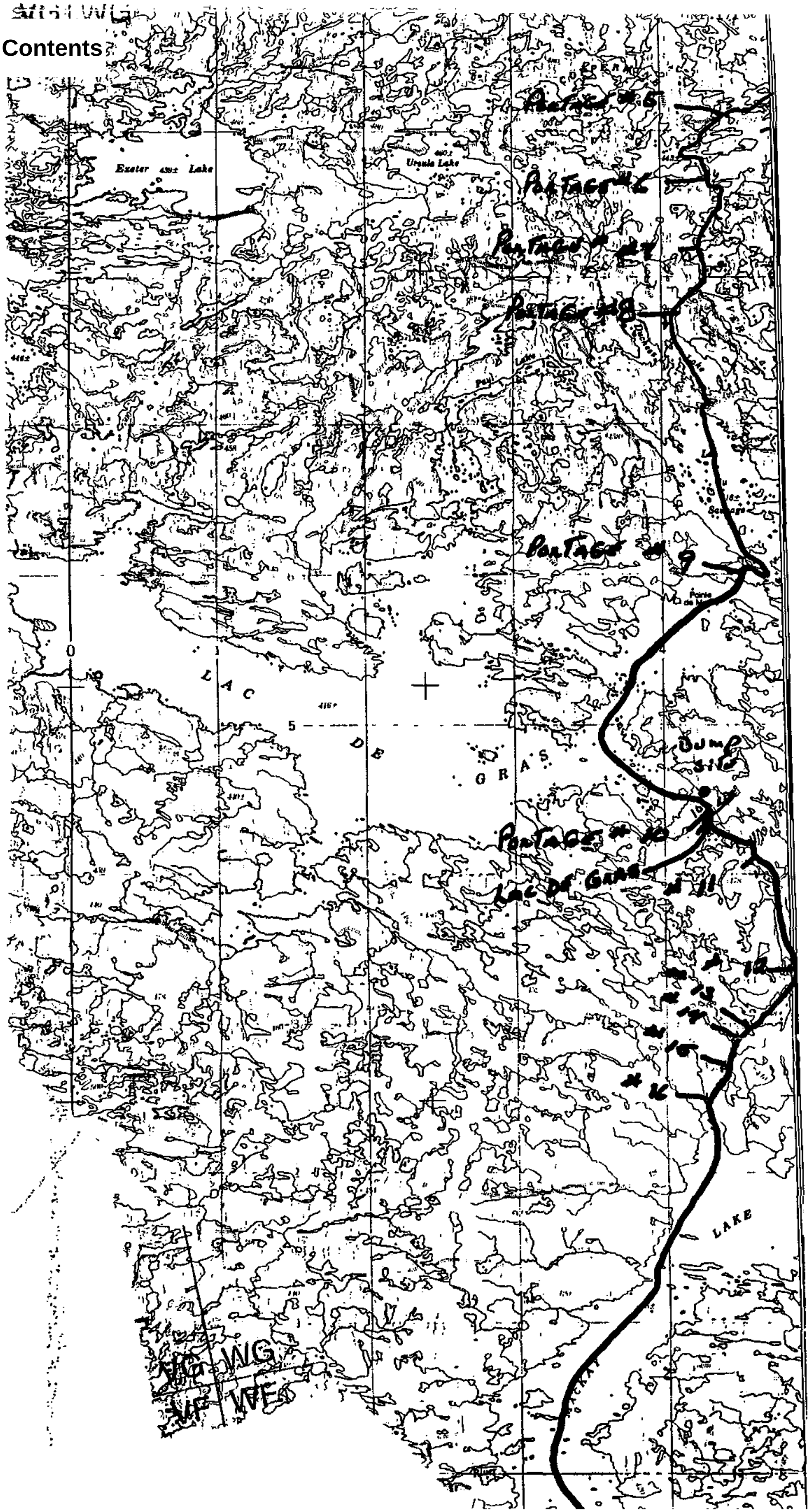

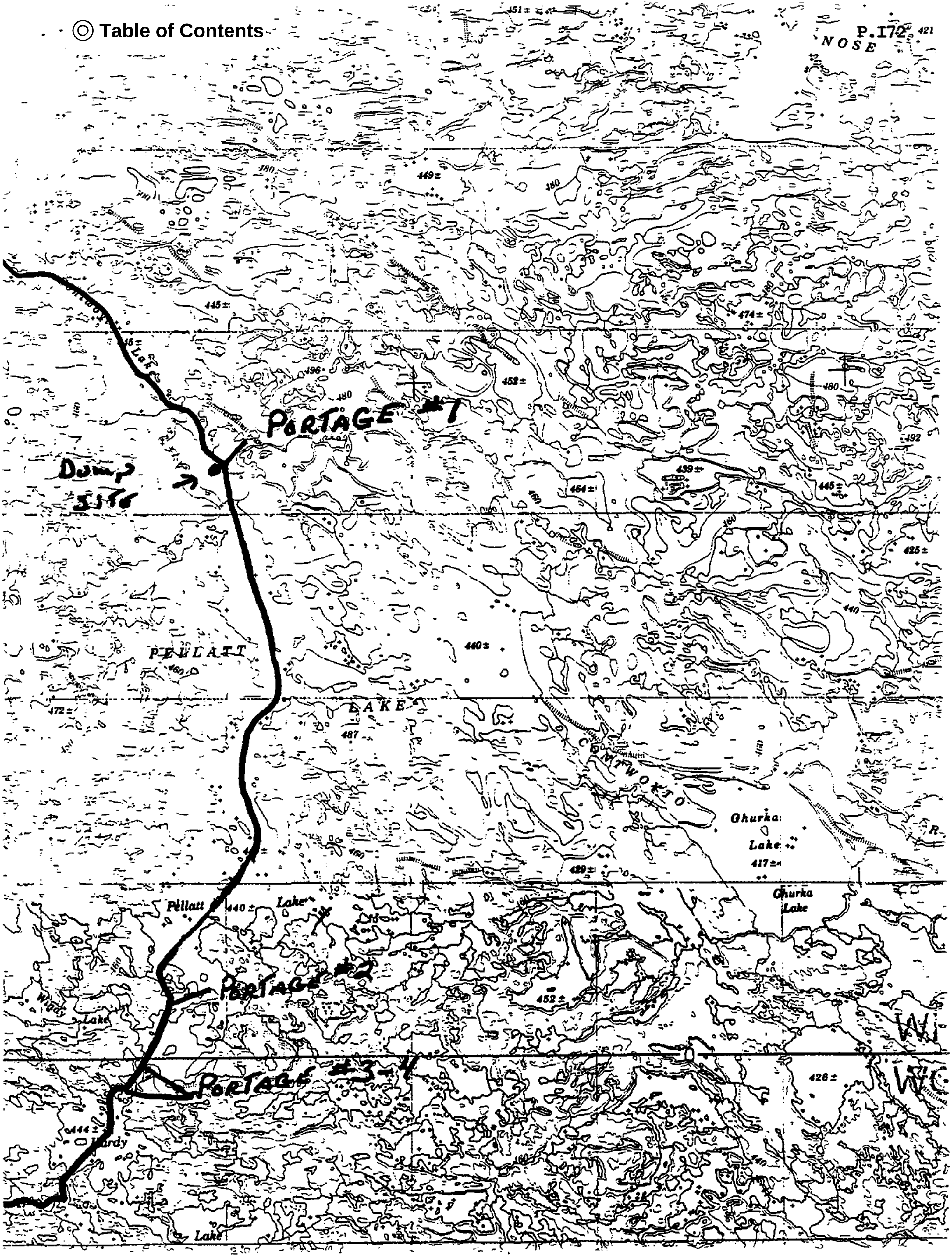
NOSE
PORTAGE #1
Dump Site
PELLATT
LAKE
CONTWOYTO
Ghurka Lake
Pellatt Lake
PORTAGE #2
Wiggy Lake
PORTAGE #3-4
Hardy
Lake

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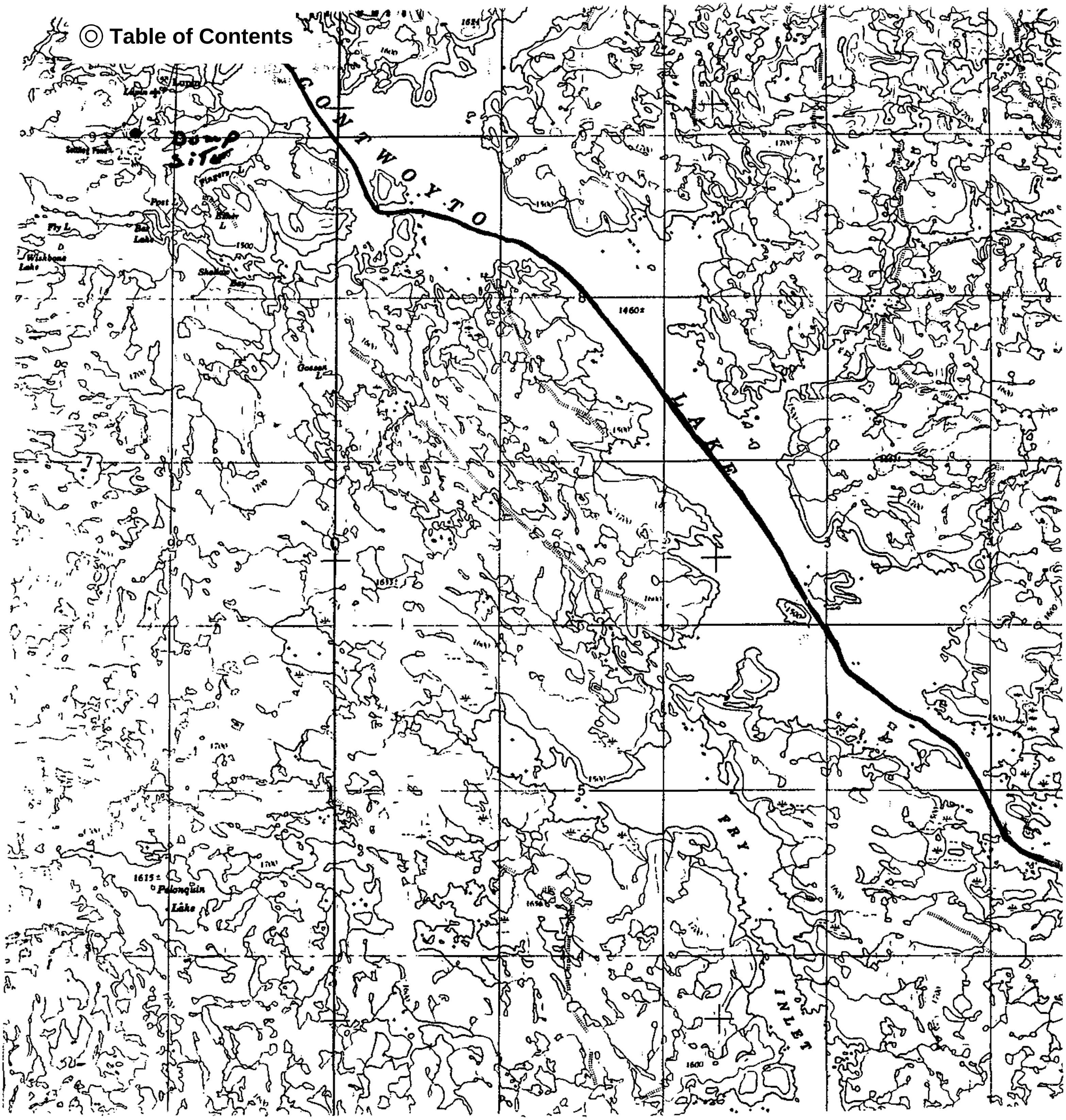

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KOALA LAKE WINTER ACCESS ROAD
INVESTIGATION 1994/95
FINAL REPORT
113418

FOR

BHP MINERALS CANADA

BY

D. Masterson

P. Spencer

W. Graham

SANDWELL INC.

May 1995

Approved by:
D.M. Masterson
Project Manager

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EXECUTIVE SUMMARY

A survey of the winter access road to Koala Camp and the Lupin Mine site was conducted during the 1994 - 95 winter season. The survey data collected were the ice thickness during road opening in December 1994, an ice and snow thickness survey to Lockhart Camp conducted in January 1995 and an electronic thickness survey to Koala Camp conducted in March 1995 Also conducted in March/April 1995 were measurements on the dynamic response of the road at portages and a journey to Lupin Mine with a fuel truck.

The 1994-95 winter at Yellowknife and at Lupin Mine was warmer than long time temperature records indicate. This lead to thinner-than-normal ice thickness along the route

We have reached the following conclusions which are listed as follows

1. The trip Dan Masterson made with the fuel truck and the observations made during the subsequent field measurement program indicate that, generally, the operation and use of the road for fuel and supply hauls is properly done, with due regard for safety being taken Speed limits and minimum vehicle spacings are enforced and observed There are areas where improvements could be made and these are discussed in Section 4 None of the improvements involve major changes in the operation of the road.

2 The continuous electronic profile reveals that on the south end of the road it may be difficult, even during a year with average air temperature and snow fall, to obtain the required 1 7 m of ice to haul the large 85 t loads Certainly a very diligent program of snow removal from early in the season would be required. This year was not average, with both temperatures and snowfall being significantly above average.

   On the northern part of the road, from Lockhart Camp north, most years would yield the required thickness if the road alignment were not changed during the season because of accumulated snow or surface cracking of the ice This section of road would have to be opened in December as well.

   It will be necessary to examine the possibility of reducing the total load by using different hauling

techniques and of reducing the ice flexural stress by load redistribution Increasing the allowable stress has been investigated and we have concluded this is not a viable option

3. Dynamic measurements made near shore do indicate dynamic amplification of deflection and stress in the ice The current thicknesses required for hauling loads plus the restriction on speeds, especially at approaches to the portages and in shallow water bodies, appear to adequately address dynamic effects.

4. Surface cracking of the road, caused by a combination of thermal stress and tensile stress induced by deep snow banks from snow removal, result in a rough travelling surface, spalling of the ice by truck wheels and the consequent need to realign the road. Keeping the road wider, by the use of more snow plows and snow blowers would significantly alleviate this problem.

5. Flexural fatigue of the ice due to the frequent, repeated passage of loads has been mentioned as a potential issue, especially if the traffic on the winter road is increased in the future. Flexural fatigue is a different phenomenon from the above mentioned surface spalling and deterioration and is also different from the near-shore dynamics discussed Fatigue of metals occurs when they fail at stress levels well below their yield strength after thousands or millions of load repetitions and stress reversals.

   In 1978, Sohio BP used an ice road at Prudhoe Bay, Alaska to haul 105,000 cubic yards (113,000 m^3) of gravel over a thirty day period Approximately 5,200 loads, weighing between 41 tonnes and 68 tonnes traversed a road between 1 7 m and 2 m thick. At peak times, there was a truck passing a given point every 3 minutes There was surface spalling and rutting of the road, necessitating repairs, but there was no evidence from stress and deflection measurements that the ice was fatiguing in flexure. There were, as a consequence, no incidences of loaded trucks failing the ice Imperial Oil hauled similar amounts of gravel in the Mackenzie Delta for their island building in the 1970's and they reported no flexural fatigue.

   Load histories for the Lupin Mine winter road indicate that, approximately, the following number of loads have passed over the road since 1989 An average load of 110,000 lbs. or 50,000 kg was used to convert the tonnages to loads.

LUPIN MINE ROAD HAULAGE DATA

Year	First Load at Lupin	Last Load at Lupin	Total Tonnage	No. of Loads
1989	Feb 14	Apr 7	24,457	445
1990	Feb 1	Mar 22	24,020	437
1991	Jan 23	Mar 13	24,032	437
1992	Jan 28	Mar 22	23,380	425
1993	Feb 3	Apr 1	27,525	500
1994	Jan 18	Apr 3	55,738	1013
1995	Jan 25		54,302	987

The tonnage and number of loads has approximately doubled in the last two years without compromising the safety of the road This traffic occurs over a period of approximately 50 days and thus the frequency for a thousand loads is 20 loads per day At Prudhoe Bay the frequency was 173 loads per day or approximately 9 times the frequency of traffic on the Lupin road. Increasing the traffic on the Lupin winter road by threefold to 3000 loads over 50 days will result in a frequency of 60 loads per day, still only 35 percent of the frequency on the gravel haul road at Prudhoe.

The design flexural stress levels for the gravel haul road at Prudhoe and for the Lupin road are the same, being limited in both cases to the 500 kPa maximum. The electronic thickness profile has enabled us to determine that, in a "warm" year, the minimum thickness on the ice road when hauling starts during the latter part of January is 80 cm or greater This is sufficient ice to support the B-Trains, which carry reduced loads at this time, with the stress levels being held at or below the allowable 500 kPa Fatigue is heavily dependent on stress level and as long as it is held at 500 kPa or lower, flexural fatigue will not be a consideration in the use and safety of the winter road.

1.0 INTRODUCTION

BHP Minerals Canada initially retained Sandwell to conduct an engineering evaluation of the feasibility of transporting payloads of 85 tonnes or more north from Yellowknife over the Lupin Mine winter road to their site at Koala Lake Sandwell has agreed to conduct this engineering work and to provide BHP with a field report and an operations manual for use in the design and planning of future winter roads.

The critical issues, for this project, in the engineering of these roads are the crossing of lakes using the naturally formed floating ice as a support for the heavy loads contemplated and as a support for significantly increased regular traffic of loads of fuel and other supplies for the Koala mine. The supply of the Koala mine by BHP would be in addition to the supply of the Lupin mine by Echo Bay, thus resulting in the increased traffic. Ice of sufficient thickness and strength must be present and the speeds at which the transport vehicles cross the floating ice must be controlled to minimize the adverse effects of dynamics. Dynamic effects are particularly of concern in shallow water and on smaller lakes

While the ambient temperatures between Yellowknife and the mine site are well below the freezing point in the winter and there is little sunlight to interfere with ice growth, snow cover, water flow and heat sources from the lakes and rivers may prevent the growth of sufficient ice thickness required to support the expected loads Sandwell addressed, in as complete a manner as possible given the budget and time frame, the issues which have major impacts on the feasibility of the use of the winter road for the purposes intended in first interim report submitted in August 1994

Between January 7 and 14, 1995, Dan Masterson of Sandwell visited the winter road and conducted, with the assistance of Echo Bay personnel, an ice thickness survey of the road Both ice thicknesses along the center line of the over-water portion of the road between the Ingrahm Trail and MacKay Lake were obtained, along with the ice thicknesses in the week of December 7 to 14, 1994 when the road was being opened An additional field investigation was conducted by Sandwell between March 23 and April 3, 1995 The investigation included a trip as a passenger with a B-Train fuel truck over the road, an ice thickness survey using ground penetrating radar and dynamic response measurements of the ice near shore.

This report covers the field investigation parts of the project and the subsequent data reduction and analysis. The "Operations Manual" will be a separate document to follow.

2.0 MEASURED ICE THICKNESSES - DECEMBER 1994

The main emphasis of thickness measurements has been on the southern portion of the road since this is usually where the thinnest ice is found This is a consequence of warmer temperatures and the fact that this portion of the road lies below the treeline and is thus protected somewhat from winds Thus if there is to be a shortage of ice for the design loads specified in the August, 1994 Sandwell report to BHP, then it is likely to be in this area. The section of road in question is shown on the 1:500,000 maps of Figures 2.1 and 2.2. From the Ingrahm Trail to Lockhart Camp, there is approximately 175 km of road and about 100 km of this road consists of floating ice over water bodies

A summary of the ice thickness measurements made by Echo Bay personnel in December, 1994 when the road was opened from the Ingrahm Trail to Lockhart Camp is presented in Table 2 1 below The individual measurements are tabulated in Appendix A.

TABLE 2.1 - SUMMARY OF ICE THICKNESSES, DECEMBER 7 - 14, 1994

LOCATION	Avg. (cm)	Std. Dev. (cm)	Min. (cm)	Max. (cm)	No. Obs.
Tibbit Lake	35	4	30	43	8
Lakes N. of Tibbit & S of Ross Lake	34	4	20	43	39
Ross Lake	41	5	33	48	8
Pensive Lake & Dome Lake	37	2	33	41	9
Waite Lake	41	5	30	48	15
Small Lake North of Waite & Lee Lake	40	6	30	48	12
Gordon Lake (45 km long)	37	4	30	43	12
Lakes between Gordon & Drybones	45	9	33	61	34
Drybones Lake	46	5	36	56	17
Lockhart Lake	53	6	46	64	12
Summary of all measurements	41	8	20	64	184

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FIGURE 2.1 - WINTER ROAD, INGRAHM TRAIL TO MACKAY LAKE 1:500,000

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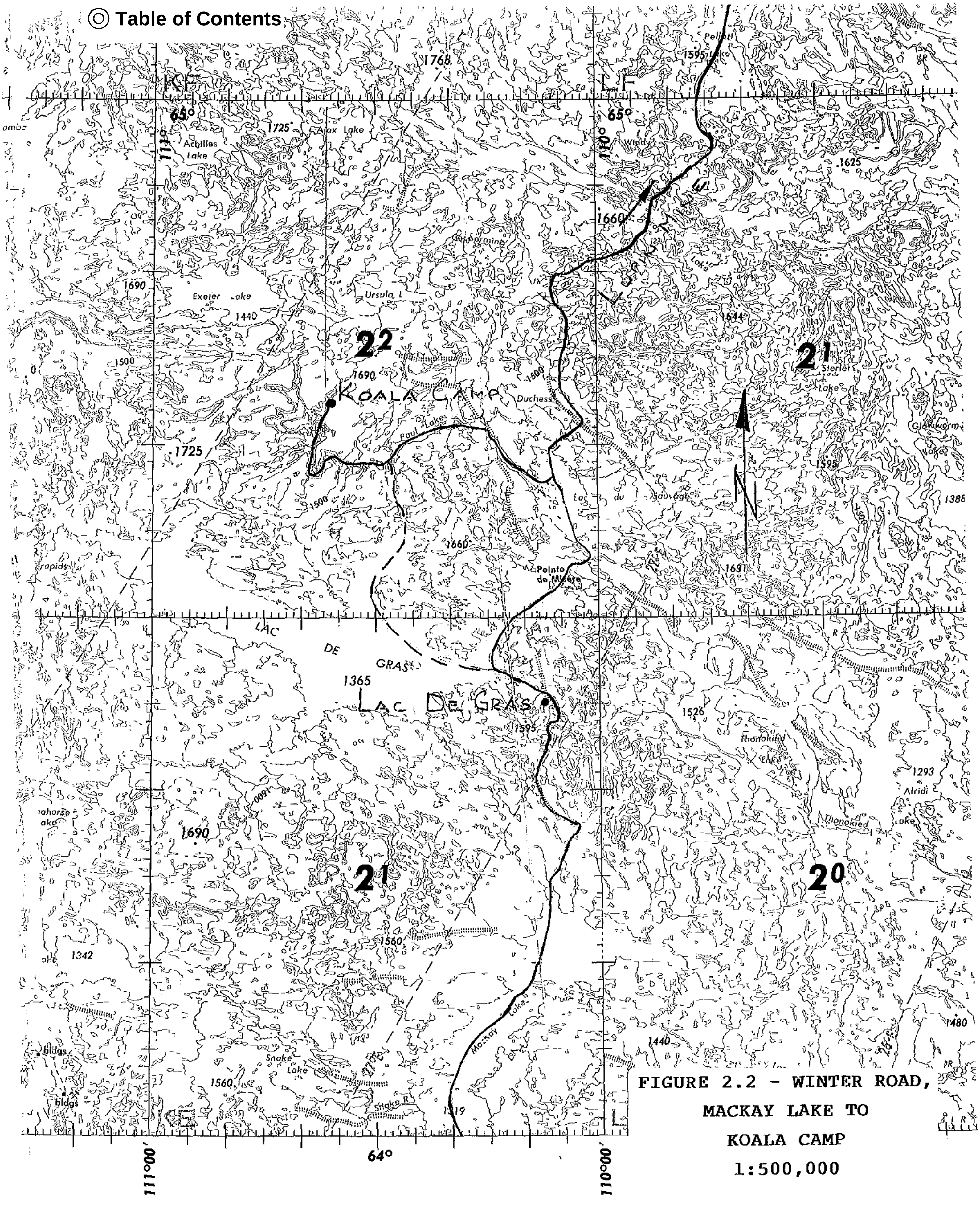


FIGURE 2.2 - WINTER ROAD, MACKAY LAKE TO KOALA CAMP 1:500,000

Note that the total number of observations at the end of Table 2 1 is more than the sum of the observations for each area since some individual measurements on small lakes are included in the grand total. The above data are of considerable use in predictions and in the planning of future winter roads which utilize the ice cover over water bodies

The average thickness overall was 41 cm or 16 in At Tibbitt Lake, the average was 35 cm or 13 8 in. while at Lockhart Lake it was 53 cm or 21 in While it is difficult to draw firm conclusions, there is an apparent trend of thicker ice as one proceeds from the Ingrahm Trail to Lockhart, Lockhart generally being regarded as the end of the treeline Both the minimums and maximums increase as one moves north as well.

Thirty years of ice thickness measurements compiled by Environment Canada, Ice Center at Back Bay near Yellowknife indicate, for the period December 10 to 16, a mean ice thickness of 55 7 cm or 22 in with a minimum of 33 cm or 13 in and a maximum of 79 cm or 31 in Thus the mean ice thickness measured between December 7 and 14, 1994 of 41 cm is 15 cm or 6 in less than the norm and is 8 cm or 3 in greater than the minimum Weather data obtained from the Yellowknife weather office for October 1994 to March 1995 are summarized in Table 2.2.

Noticeably, the temperatures in November and December were warmer than normal, especially in December Snowfall was greater than the norm, being 38 percent greater in November and 23 percent in December These factors are major contributors to the lower than normal measured ice thicknesses

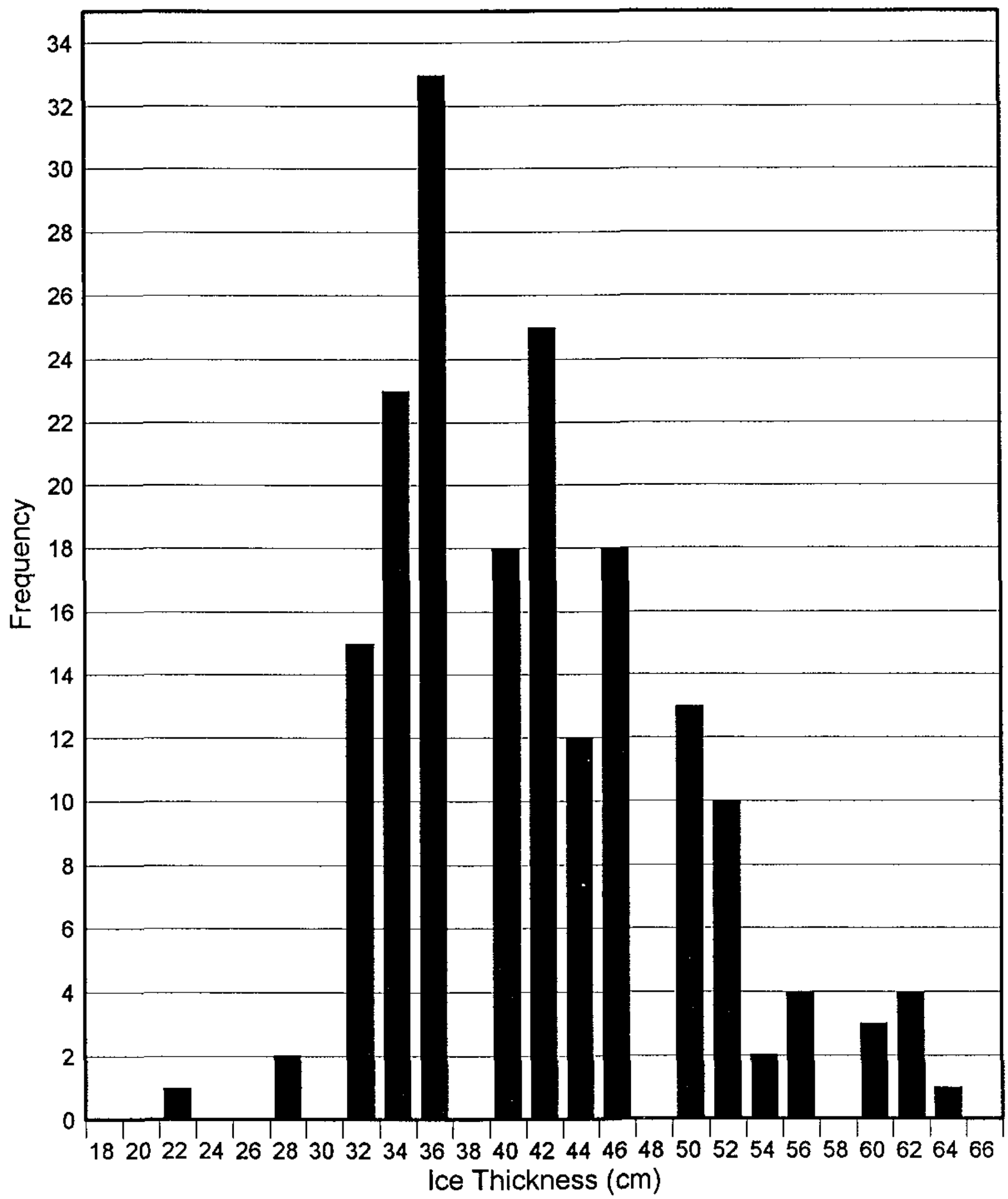
The ice thickness measurements were grouped into bins of 2 cm intervals and a histogram was produced which is shown in Figure 2 3 Examination of the histogram shows that the distribution is skewed to the right. The mode, or most frequently measured thickness, is 37 cm while the mean, or arithmetic average, is 41 cm This distribution will be compared to distributions found in January and conclusions drawn.

TABLE 2.2 - WEATHER DATA AT YELLOWKNIFE

	OCTOBER		NOVEMBER		DECEMBER	
	1994	NORMAL	1994	NORMAL	1994	NORMAL
Mean Daily Maximum (° C)	+3.6	+1.3	-8.5	-10.8	-16.1	-20.1
Mean Daily Minimum (° C)	-1 0	-4.2	-16.3	-18.9	-25.5	-28.2
Mean Daily (° C)	+1.3	-1 4	-12.4	-14.8	-20.8	-24.1
Snow Fall (cm)	14.0	21.7	46.4	33.5	25.4	20.6

	JANUARY		FEBRUARY		MARCH	
	1995	NORMAL	1995	NORMAL	1995	NORMAL
Mean Daily Maximum (° C)	-17.2	-23.9	-18.7	-19 7	-13.0	-12.5
Mean Daily Minimum (° C)	-23 7	-32.2	-28.6	-29 4	-26.0	-24.6
Mean Daily (° C)	-20.5	-27.9	-23 7	-24.5	-19.5	-18.5
Snow Fall (cm)	18.6	18.8	18.8	17.1	51.4	13 7

FIGURE 2.3 December Ice Thickness Histogram - Tibbitt to Lockhart Lk.



3.0 WINTER ROAD SURVEY - JANUARY 7 - 14, 1995

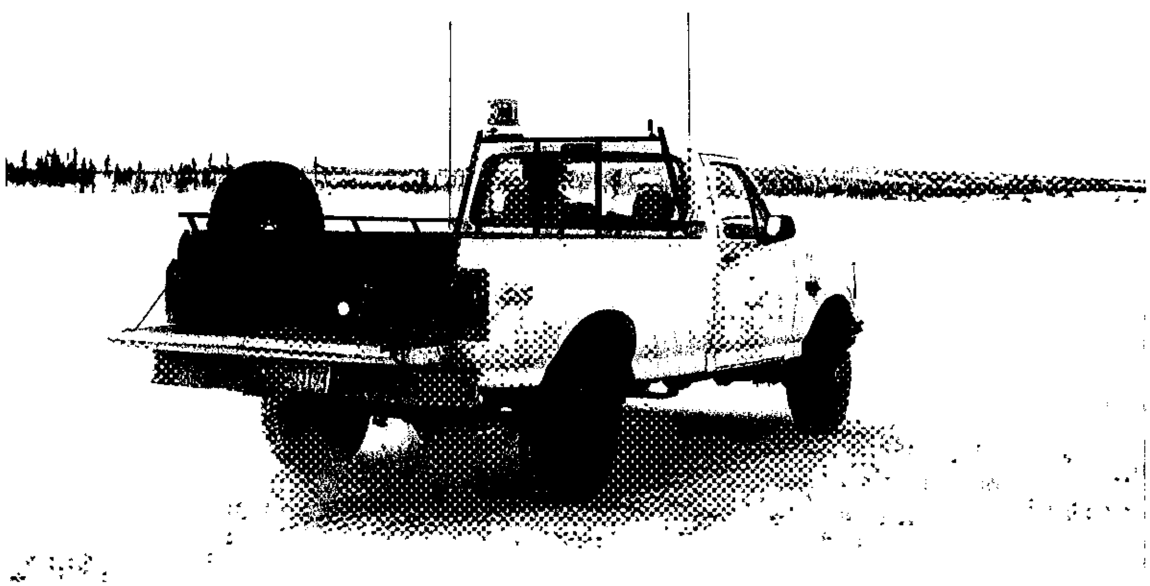
3.1 Main Survey Results

To gain preliminary site information on the road, in particular ice thicknesses, Dan Masterson of Sandwell, with the assistance of Echo Bay personnel, conducted a site survey in early January. During that time, ice thicknesses both on the plowed road and off the road in the snow were measured. As well, snow thickness was measured near the holes drilled off the road Water depth was measured at several stations and the freeboard (distance from the top of water to the top of the ice) of the ice was measured The survey was conducted in three stages The first was south from the pressure ridges on MacKay Lake to Lockhart camp. See Figure 2.1 for the location of major features of the road. The details of the measurements taken are contained in the tables in Appendix B.

Figures 3.1 and 3 2 contain photographs of the over-ice portion of the road and of the portages between the lakes and ponds There are several more photographs of the road, Lockhart camp and of the pressure ridge in Appendix C In general, the road over-ice was kept well plowed and had been widened to about 23 m or 75 ft Because of its exposure, the ice portion of the road was drifted at the edges on Gordon Lake but was otherwise clear of snow When the survey was initiated on January 7, the road had not been opened north from Lockhart camp and this process was begun at that time. Sandwell proceeded with its survey to the south while the opening to the north was in progress

Work on the portages was in progress at the time, particularly in the regions of Drybones Hill and Charlie Hill, apparently two of the more difficult portages The improvements consisted of snow removal, levelling with snow and water and sanding to improve traction Photographs in Appendix C show some of this process. Examination of the photographs will show that widening of the portages would be necessary to accommodate the large vehicles which would haul BHP's large loads The vertical curvatures would also cause "high centering" at certain locations, as discussed in the Sandwell August report In general, though, the portages should be traversable by the carriers.

During the survey, the odometer of the pick-up truck used for transport provided the distance



ROAD OVER LOCKHART LAKE - JANUARY 1995

FIGURE 3.1

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PORTAGE SOUTH OF BROWN LAKE
ON WAY TO GORDON LAKE - JAN 1995

PORTAGE ON WAY TO GORDON LAKE - JAN 1995

FIGURE 3.2

3418\3418C0022.DWG

from the starting point and enabled good correlation with features on the 1·50,000 maps provided by Echo Bay and which had the exact routing of the road marked on them. Thus we were able to identify small ponds and lakes as well as the major bodies of water From Lockhart Camp south, holes were generally drilled at a spacing of 1 km One or two holes were drilled in the small ponds and lakes, with the ice of some smaller water bodies not being measured From the examination of the measurements taken, and from conversations with Echo Bay personnel, it is felt that the sample obtained is representative of the ice thicknesses along the road, especially for a preliminary survey. In total, 159 ice thickness measurements were made on the road centerline and 84 measurements were made off the road right-of-way in snow covered ice In addition, a few measurements were made at the road edge to determine the road cross section thickness, especially since the road had been widened to the 23 m after initially plowing out about an 8 m width The major results of the survey are summarized in Table 3 1

Over the route from Lockhart Camp to the Ingrahm Trail, the average ice thickness measured on the road centerline was 81 9 cm (32 2 in) The minimum measured was 55 cm (21 6 in) The minimum measurements occurred at two locations, one being 3 km south of the north end of Gordon Lake and the other being the second lake north of Gordon Lake, called Gravel Pit Lake by Echo Bay. There is no obvious reason for the thinner ice found at these two locations but water flow late in the fall, an open lead on Gordon Lake or thicker snow may have contributed. Table 3 shows that the average thickness from Ingrahm Trail to Ross Lake, which can be regarded as the more southerly part of the road was 80 9 cm, only 1 1 cm (0 4 in) less than the average thickness along the entire route from Lockhart to Ingrahm Trail The standard deviations are also very similar Thus the ice thickness is generally quite uniform between Lockhart Camp and the southern terminus of the winter road except for the anomalies identified.

The ice north of Lockhart Camp was significantly thicker than that to the south, having an average of 102 5 cm (40 3 in) and a minimum of 74 cm or 29 in Because of the distance involved and limited time, ice thicknesses were only taken every 5 km from the pressure ridges on MacKay Lake to Lockhart camp (see Figure 1 for locations) The tables in Appendix B show that the ice thickness at the north end of Lockhart Lake was 103 cm or 40 5 in. Near Lockhart Camp it was 80 cm or 31.5 in, similar to the thicknesses to the south Thus there was a transition from thicker to thinner ice in the northern arm of Lockhart Lake

TABLE 3.1 SUMMARY RESULTS OF JANUARY ICE THICKNESS SURVEY

LOCATION	CENTERLINE		OFF-ROAD IN SNOW		
Dimension Measured	Ice Thickness (cm)	Freeboard (cm)	Ice Thickness (cm)	Snow Depth (cm)	Freeboard (cm)
Data From Lockhart Camp South to Ingrahm Trail					
No Meas	140	133	84	85	80
Average	81.9	7.5	65 6	13.3	1.3
Std Dev.	8 2	1.5	11 4	5 1	2
Minimum	55	3	44	2	-5
Maximum	98	13	91	30	7
Data From Ingrahm Trail North to Ross Lake					
No Meas.	14	14	12	12	12
Average	80 8	7 2	54.1	15 6	1.3
Std Dev.	8 5	1.7	6 4	3 8	1 2
Minimum	55	3	44	10	0
Maximum	92	9 5	66	23	3
Data From MacKay Lake South to Lockhart Camp					
No. Meas	19	19	N A	N.A.	N A
Average	102.5	7 4	N.A.	N A.	N.A.
Std Dev.	11.6	1 6	N A	N.A.	N.A.
Minimum	74	3	N A	N.A.	N.A.
Maximum	117	10	N.A	N.A	N.A

3.2 Comparison of Ice Thicknesses

The ice thickness data from the road centerline and that from the ice off the road right-of-way was divided into 2 cm bins and histograms were produced, similar to the one for the December ice thickness data of Figure 2.2 Figure 3.3 shows the probability distribution for the ice off the road where the snow cover had not been disturbed. It is seen that the distribution is skewed to the right, as it had been in December From Table 3 1 the average thickness over the road from Lockhart Camp to Ingrahm Trail is 65 6 cm or 26 in. The distribution for the ice along the road right-of-way is shown in Figure 3 4 It is seen to be skewed to the left rather than the right and the average thickness is 81 9 cm or 32 2 in. There is a difference of 16 3 cm or 6 4 in. in ice thickness

FIGURE 3.3 Off-Road Ice Histogram January 1995 Survey

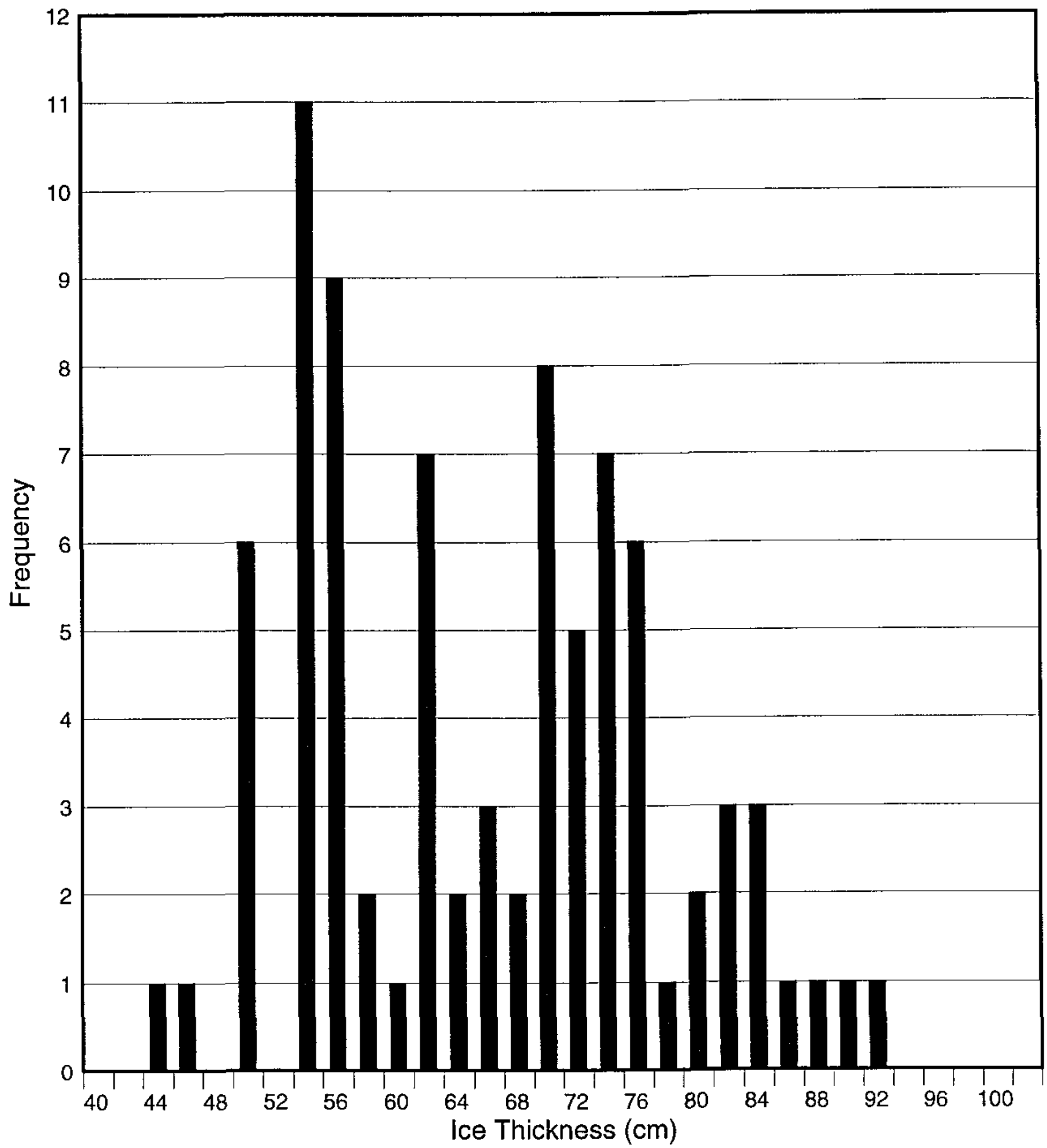
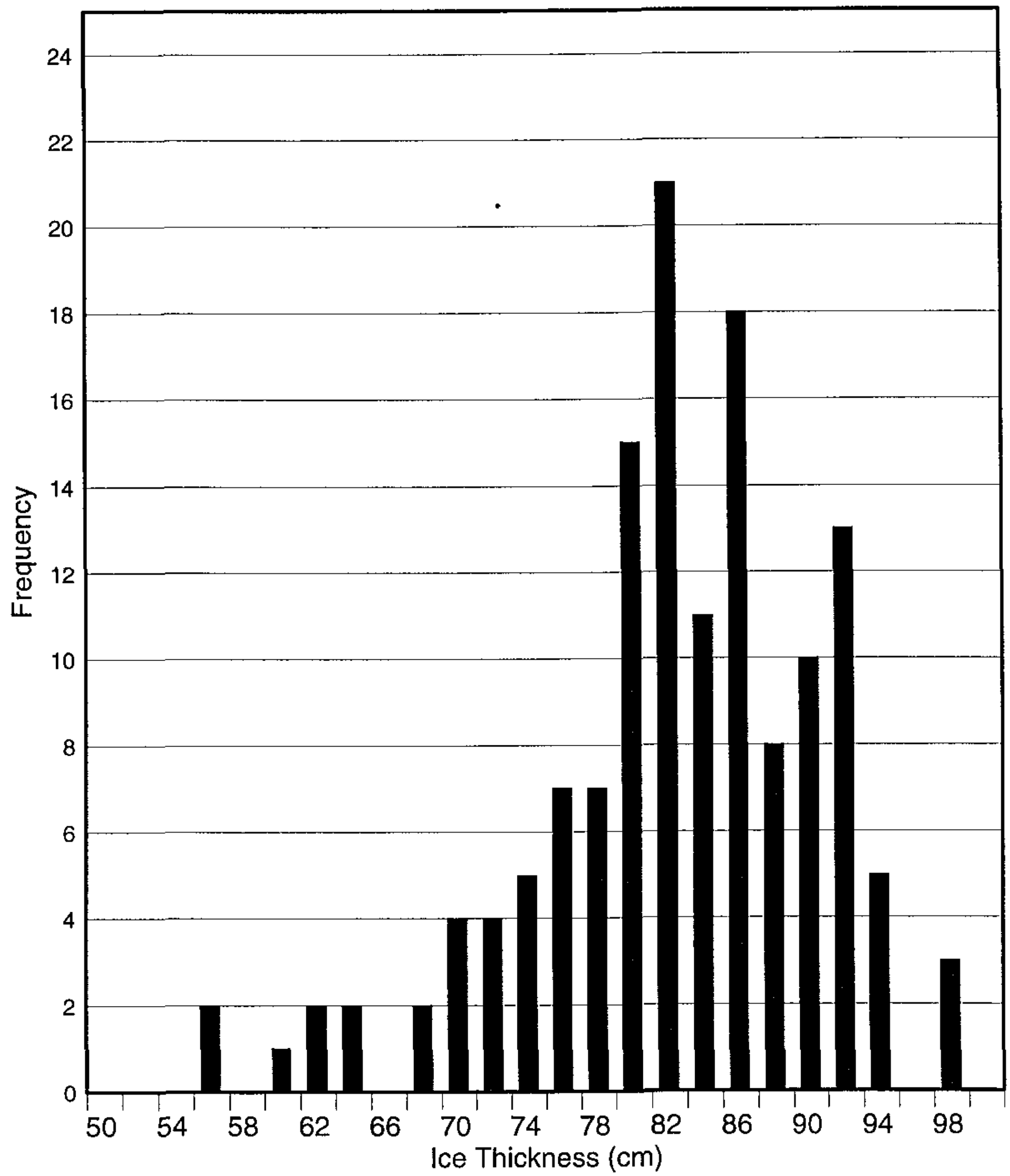


FIGURE 3.4 Centreline Ice Thickness Histogram - January Survey - 1995



This demonstrates the advantage gained over one month in ice growth by the removal of snow from growing ice Not only is the ice thicker by 25 percent, but the probability distribution has been shifted in such a manner that, statistically, the probability of finding ice of a thickness equal to or greater than the average is enhanced

Examining the data in Table 3 1 for the Ingrahm Trail to the South end of Ross Lake, we see that the ice on the plowed road is 26 7 cm or 10 5 in thicker than that where the snow has been left undisturbed Thus snow removal is apparently even more effective on the very most southern portions of the road

The Sandwell report of August, 1994 discusses theoretically the advantages of snow removal and this topic is revisited in Appendix D of this report where the measured thicknesses from the road are compared to those measured historically at established Environment Canada stations and thicknesses predicted theoretically using historical weather information

3.3 Ice Thickness at the Edge of the Plowed Road

Initially, the road right-of-way was plowed to a width of about 8 m and then was later opened to 23 m width. Thus the ice along the centerline was exposed directly to the ambient temperatures for a longer period than that at the edges 17 thickness measurements were made at the road edge at various stations listed in the tables of Appendix B The average thickness at the edge was 72 cm, 10.7 cm or 4.2 in less that the centerline average.

Since the original stress calculations were done assuming a uniform ice thickness over the entire width of the road, this variation in thickness will have the effect of increasing the maximum stress in the ice due to the applied load Since the ice thicknesss varies across the road, finite element analysis will be used in the future to determine the validity of using infinite plate theory for stress calculation and determination of required thickness.

At certain stations, measurements of thickness were made at points east and west of the centerline at the "middle third" points on the road cross section The results are tabulated in Table 3 2

TABLE 3.2 COMPARISON OF ICE THICKNESSES AT THE CENTERLINE AND AT THE "MIDDLE THIRD" POINTS

LOCATION	THICKNESS E. of C.L. (cm)	CENTERLINE THICKNESS (cm)	THICKNESS W. of C.L. (cm)
Gordon Lake - 0.2 km S of N. end		77	70
Gordon Lake - 2.5 km S of N. end	80	84	
Gordon Lake - 3 km S of N. end	75	60	
Tibbit Lake - 2 km N of S end	84	85	81

Generally there is little difference between the ice thickness at the centerline and at the offset points in the middle third of the road, indicating a nearly constant thickness over and 8 to 10 m width of road. The exception is at the station on Gordon Lake where the centerline thickness in 15 cm less than that at a point east of centerline The reason for this is not known, unless the original plowed route was east of the present centerline and thus the ice is thicker there.

3.4 Freeboard Measurements

As stated earlier, freeboard measurements of the ice were made at most points where ice thickness measurements were made. This is the distance from the top of the water in a drilled hole to the top of the ice and the measurement has several uses Where there is no snow cover, the freeboard can be used to determine the average ice density, as was done in Appendix D. The average of 910 kg/m^3 compares well with 917 kg/m^3 for bubble free ice The average freeboard off the road right-of-way, coupled with the ice thickness measurements, made possible snow density calculations which are important in predicting ice growth using historical ambient data

Because of the weight of the snow near the edge of the road and off the road, the freeboards are small compared to those along the centerline. This is illustrated in Table 3 1 and in Appendix B The average freeboard off the road was only 1 3 cm, compared with 7 5 cm along the centerline At some locations the ice surface was submerged and water flowed onto the ice when a hole was drilled

It is important for heavy loads to remain on the snow free road right-of-way since submerged ice has a lower carrying capacity than does fully buoyant ice. It is also important to keep the road right-of-way clear of major snow accumulations to maintain maximum load bearing capacity.

3.5 Water Depths

Water depths were measured at many of the thickness measurement stations along the road. This was done as a matter of interest and also to determine if thinner ice was a result of shallow water Examination of the data in Appendix B indicates that, for example at the north end of Gordon Lake, the water depth was 31 m and the ice thickness was 60 cm At the second lake north of Gordon Lake, called Gravel Lake, the ice thickness on the centerline varied from 69 to 61 cm and the water depth at the measurement stations was between 7.3 and 9 m Thus at the spots with thinner ice, the water depth was found to be substantial

The one location where shallow water was associated with thin ice was the small slough just off the Ingrahm Trail south of Tibbitt Lake The ice in this small pond was found to be grounded out by the end of March. Otherwise, flooding of its short length would insure the ice was on bottom for the effective and safe transport of heavy loads.

4.0 MARCH FUEL TRUCK TRIP DESCRIPTION AND OTHER OBSERVATIONS

4.1 Introduction

Between March 23 and 26, 1995, D. Masterson of Sandwell made a round trip from Yellowknife to the Lupin mine over the winter road as a passenger in a truck tractor hauling a B-Train with two tankers of diesel fuel. The total volume of fuel carried was 43,000 liters and the gross weight of the vehicle was 56,800 kg. or 125,000 lb The distance one way between Yellowknife and Lupin is 641 km. according to the truck odometer. Figure 4 1 shows the fuel carriers.

The purpose of making the trip was to familiarize D Masterson and the ice engineering team with the road over its entire length, especially from a truckers perspective. It was of particular interest to obtain information from someone who had driven the road many times and to identify any sections of the road which may have proved to be problematic in the past First hand knowledge of, and feeling for, what might be involved in piloting a large load over the winter road, three quarters of which traverses floating lake ice was also obtained

Randy Turlock, an independent owner/driver, was the driver and he proved to be an excellent choice as one to accompany on the trip. He had been hauling over the Lupin road for seven years and had made in excess of 130 trips with loads of fuel. He knew the route well and was able to identify each portage by name. The trip was certainly a positive experience for both driver and passenger and Sandwell's confidence in the road as a viable means of transferring mine supplies was reinforced At the same time, issues were identified which will have to be addressed in the future

We were accompanied on the trip by Randy's partner who was also hauling a B-Train of fuel Between Yellowknife and Lockhart Camp, a third B-Train hauling cement was part of our group. Usually the trucks travel in pairs or threes, enabling one driver to assist another in case of breakdowns, illness, etc. A minimum distance to be maintained between trucks is specified and this ruling is adhered to

Following the return trip to Lupin with the fuel B-Train, Sandwell conducted an electronic thickness profile of the road and also performed some dynamic measurements The results of

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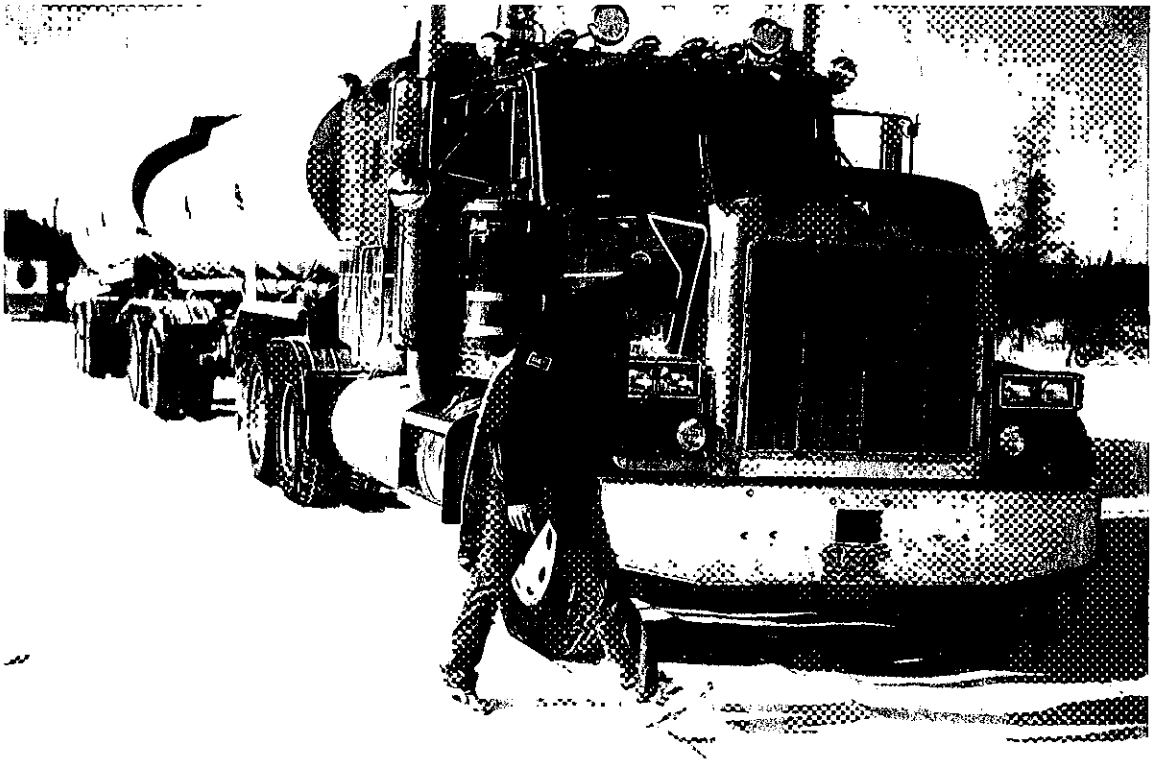

FUEL CARRIERS

FIGURE 4.1

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these measurements are contained in Sections 5 and 6 of this report Some general observations from this part of the work, made by Paul Spencer and Bill Graham, are contained in Section 4.5.

4.2 Observations by D. Masterson

1 Randy was a careful driver who watched the road at all times and who knew the road well. The drivers have to be particularly responsive on the southern portion of the road since there are often numerous drivers from "town" on the road. These drivers are not always responsible, especially when meeting trucks at the portages where the road narrows and often has difficult grades.

2. Randy observed all speed limits on small lakes and at shore approaches Even though D. Masterson was along, one got the impression that this was normal procedure for him The road is patrolled by Echo Bay by pickups equipped with radar. Speeders can be reprimanded, given "time off" or dismissed

The distances travelled, travel times and average speeds for the trip north are listed below

Leg of Trip	Travel Time	Distance Travelled (km)	Average Speed (km/hr)
Yellowknife to Lockhart Camp	7 hrs 25 min	242	32 6
Lockhart Camp to Lac de Gras Camp	5 hrs 8 min	177	34 5
Lac de Gras Camp to Lupin Mine	6 hrs 40 min	222	33 3
Total/Average	19 hrs 13 min	641	33.4

3 The ride was generally smooth, the roughest sections being on the more northerly lakes, especially Contwoyto Lake, where thermal and flexural cracking of the surface made

driving more difficult. The reasons for the thermal cracking of the surface are obvious and flexural cracking is caused by plowed snow piled at the edges of the road Some of these piles were window high to the truck and caused a "hogging" moment along the center of the road, with the attendant enhancement of the surface cracks Some of the cracks in the road's central portion were quite wide and were "wheel catchers" in truckers' parlance. Some of the cracks at the edge of the road near the plowed snow banks were wet and to be avoided There have been reports of failures (trucks going through the ice) attributed to these wet cracks Figure 4 2 contains photos of this section of the road.

4. The three and then two trucks in our group never met while on the ice and maintained at least a 1 km. separation Other pairs maintained a smaller separation but observed the minimum. On Gordon Lake on the return trip, we stopped empty to help a truck which was full northbound to help fix a broken air line The tractor cabs were adjacent at this point The ice did not appear overloaded and no extra or excessive cracking was observed This is shown in Figure 4 3.

5. There were no dynamics observed in the ice during the trip or no evidence of a deflection wave developing in front of the truck No blowouts (water wave pressure releases) observed to form near shore as we approached a portage, although there were relics of ones which had previously formed A blowout relic is illustrated in Figure 4.4

4.3 Comments From Randy Turlock

1 Blowouts

- These occur early in the trucking season when the ice is thinner.
- They are always at shore.
- They result in a "messed up" approach at shore with broken ice which has to refreeze or be repaired
- No trucks are sunk as the ones causing the blowouts are ashore by this time and they are safe Also, they occur in shallow water

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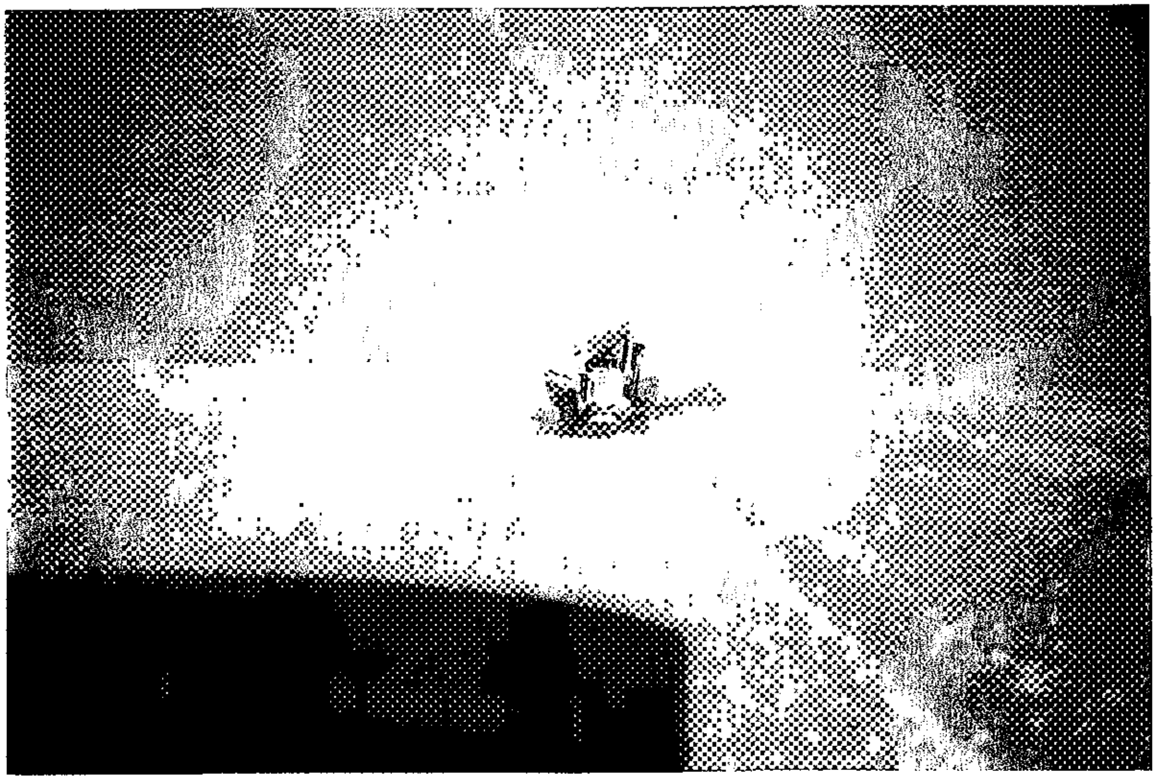

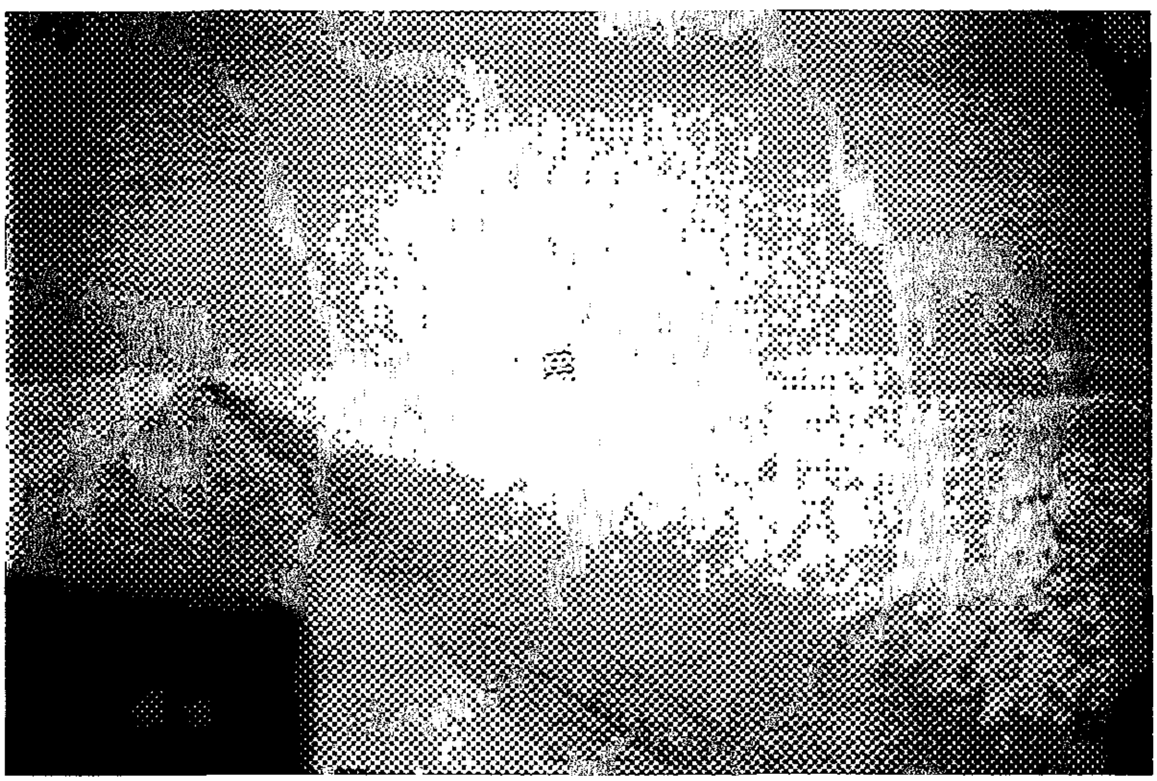

HIGH SNOW DRIFTS LEADING TO ROAD CRACKS

FIGURE 4.2

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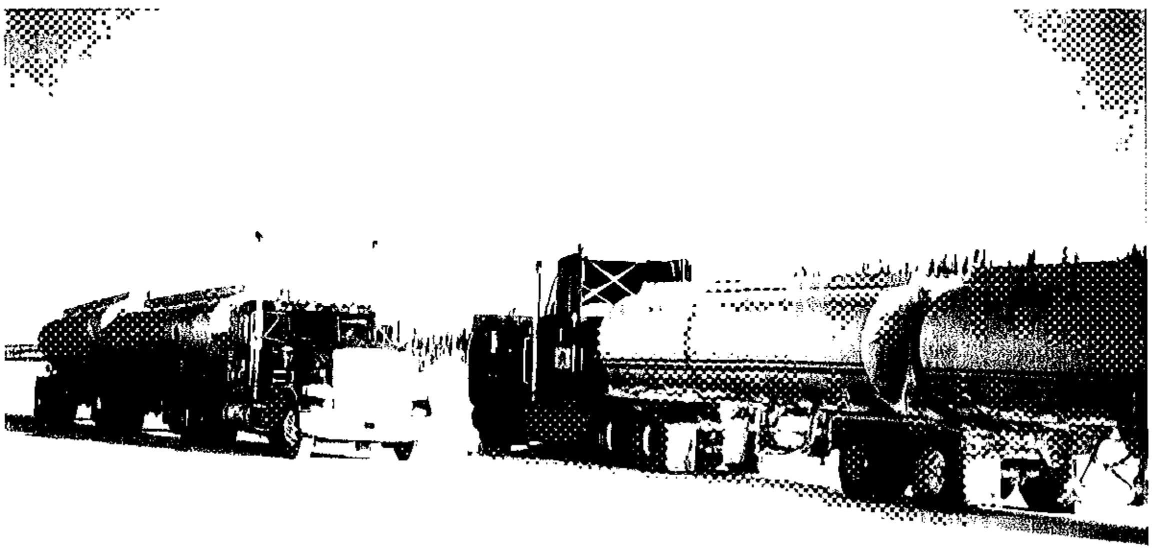

LOADED AND EMPTY TRUCKS
MEETING FOR REPAIRS

FIGURE 4.3

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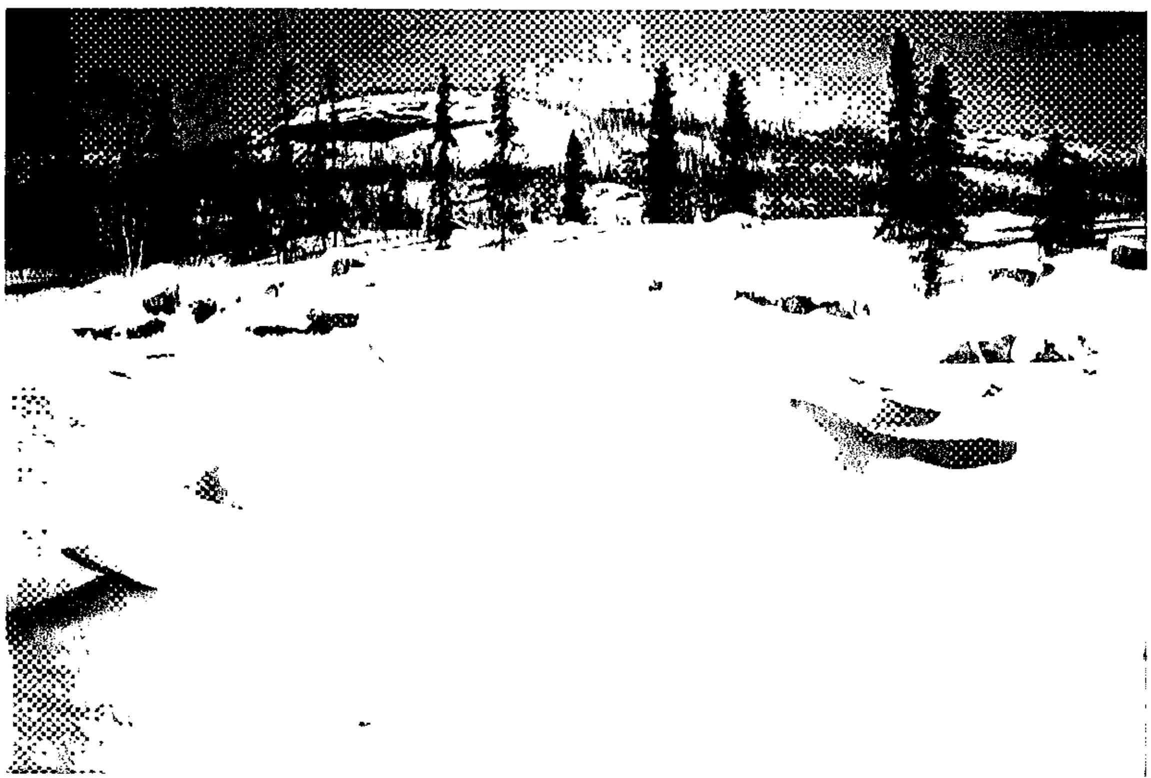

BLOWOUT RELIC ON LONG LAKE

FIGURE 4.4

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- Randy has never had a blowout in seven years of hauling over 130 loads

2 Dynamics

- In 7 years of hauling on this road Randy has never experienced classic dynamic wave affects (waves of ice deflection in front of the truck).
- He was not aware of <u>any</u> dynamic effects The phenomenon was unknown to him and had to be explained and, when it was explained, he confirmed that he had never experienced its effects.
- He said a lot of people function on rumor and lack of knowledge.

3 Cracks

- Surface cracks cause roughness, catch wheels and are a general nuisance.
- They are better after they fill with snow, either as a result of plowing or of drifting
- When the ice surface is clear and the weather is cold and sunny, you can see cracking in front of the truck (probably flexural micro cracks) As a result of these micro cracks forming, there is a shower of ice crystals which reflect the sunlight Randy commented on the beauty of the shower and light reflection with fascination, but no expression of fear Others who travel the road, including Phil Flaumitsch commented on the crystal showers

4 Driving

- Take it easy on sharp turns and descending hills
- Keep in contact with other trucks.
- Keep up momentum going up hills to avoid "spinning out"
- Watch for cracks, especially the "wheel catchers" and surface spalls

5 Wash Boarding and Undulating Road Surface

We discussed this phenomenon during the trip It causes the road surface to be rougher than desired and necessitates a lower speed The washboarding was observed especially on the south end of MacKay Lake and Portage Bay We generally agreed on the following, which is partly borne out by the thickness survey.

- Some are due to grounded ice.
- Some are due to the inability of the plows to remove prepacked snow
- Some are due to thermal stress and surface buckling, perhaps ("Wanna Be" pressure ridges)

4.4 General Discussion Conducted at Lac De Gras Camp

The information below was obtained from a group discussion with
Ron Lebrun
Phil Flaumitsch
John Zigarlick

4.4.1 General

- Thin ice areas occur in narrows and shallow waters.
- There are water currents causing this but these currents are unquantified
- Ron and Phil indicated that there are some open water areas throughout the winter
- Blowouts occur mostly to the side of road and there are visible ones on the southern portion of the road (see Figure 4 4).
- The approach of the road to shore or to a ridge is important The best practice, according to Ron is to curve the road at shore, driving away from the direction of the wave, letting it hit straight on while you drive off in a different direction This also forces the trucks to slow down

- Blowouts off to the sides of the road in shallow waters or at portages serve a useful purpose since these provide a permanent release of wave energy

4.4.2 Discussion On Dynamics And Critical Velocity

D Masterson pointed out that the allowable speeds are actually about at the critical velocity where dynamic amplification is maximum It is difficult to avoid this given the water depths and ice thicknesses and it generally does not cause a problem with operation of the road as evidenced by Randy's not having experienced any difficulties in seven years of hauling on the road Thus, the trucks are forced to pass through the critical velocity and Sandwell's field measurement program later demonstrated this Phil found it difficult to accept and completely comprehend the fact that the regulated speeds caused the maximum dynamic amplification of stress and deflection.

4.4.3 Variability In Ice Thickness On Lakes

The ice road seems uniform because Echo Bay have already scouted the shallows, thin ice, etc. and know where currents apparently are delaying the thickening of the ice This knowledge has been gained since 1983 and also reflects the fact that thin ice occurs at similar locations year after year. D. Masterson marked spots to electronically profile where there is often thin ice, one being on MacKay Lake However, it was not possible to cross section off the road with the electronic profiler because of the snow depths and the fact that we were transporting the profiler with a standard passenger vehicle. This may have been useful since rerouting of the road, because of surface spalling and the resulting roughness, or because of heavy snow accumulation as a result of plowing, is occasionally required and thin ice poses limitations.

4.4.4 Snow

They all agreed snow is a big problem and that snow blowers do help, but a greater number of larger ones are needed to use in conjunction with plows Snow blowers are very effective in getting the snow back from the edge of the road and avoiding the deep piles next to the road edge discussed above These lead to hogging moments down the road centerline and to submergence of the ice at the edges, where there are also thinner ice and dangerous wet cracks (Figure 4.2)

4.4.5 Routing

Finding alternate routes for the road is a problem in the south, especially from Tibbitt to Gordon, and south of Drybones Lake There is little available borrow material for improving and building up portages. If alternate routes are not available to accommodate increased traffic, then the main road will have to be considerably widened, including the portages

4.4.6 General

John indicated that the type of planning being undertaken by BHP will be needed regarding the establishment and use of the road to avoid problems in future with increased traffic.

4.5 Observations by Bill Graham and Paul Spencer

The following lists the observations and discussion obtained by Bill Graham and Paul Spencer of Sandwell during their field visit March 28 to April 02, 1995

- Because of the vertical longitudinal crack in the road, trucks were seen driving on the smoother ice surface adjacent to the snow banks.

- The ice "boil" on MacKay Lake, south of the Fish Camp access road, was investigated Prior to investigation, maintenance personnel indicated that the boil was caused by uplift from an underlying rock This judgement was based not on actual investigation but on the fact that some other boils had been caused by rocks Our investigation indicated that the water depth under the boil was approximately 5 m We did find that some other boils had rocks under them.

- There was a general correlation between surface cracking and road width, with fewer cracks occurring with wide roads.

- When a cement truck was approaching at about 30 km/hr, cracking could be heard when the vehicle was about 100 m away, then when the vehicle was at the location of the observer and after a pause when the vehicle had passed. After about another 30 - 60 seconds, cracking could also be heard This later cracking was believed to be caused by waves being reflected off the shore line

- One or two maintenance personnel indicated that wet cracks were safer than dry cracks because the ice is more flexible This is not true as a load placed near a wet crack is an edge load on the ice and the factor of safety against ice failure in this case is greatly reduced. This perception was, and will be, countered.

- From auger measurements on Gordon Lake, ice and snow depth measurements were obtained. Although the ice in the road was 1.38 to 1 58 m thick, under the West side snowbank the ice was only 0 85 m with a negative freeboard.

- The idea that an "event", such as a vehicle falling through the ice, could have multiple contributing causes was difficult to convey Generally, the single cause mode of thinking was found although it was usually possible to determine, upon probing, that several factors contributed to past ice failures. Contributing factors could be, for example, driving adjacent to a snow bank where the ice is thinner, the possibility of a wet crack adjacent to the snow bank, a heavier than normal vehicle, a vehicle travelling at a speed where dynamic effects are experienced.

5.0 ICE THICKNESS SURVEY MARCH 28 - APRIL 03, 1995

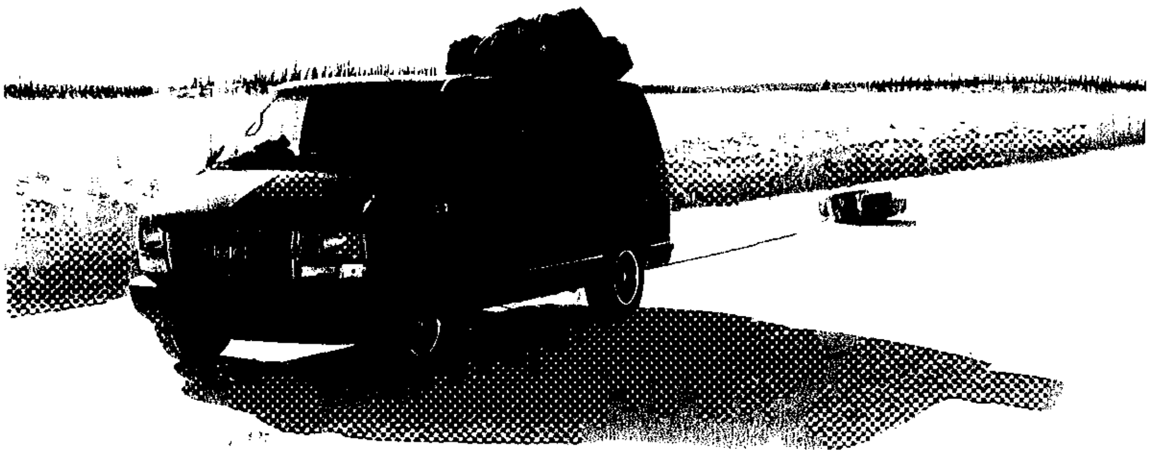
An ice thickness survey from the Ingrahm Trail to Koala Camp was conducted between March 28 and April 03 by Sandwell personnel and a sub-contractor The trip schedule is provided in Table 5.1.

TABLE 5.1 ICE THICKNESS SURVEY SCHEDULE

March 28	Equipment installation, Electronic survey from Ingrahm Trail to Grader Camp
March 29	Electronic survey from Grader Camp to Lockhart Camp
March 30	Electronic survey from Lockhart Camp to Lac De Gras Camp
March 31	Electronic survey from Lac de Gras Camp to Koala Lake. Spencer and Graham return to Lac de Gras Camp
April 01	Electronic survey personnel and equipment fly to Yellowknife. Conduct subsidiary measurements on route to Lockhart Camp
April 02	Conduct dynamic response tests
April 03	Conduct subsidiary measurements between Lockhart and Ingrahm Trail

5.1 General Information

The survey was conducted using a GSSI Ground Penetrating Radar (GPR) System supplied and operated by Jim Greer through Guben Transport, Tuktoyuktuk, N W.T. Also present during the survey were Bill Graham and Paul Spencer of Sandwell. The system consisted of a transmitter/receiver antenna unit which was towed 10 m behind the vehicle and an electronic unit mounted in the vehicle The system is illustrated in Figure 5.1. The unit was manually operated in that the output of the GPR was a trace on the chart recorder. The GPR was powered using the +12 V battery in the vehicle. The unit operates by generating a short high frequency pulse into the ice sheet Boundaries and objects within the ice sheet can scatter and reflect the radio frequency signal Some of the scattered/reflected energy is picked up by the receiver antenna. The electronic unit then processes the retrieved signal by providing amplitude/time delay information on the chart recorder (Arcone 1985). The unit was set up so that approximately 30



GROUND PENETRATING RADAR

FIGURE 5.1

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measurement pulses per second were generated and recorded The unit was calibrated by adjusting the time delay scale factor so that the reflection corresponding to the bottom of the ice sheet provided a depth reading equal to the measured ice thickness The ice thickness was physically measured at several locations along the road by drilling 5 cm diameter auger holes through the ice sheet. This allowed calibration and checking of the profile For convenience of the operator and efficient use of the recorder paper, the scale factor was adjusted so that 1 inch corresponded to 1 foot of ice thickness.

Depending upon the smoothness of the road surface, 20 km/h was achieved when travelling over ice and 5 - 10 km/h when travelling over the portages The antenna unit was towed behind the vehicle over the portages. Including time spent on calibration, adjustments and required rest stops, an average speed of about 12 km/h was achieved. The road surface was generally snow free and visibility was excellent Ambient temperatures were between -10 and -30° C during the survey period.

The GPR device relies on a strong reflection from the bottom of the ice in order to determine ice thickness A strong reflection is obtained at a water/ice interface If the ice is grounded on rock for example, which contains no water, then no reflection is obtained. On the other hand, if the ice is grounded on mud, there will be a reflection if there is still liquid water in the mud. Texts on permafrost (Johnston 1981) indicate that the unfrozen water content in soils can be appreciable even at -2° C Thus while the bottom of the ice sheet is initially at 0° C when it contacts the bottom, for the soil layer to "freeze" requires temperatures less than 0° C Thus the GPR is ambiguous in distinguishing between a floating ice sheet and one resting on an un-frozen soil layer The ambiguity can be removed by drilling auger holes through the ice

5.2 Data Processing

The electronically recorded data were manually processed in Calgary by Sandwell to provide the minimum, maximum and mean thickness data for either a lake or every kilometer section of the larger lakes These data are presented numerically in Appendix E and graphically in Figures 5.2 to 5.5. Examples of the recorded traces are also presented in Appendix E It illustrates that a complete road profile can be achieved using the GPR system As may be observed from Figure

FIGURE 5.2 : ICE THICKNESS, MARCH 1995
MINIMUM THICKNESS

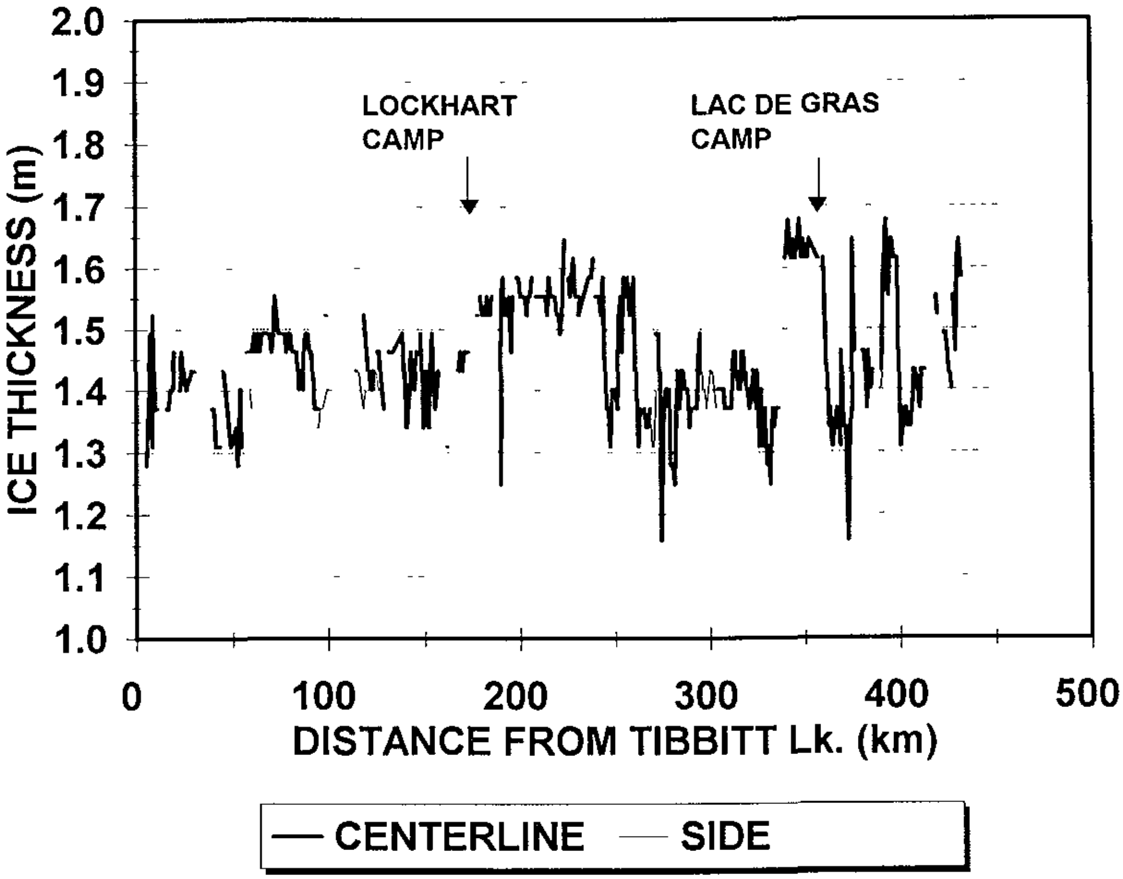

FIGURE 5.3 : ICE THICKNESS, MARCH 1995
MEAN THICKNESS

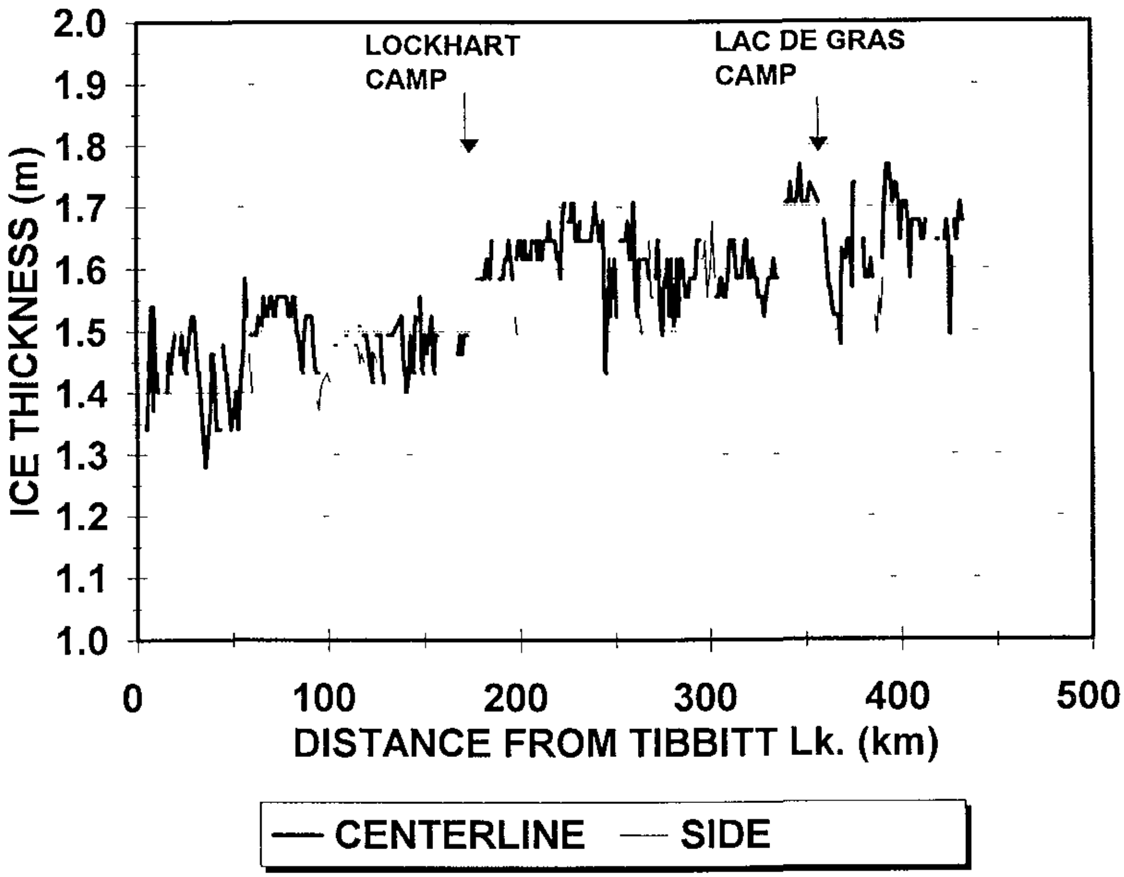

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FIGURE 5.4 : ICE THICKNESS, MARCH 1995
MAXIMUM THICKNESS

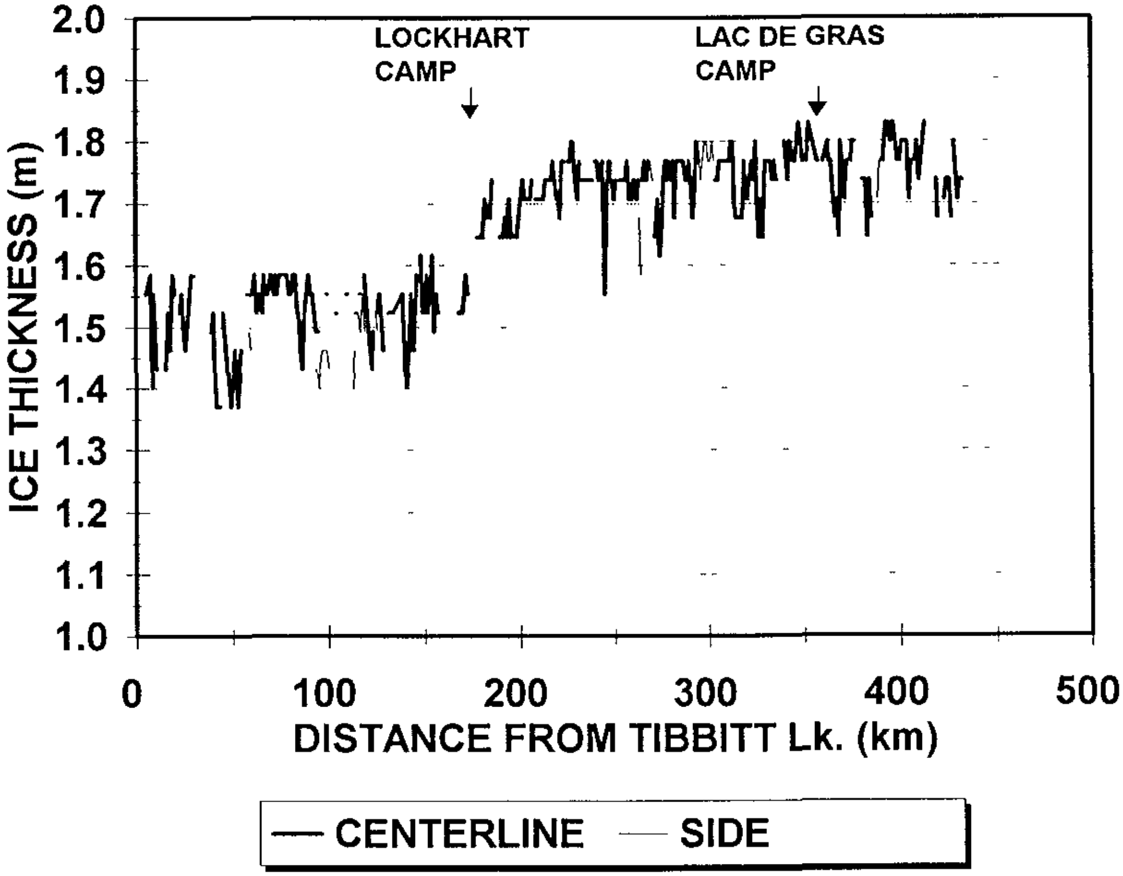
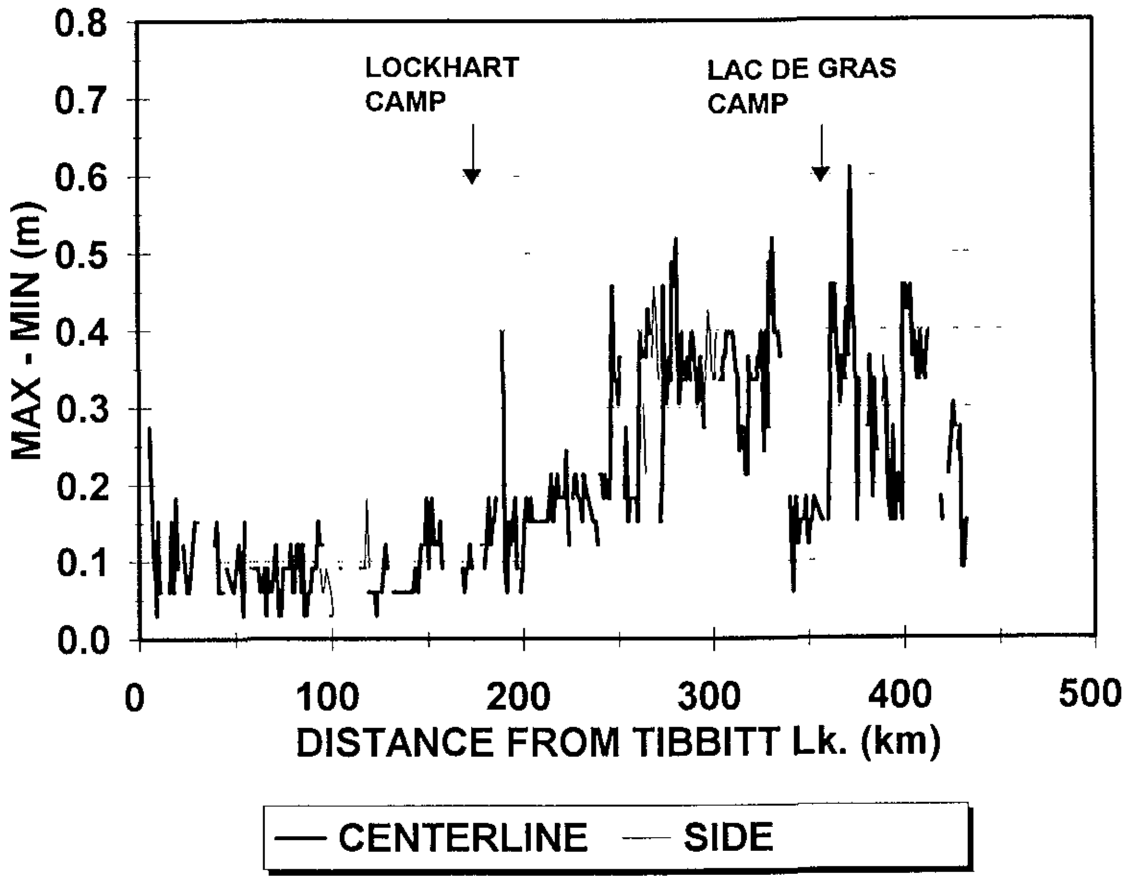


FIGURE 5.5: ICE THICKNESS, MARCH 1995
VARIATION IN THICKNESS



5 3 there was a gradual increase in mean ice thickness with distance north along the road, an increase observed during the January survey The variation in ice thickness within a section also depended on which lake was being observed as illustrated in Figure 5 5 For example, Gordon Lake had relatively constant ice thickness whereas MacKay Lake has a much greater variation in thickness. This is believed to be caused by the following mechanisms. Snow drifts, once formed, tend to be fixed in location because of the high density and hardness of the wind blown snow When the snow is thickest the underlying ice is thinner On MacKay Lake, the road location had been moved on a number of occasions and thus the current road had only been used for a short time This resulted in the changes in ice thickness since the snow cover had been thick over the relocated portion of the road On Gordon Lake, in contrast, the same road location had been used over the entire winter season, and it was opened earlier in the season, thereby leading to a smaller variation in the thickness This phenomena is further investigated in Appendix D

The minimum ice thickness in either a small lake or kilometer section of a lake is presented in Figure 5.2 Two locations with an ice thickness of less than 1 2 m were found. One at 274 4 km corresponds to the ice boil found south of the Fish Camp access road on MacKay Lake. This location was investigated on the return journey. The second location is at 372 6 km on Lac De Gras. This location could possibly be grounded or it could be an incipient "boil" in the road South of Lockhart Camp (175 km) the minimum ice thickness was between approximately 1 3 and 1.5 m Between Lockhart Camp and MacKay Lake, the minimum were generally between 1.5 and 1.6 m However for MacKay Lake and further north, the minimum ice thickness were generally 1.25 to 1.45 m These data are generally consistent with the effects on snow drifts discussed earlier in this section and less cooling south of the treeline The maximum ice thickness data are presented in Figure 5 4 and they again emphasize the increase in cooling north of the treeline These maximum thickness data also illustrate what the ice thickness could potentially be

A histogram of ice thickness for the whole data set (Tibbitt Lake to Koala Lake) is presented in Figure 5 6 giving the minimum maximum and mean thickness. The data are also presented numerically in Table 5.2. As may be seen, the most common minimum thickness is in the 1 5 m bin and the most common maximum thickness is in the 1.8 m bin.

In the survey conducted in January, there was a trend for the ice to be thinner near the edge of

FIGURE 5.6 : ICE THICKNESS, MARCH 1995
THICKNESS HISTOGRAMS

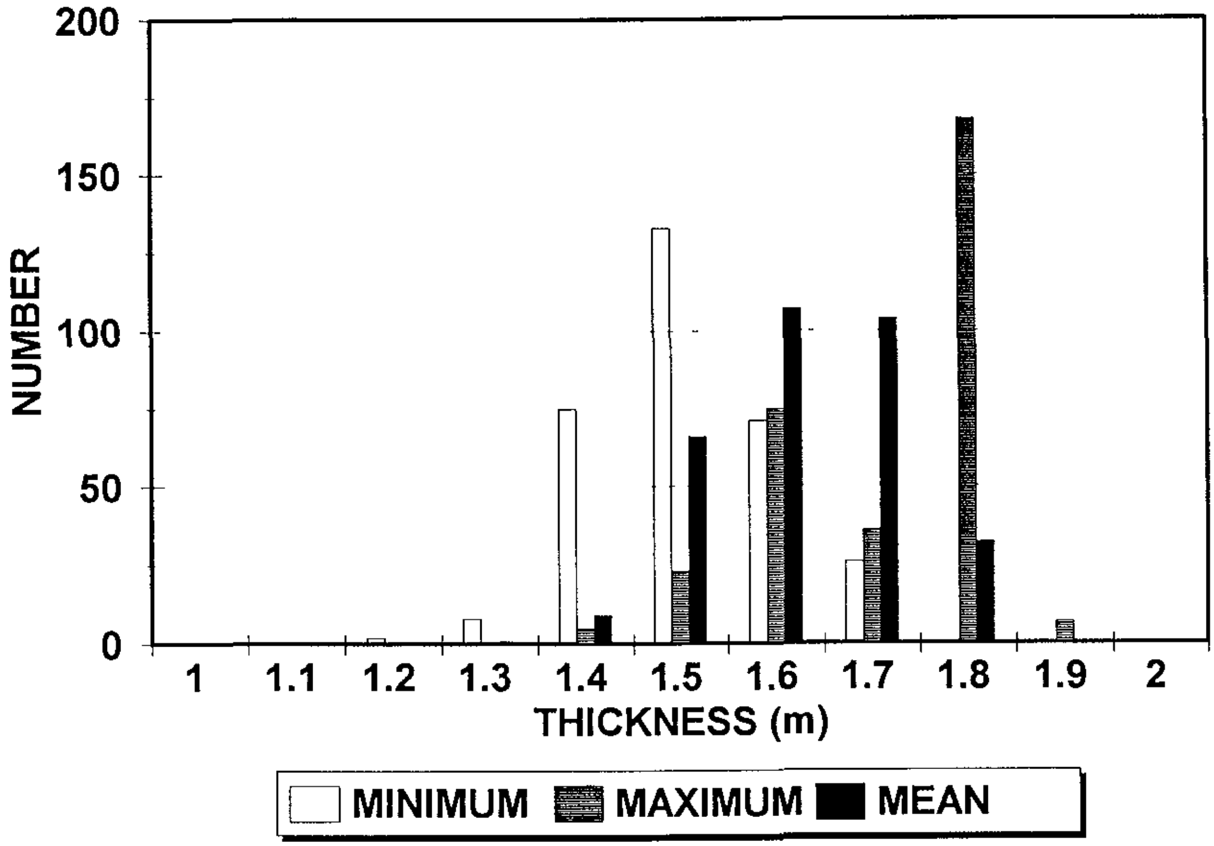


TABLE 5.2 THICKNESS HISTOGRAM DATA, WHOLE ROAD

BIN VALUE (m)	MINIMUM (number)	MAXIMUM (number)	MEANS (number)
1	0	0	0
1.1	0	0	0
1 2	2	0	0
1.3	8	0	1
1.4	75	5	9
1.5	133	23	66
1.6	71	75	107
1.7	26	36	104
1 8	0	168	32
1 9	0	7	0
2.0	0	0	0
TOTAL	315	314	319

the roadway than along the centerline. Data were also obtained along the center and towards the road edge during the April electronic profile These data points are plotted separately in Figures 5.2 to 5 5 To make the interpretation easier, a linear fit has been done to the two data sets as a function of distance along the roadway These linear trends are displayed in Figures 5 7 to 5.9 for minimum, mean and maximum thickness For the minimum and mean thickness there is a systematic difference of about 8 cm between edge and center with the edge being thinner. For the maximum thickness, the difference is greater further south and minimizes close to Lac De Gras Camp From Figure 5 7, note also that the minimum trend ice thickness is essentially constant over the whole roadway in spite of the cooler conditions north of the tree line These aspects are further discussed in Appendix D

From the inspection of the GSSI recorder traces, the thinner spots are generally less than 100 m

FIGURE 5.7 : ICE THICKNESS, MARCH 1995
MINIMUM THICKNESS TREND ANALYSIS

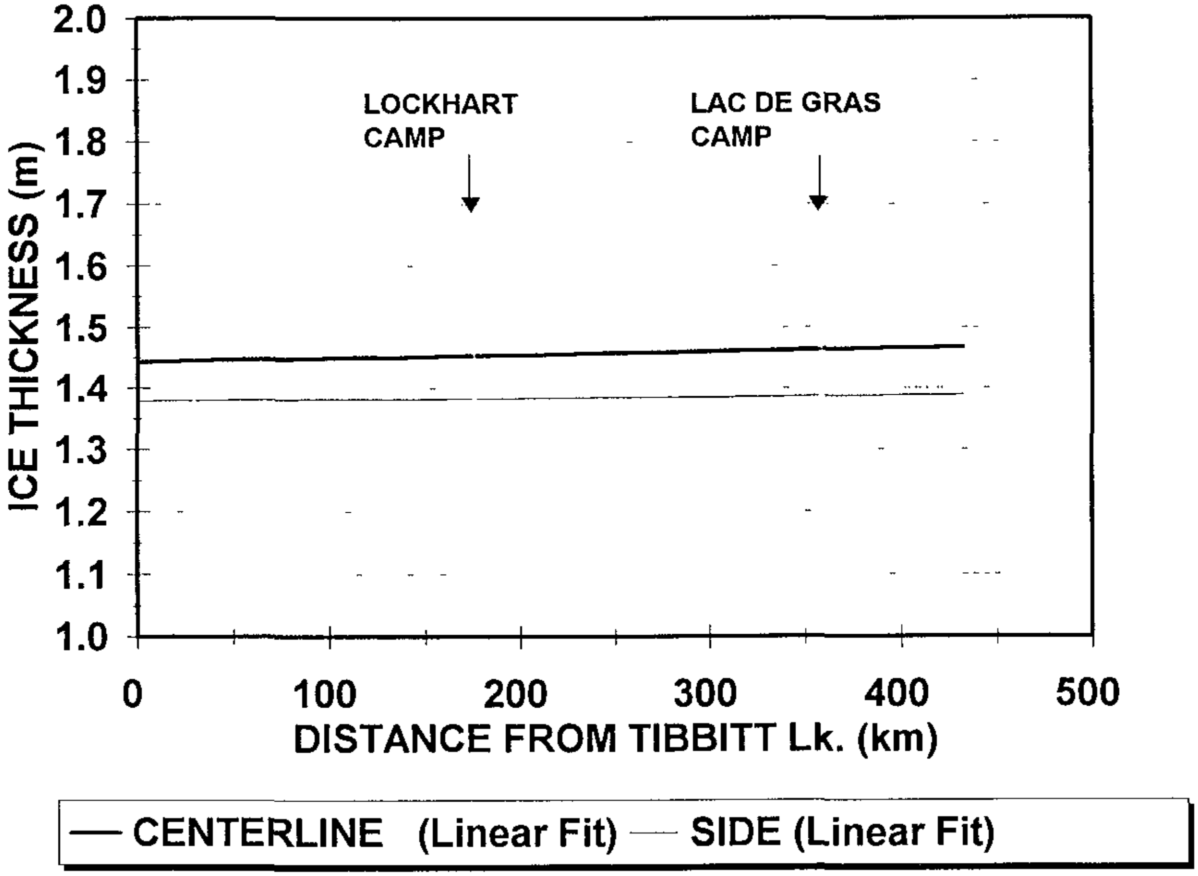


FIGURE 5.8 : ICE THICKNESS, MARCH 1995
MEAN THICKNESS TREND ANALYSIS

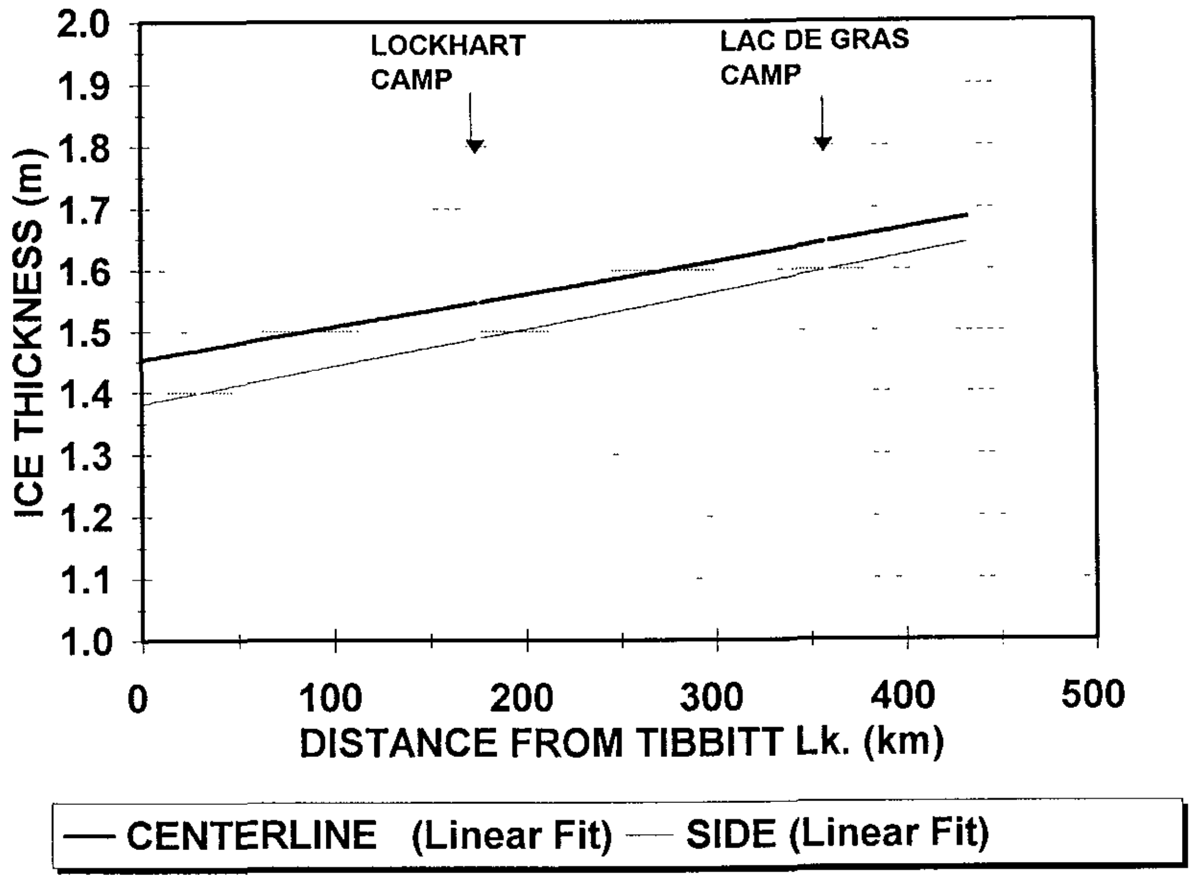
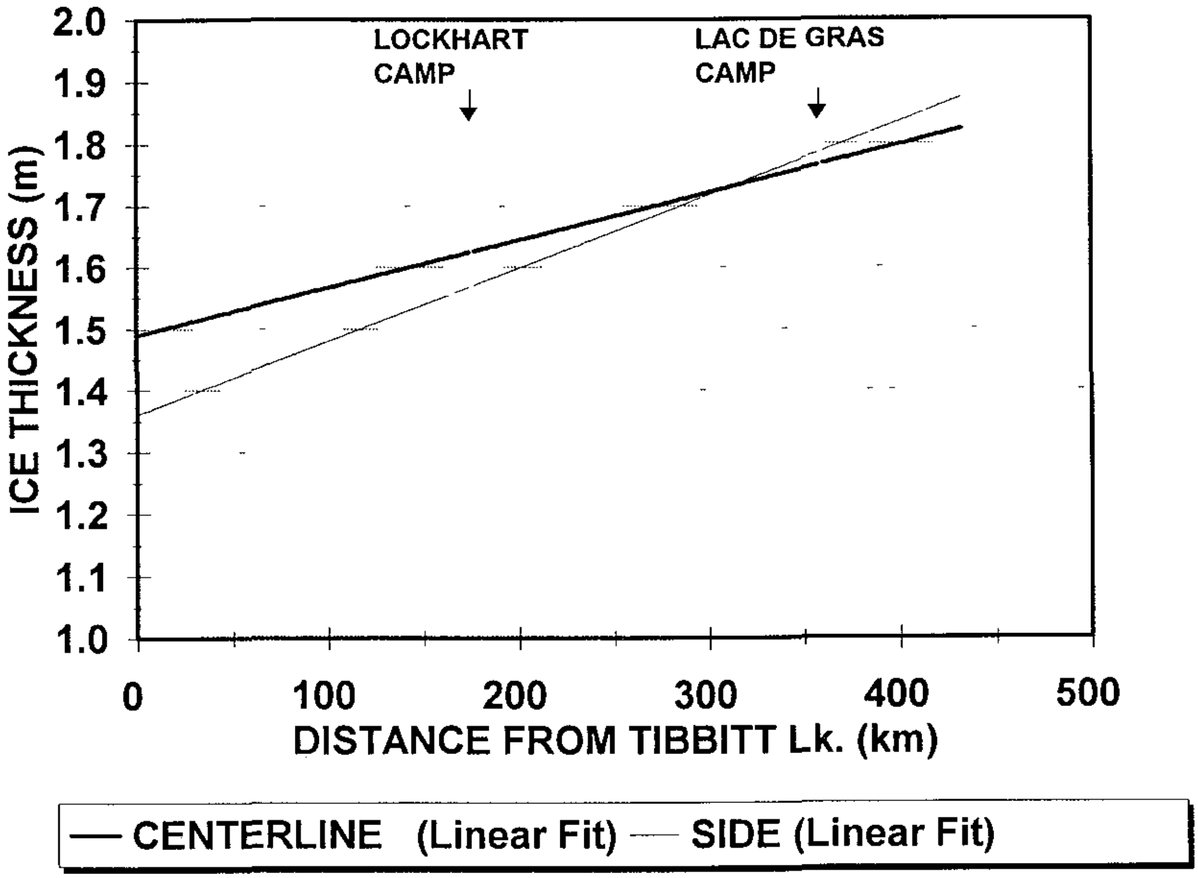


FIGURE 5.9 : ICE THICKNESS, MARCH 1995
MAXIMUM THICKNESS TREND ANALYSIS



in length along the roadway Thus in order to have a good probability of finding them with a survey, measurements would have to be made at least every 50 m For this road with about 360 km over ice, at least 7,200 point measurements would be required Note that the GPR unit obtained a thickness measurement approximately every 0 2 m for a total of about 1.8 million individual thickness measurements. In the January 1995 survey 269 ice thickness measurements were obtained by manual methods. In terms of coverage, the electronic profile system is superior to a manual method based on drilling holes at regular intervals.

5.3 Subsidiary Measurement

Subsidiary investigations were also conducted as part of the field project These were measurements of snow depth, ice thickness under snow banks, investigation of the ice "boil" adjacent of the road to the Fish Camp access road on MacKay Lake, and thickness survey of the road to the Fish Camp, snow density measurements and a crack survey on a section of the road

5.3.1 Snow Data

A snow depth profile was conducted on MacKay Lake and illustrated in Figure 5 10 and numerically in Table 5 3. Snow density measurements are given in Table 5 4

5.3.2 Road Cross Section and Crack Pattern

A transect was conducted on Gordon Lake to investigate the effect of snow thickness on ice thickness The data are presented in Figure 5 12 which illustrates the significant thinning of the ice underneath the snowbank at the edges of the road. Immediately adjacent a crack survey was conducted every 30 m along the roadway and the results are given in Figure 11 The location and width of the cracks at the road surface was recorded Crack widths up to 250 mm were recorded at this location.

TABLE 5.3 UNDISTURBED SNOW THICKNESS AT NORTH END MacKAY LAKE MARCH 30, 1995

DISTANCE (m)	SNOW THICKNESS (cm)		
0	36		
2	3		
4	10		
6	0		
8	4		
10	6	mean	15 2 cm
12	13	std. dev.	10.7 cm
14	18	min	0 cm
16	18	max	36 cm
18	30		
20	23		
22	18		
24			

TABLE 5.4 SNOW DENSITY MEASUREMENTS- MARCH 1995 (Obtained from Uve Embacher of Elgin Drilling)

CONDITION	DENSITY (kg/m^3)
1/2 day old drift	277
Sastrugi	390
1 day old drift	252
Hard sastrugi	408
Very hard sastrugi	508
Wild snow	104
Wild snow behind drift	240
Very hard sastrugi (no boot mark)	415

5.3.3 Investigation of the "boil" on MacKay Lake

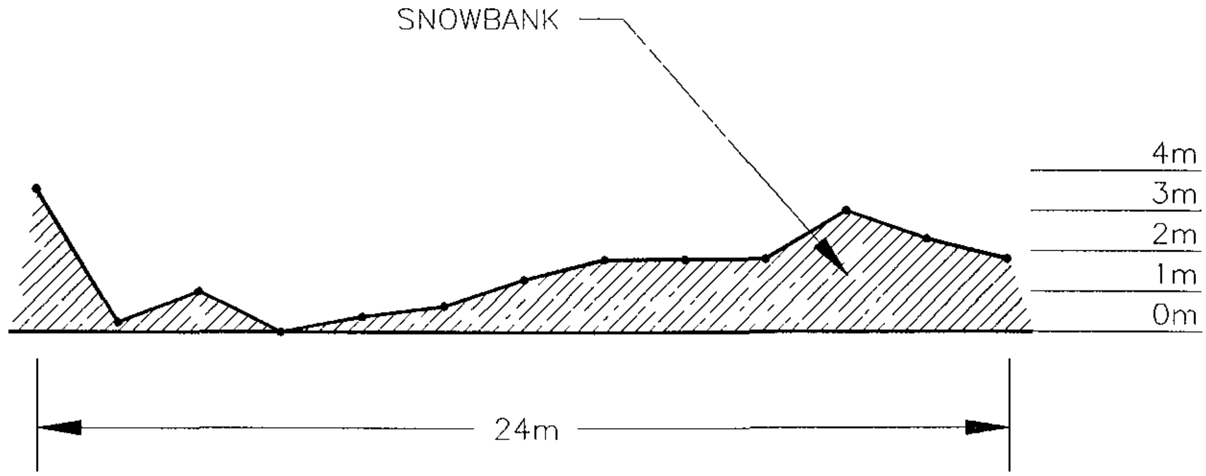
There are two significant ice features on MacKay Lake, the pressure ridge requiring a bridge and the "boil" in the road south of the Fish Camp access road The roadway adjacent to the boil was profiled with the GSSI electronic profiler on the journey north and other investigations conducted on the return journey. The boil was detected in the electronic profile as an area of thinner ice

The results of the manual investigation are illustrated in Figure 5.13 The ice in the boil was only 91 cm thick with up to 61 cm freeboard After augering four holes within the crown of the boil the water depth was found to be 4 5 m This is significant since prior to our investigation, some maintenance personnel had indicated that the boil was caused by a submerged rock Adjacent to the boil were also areas of thinner than normal ice

The thin ice in the boil may be a result of a spring in the lake causing mixing and warmer water adjacent to the underside of the ice sheet The uplift in the boil could then be a result of local buckling from a compressive stress field and/or an uplift due to any drawdown of water levels in MacKay Lake. If the presence of the boil is related to springs, then it is likely that there will be similar features at this location in future years.

5.3.4 Observations Along Fish Camp Access Road - April 02, 1995

The access road to the fish camp had been opened a few days previously and no major snowfall had occurred since the opening. By using the height of snow at the edge of the ploughed road, estimates of the number of drifts was made. These counts indicated that between 30 and 37 snow drifts occurred in 1.2 km Four holes were drilled which ranged from 1.15 m to 1 65 m with the thinnest ice corresponding to the thickest snow layer and visa-versa A small pressure ridge was crossed along the access road.



SNOW PROFILE ON MacKAY LAKE
FIGURE 5.10

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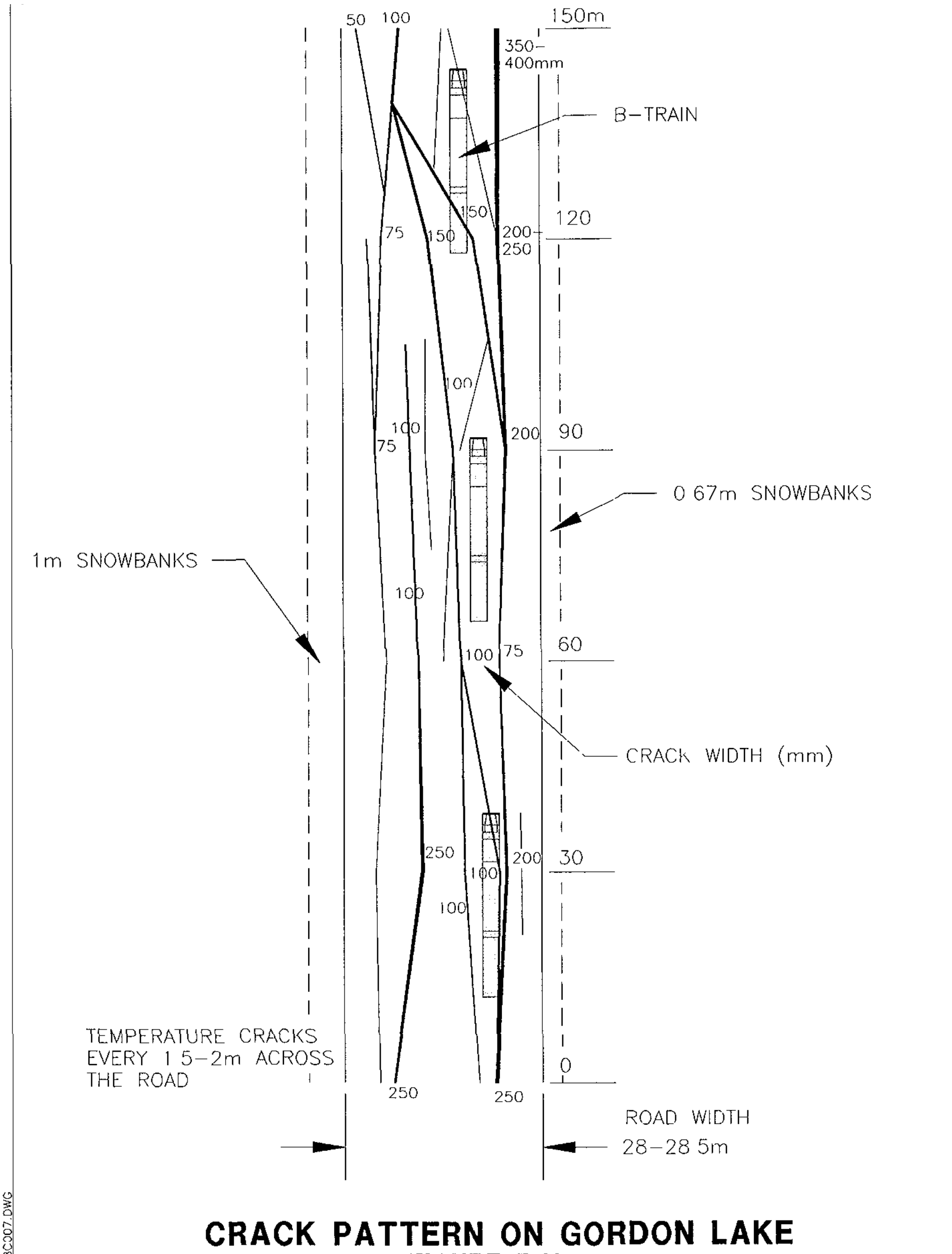

CRACK PATTERN ON GORDON LAKE
FIGURE 5.11

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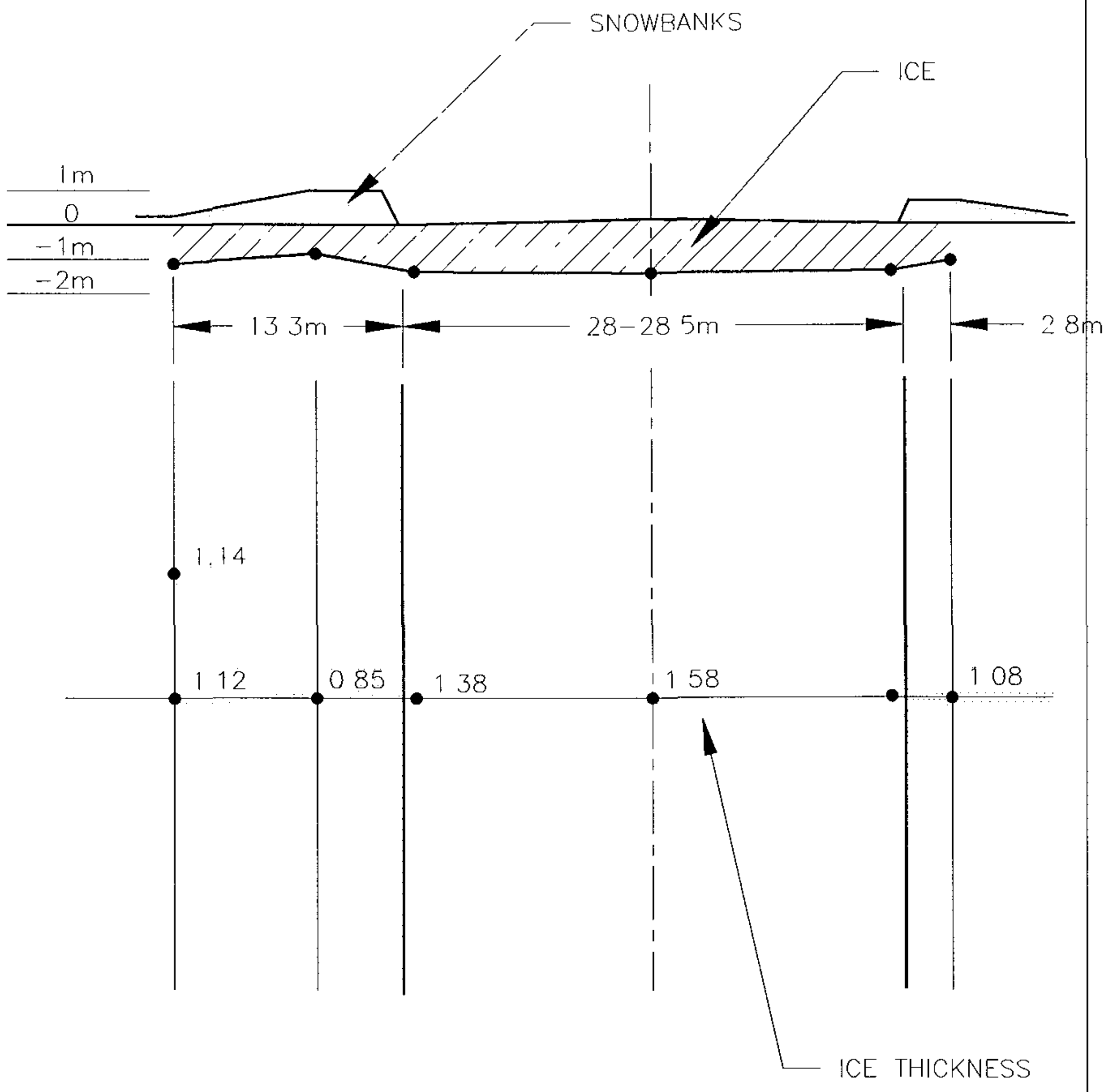

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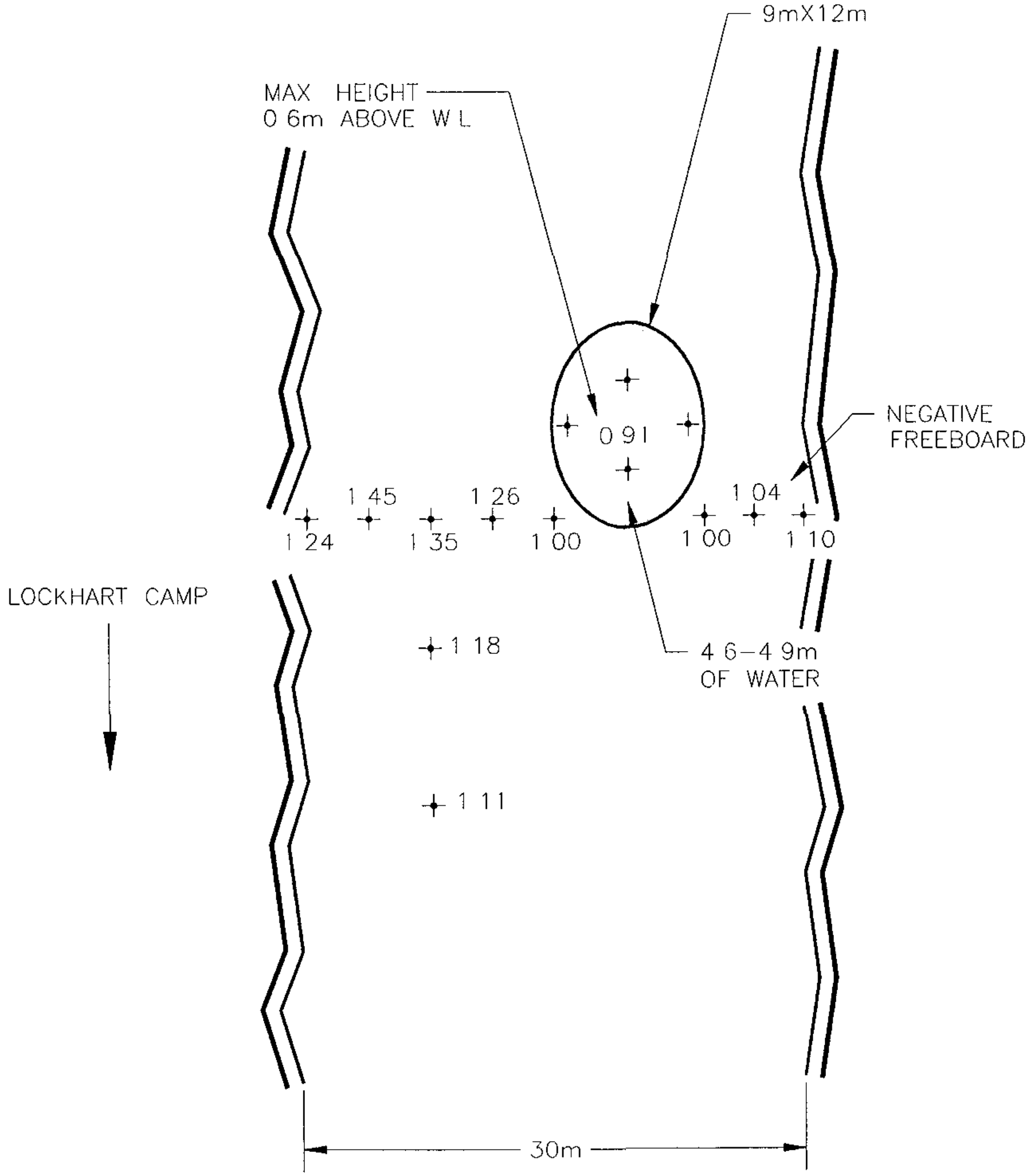
ROAD CROSS-SECTION ON GORDON LAKE
FIGURE 5.12



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BOIL IN ROAD ON MacKAY LAKE
FIGURE 5.13

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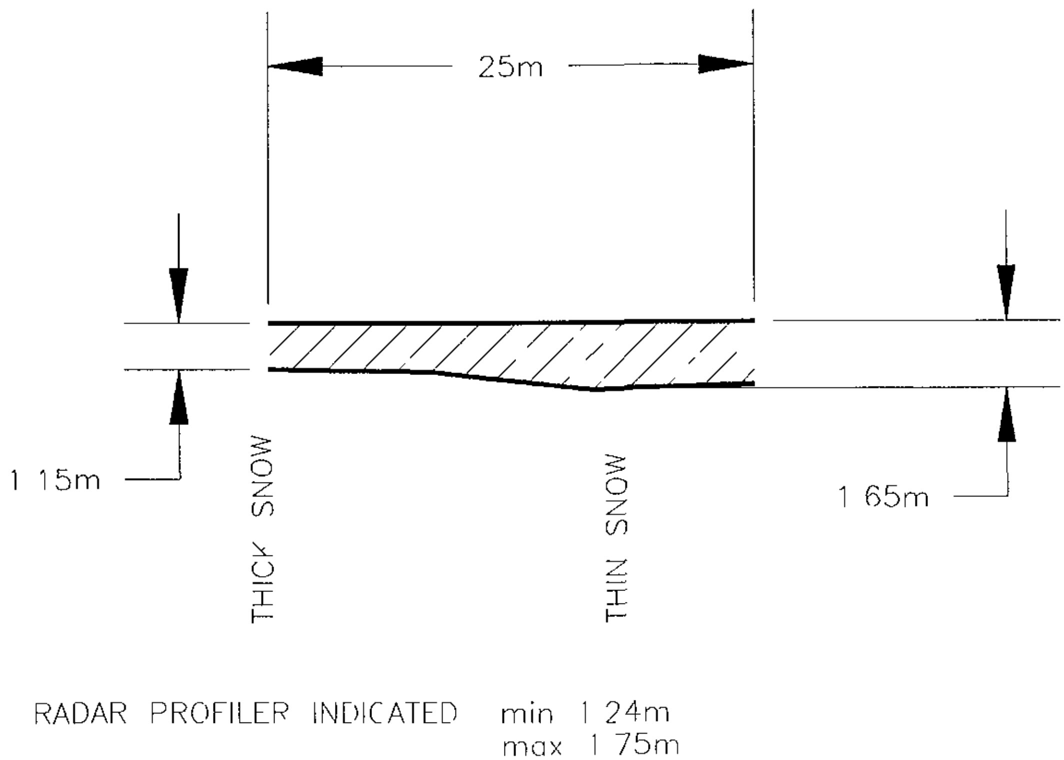

PROFILE ALONG FRESHLY CLEARED ROAD TO THE FISH CAMP ON MacKAY LAKE

FIGURE 5.14

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6.0 DYNAMIC RESPONSE MEASUREMENTS - APRIL 02, 1995

6.1 Background

When a vehicle moves over the ice sheet it can generate waves within the underlying water When the vehicle is travelling at the same speed as the water waves the deflection of the ice sheet can be larger than for a slowly moving or stationary load This phenomena of dynamic magnification has long been known [Hetenyi, 1946]. There are mathematical solutions to the situation of constant water depth and constant ice thickness Ignoring damping or losses in the ice and the water results in the deflection theoretically being infinite at the critical speed [Nevel 1970, Bates 1981] There have been measurements of the strain and deflection profile, at various speeds which have shown the deflection to be finite at the critical speed [Haspel et al 1981, Eyre 1977, Davys 1985, Squire et al 1985]. These data have been collected at a constant water depth, usually very large. It was therefore uncertain as to how much the steady-state constant water depth data would apply to the shoreline approach of a floating ice road Note that the usual gravity water waves shorten and steepen as the shoreline is approached [Lewis 1988]

6.2 Purpose

The purpose of the dynamic tests was to observe the ice sheet response as a vehicle approached a portage

6.3 Test Location

For logistical reasons, the testing was based out of the Lockhart Camp The following shore approaches were inspected for suitability; the access ramp at Lockhart Camp, North end of Lockhart Lake, South end of Lockhart Lake and lakes to the North end of Drybones and the gravel pit access road south of camp The gravel pit access was selected since the road met the shore at right angles, was straight and was close to camp. The general site layout is given in Figure 6.1. These deflection gauges were installed along with an accelerometer.

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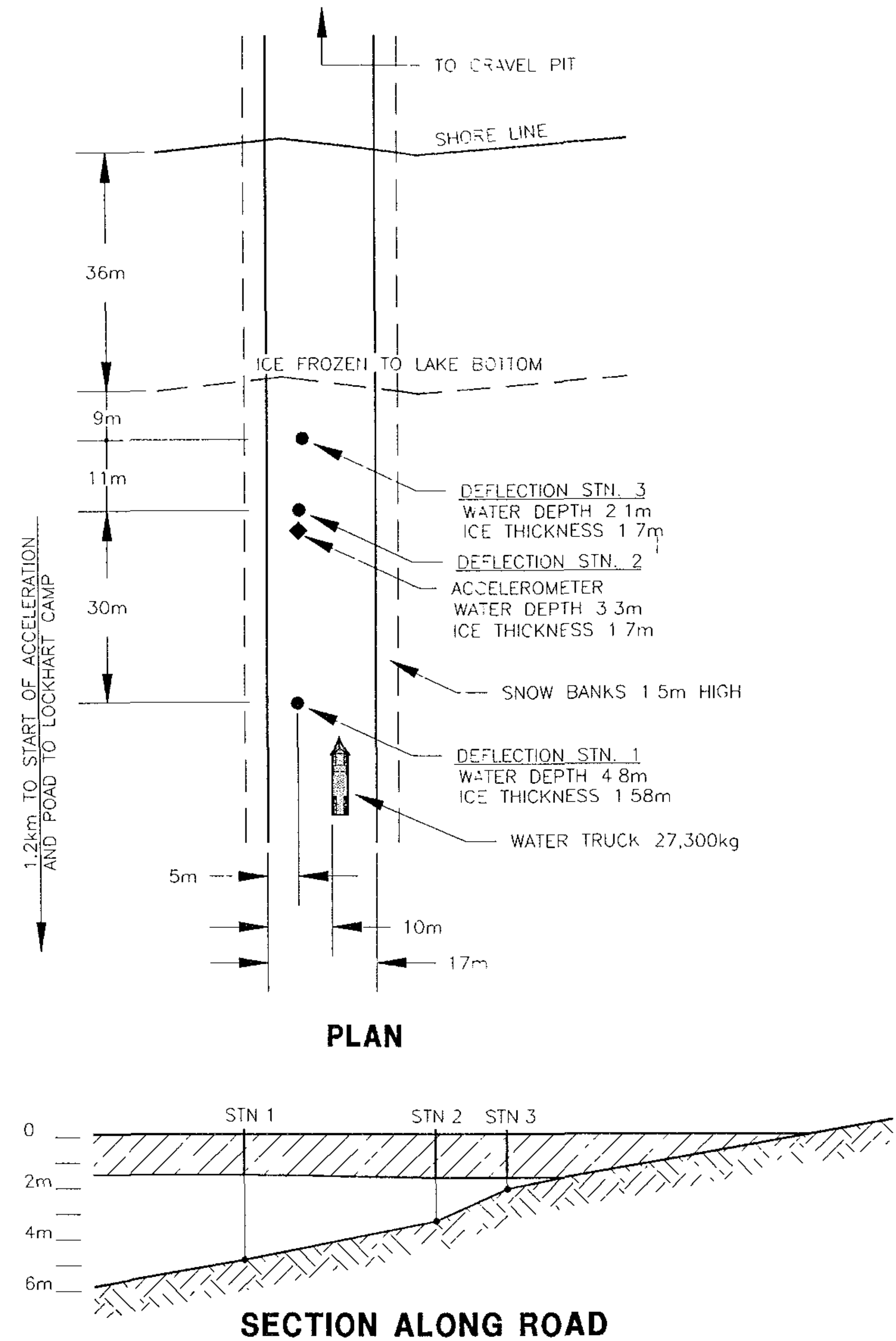


GENERAL ARRANGEMENT
DEFLECTION STATIONS
FIGURE 6.1

6.4 Apparatus

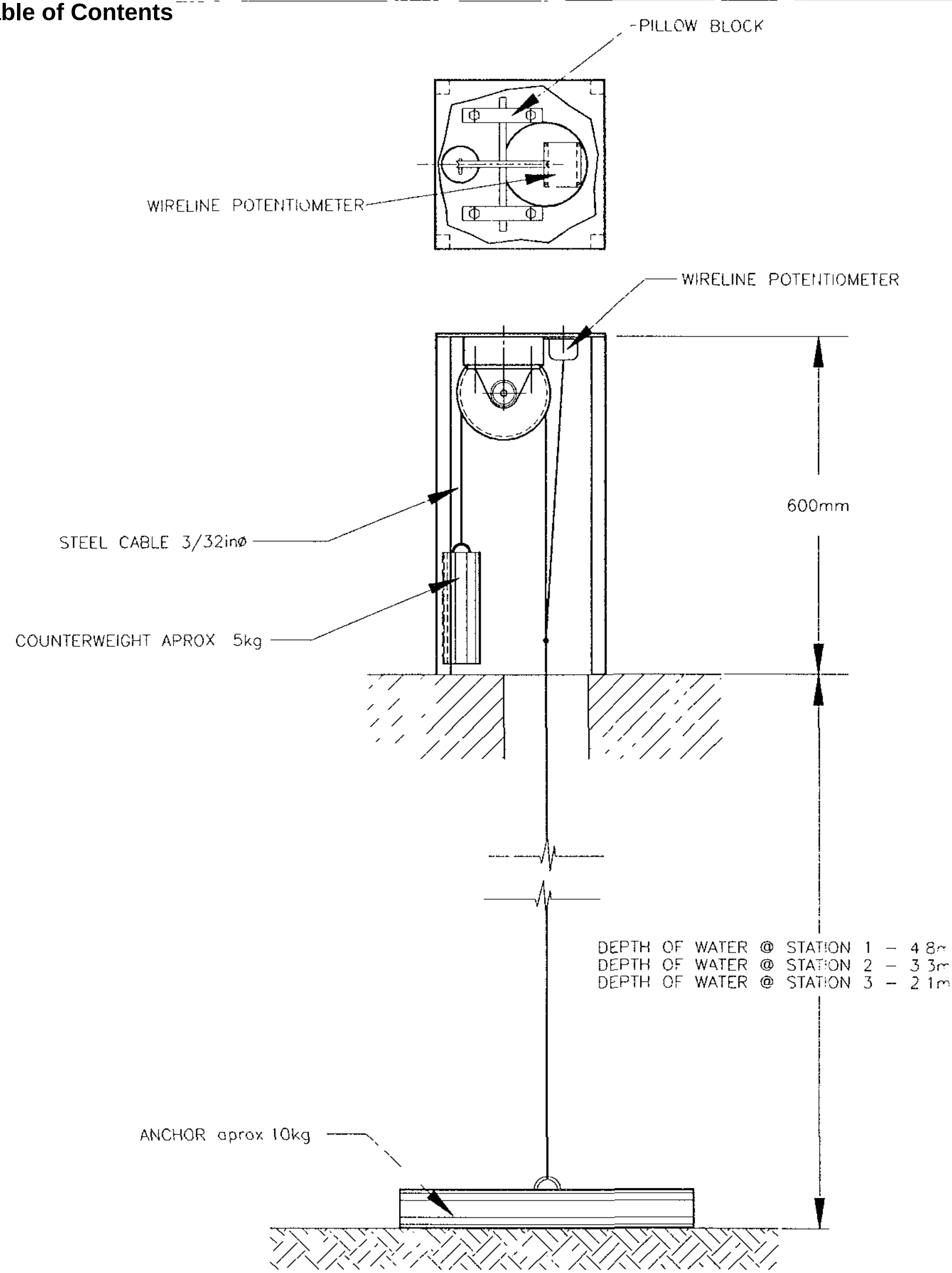
The construction of the deflection gauges are illustrated in Figure 6.2 and are based on wireline potentiometers The accelerometer mounted adjacent to Station No. 2 measured the vertical acceleration of the sheet Signals were recorded on a 4 channel Hioki 8801 chart recorder. The overall instrumentation schematic is illustrated in Figure 6.3 Electrical power (110 V.AC) was supplied by a portable 1500 W generator. Figure 6 3a contains photographs of the tests

6.5 Test Procedure

The tests were conducted on April 2, 1995 when the air temperature ranged between -30° C and -25° C with up to a 20 km/h wind speed Because of the cold conditions, the installation of sensors and equipment took until about 1·30 PM The test vehicle used was a water truck with an estimated weight of 27,300 kg The first set of tests consisted of the vehicle driving at constant speed from the junction with the main road onto the shore, then slowly backing up the road. The measurement of the vehicle velocity was not independently verified but relied on the vehicle speedometer. Tests were conducted at 5 km/h increments from 10 km/h to 40 km/h The maximum deflection occurred at speeds between 25 and 30 km/h and so additional test runs were conducted at 22 5, 27.5 and 32 5 km/h An additional set of tests were conducted to investigate if the vehicle slowing down or accelerating near the shore line had any significant effect on the deflection data. The test runs were completed by approximately 6·00 PM

6.6 Data Reduction

The data were recorded on the chart recorder and then manually digitized. Examples of the deflection signal shapes are presented in Figure 6 4 for three different speeds. The maximum downward (negative) and upward (positive) deflection for each constant speed run are shown in Figure 6 5. From data in Figure 6 5 it can be seen that maximum ice depression occurs between speeds of 25 and 30 km/h. Furthermore, the magnitude of deflections decrease as the water depth decreases. This presumably reflects the effect of the grounded ice at the shore providing support for the floating ice sheet. The dynamic magnification factor shown in Figure 6 6 uses the mean



DEFLECTION APPARATUS

FIGURE 6.2

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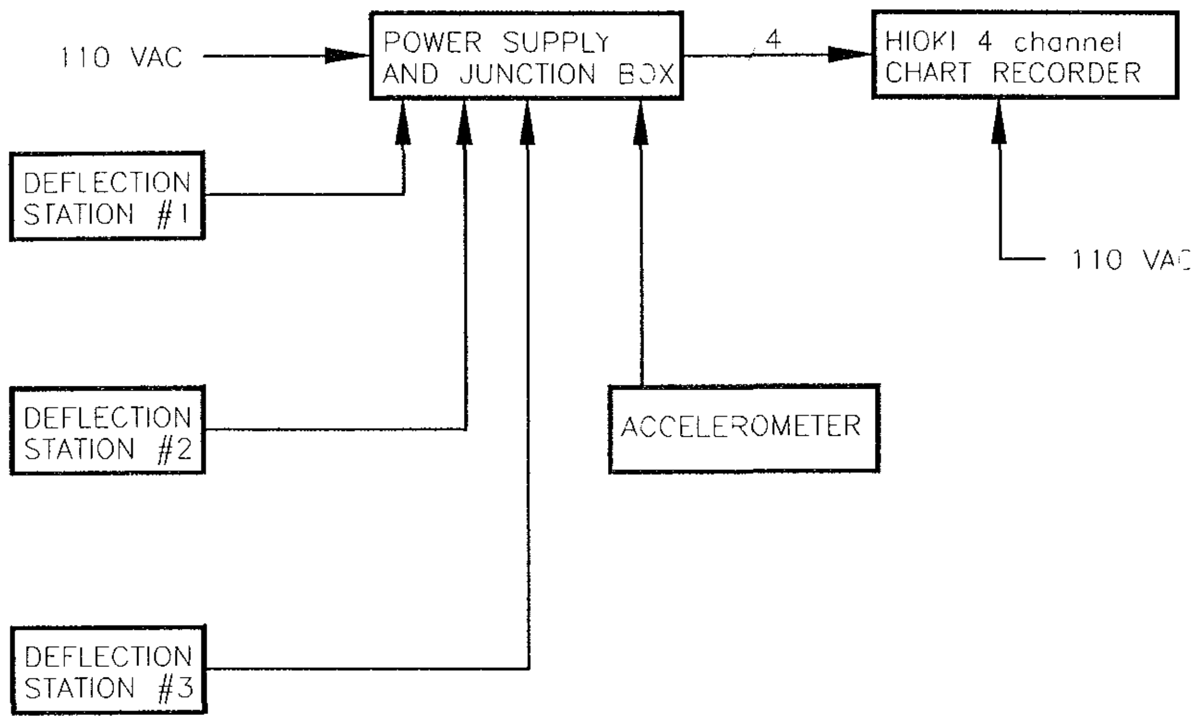

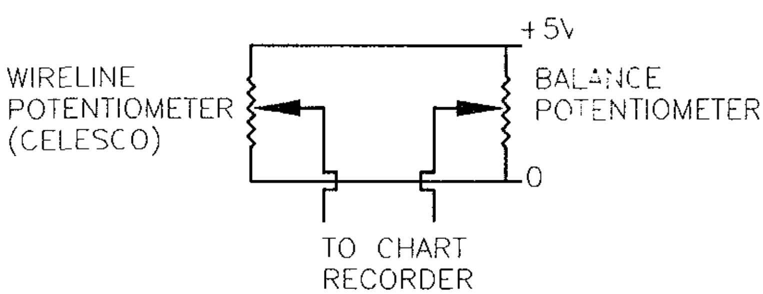

DEFLECTION STATION

INSTRUMENTATION SCHEMATIC
FIGURE 6.3

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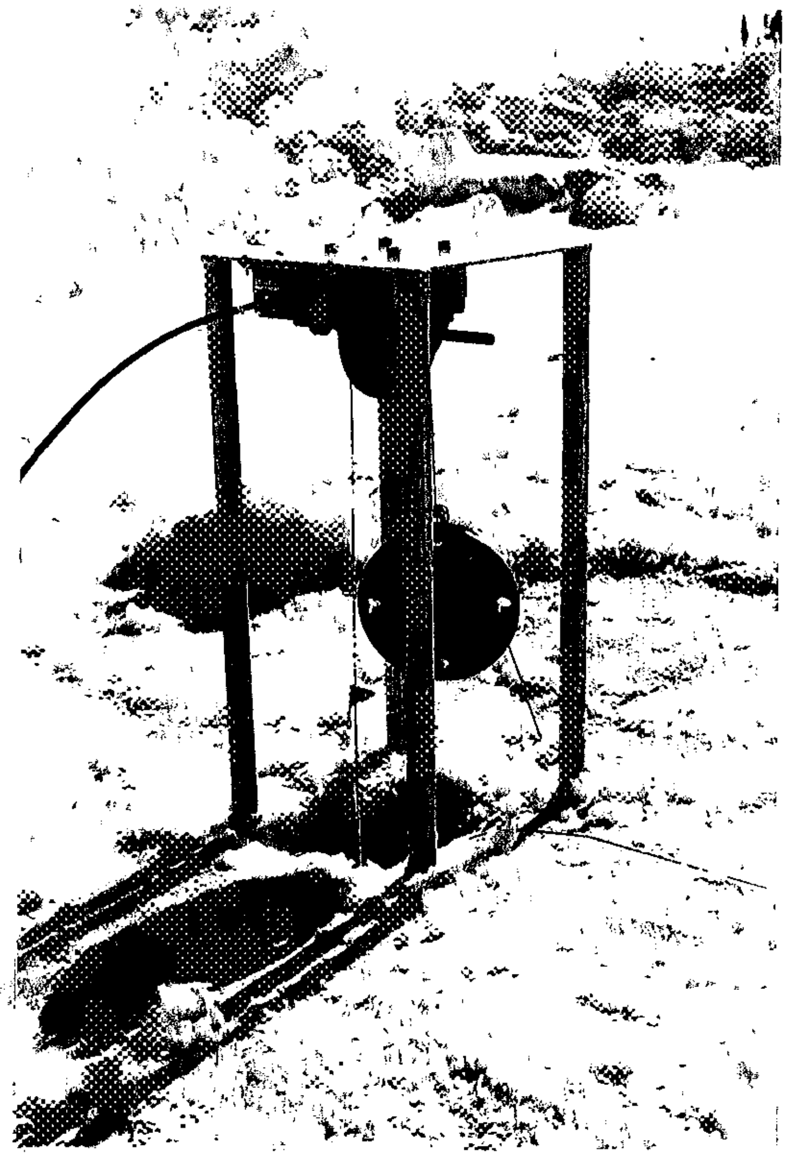

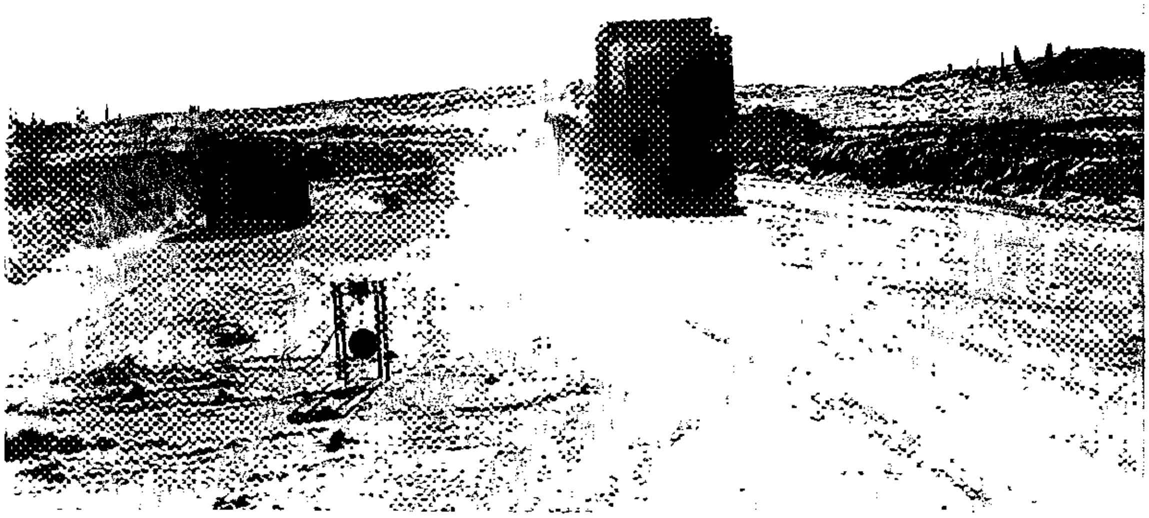

DEFLECTION TEST ARRANGEMENT

FIGURE 6.3a

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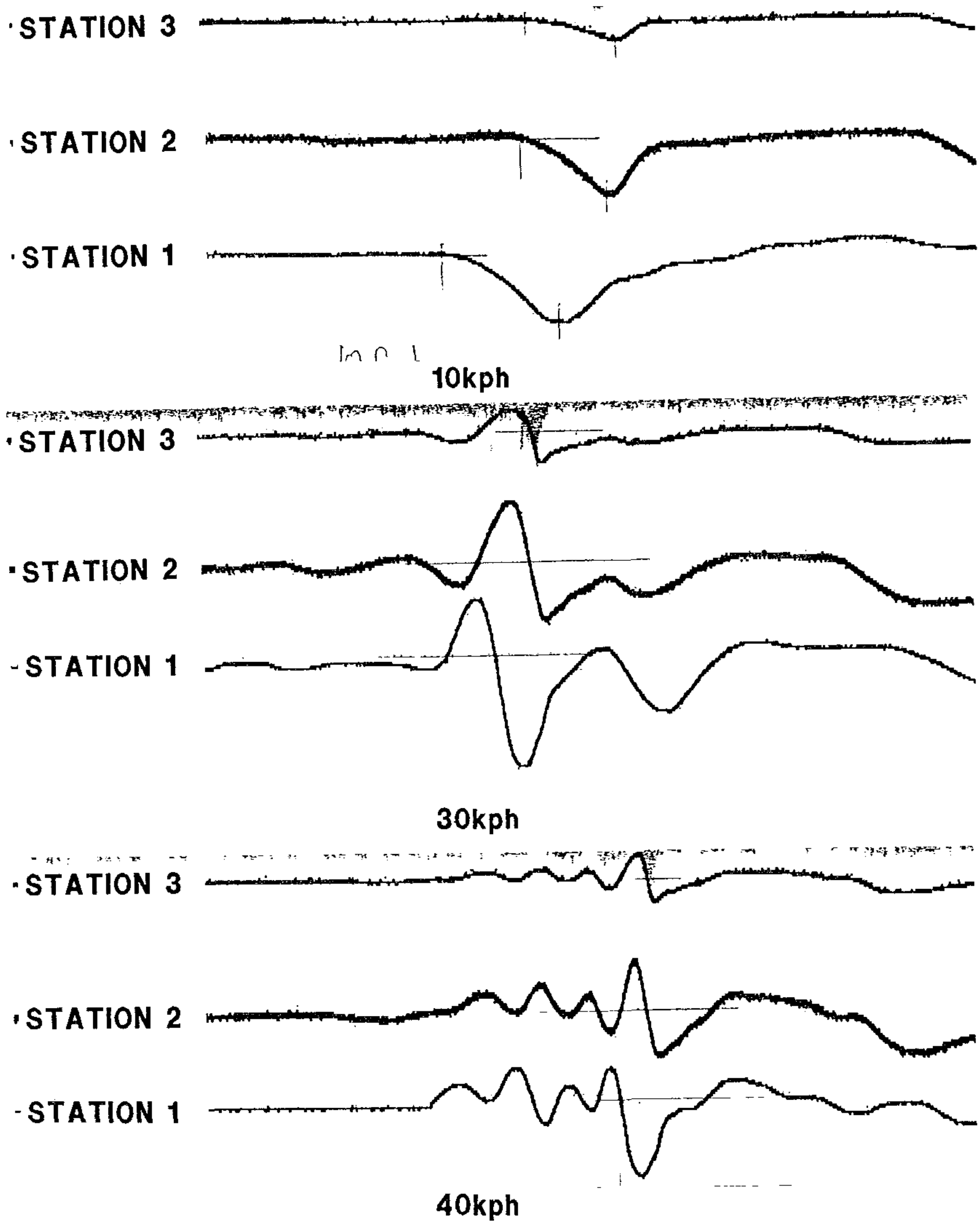

SCALES VERT 10mm = 10 7mm HORIZ 10mm = 10sec

EXAMPLES OF DEFLECTION TRACES

FIGURE 6.4

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FIGURE 6.5 : DEFLECTION MEASUREMENTS
AT CONSTANT SPEED

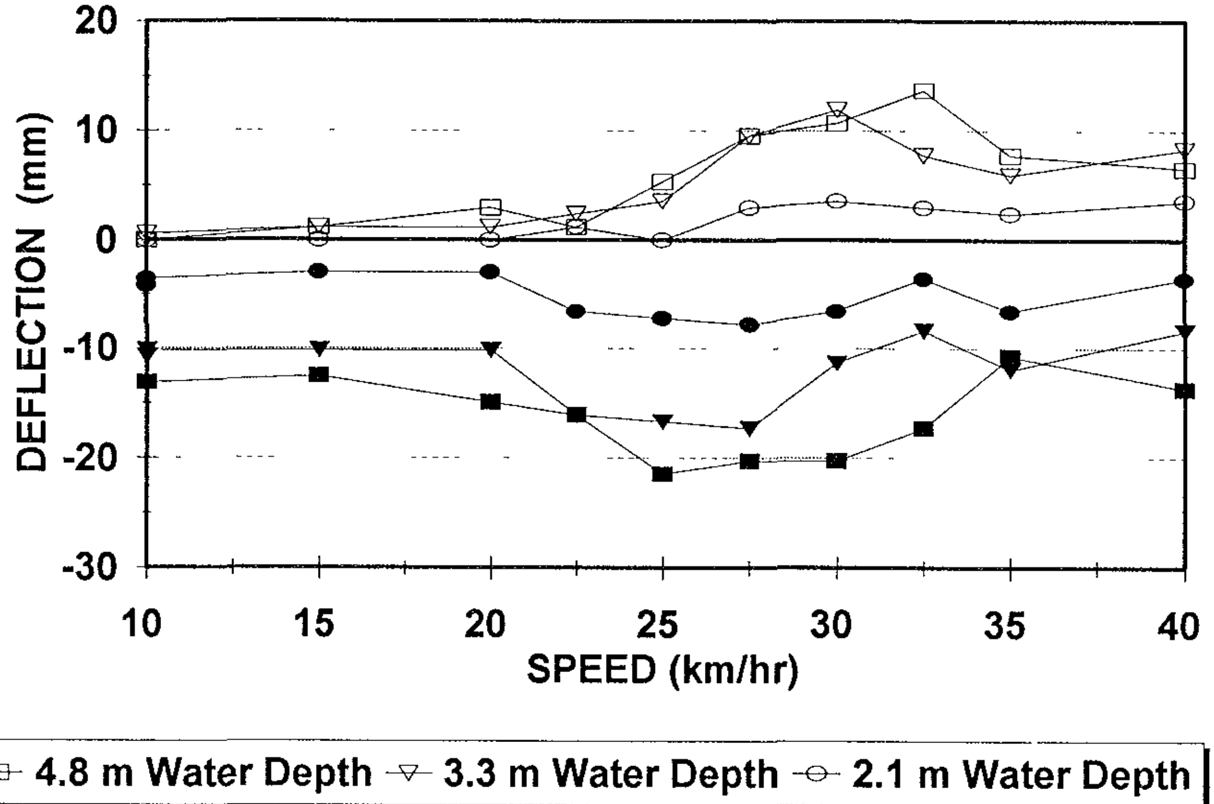
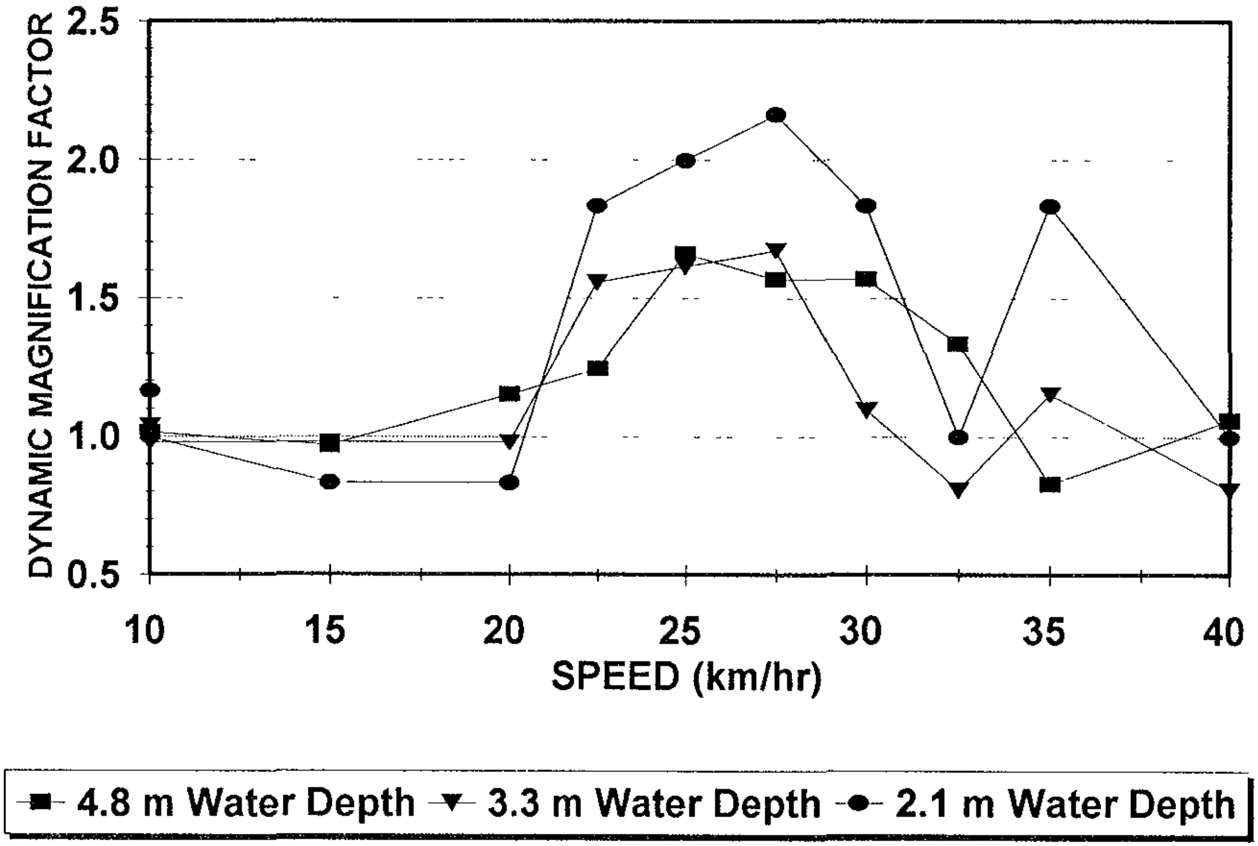


FIGURE 6.6 : DYNAMIC MAGNIFICATION FACTOR AT CONSTANT SPEED



deflection at 10 and 15 km/h and quantifies the increase in ice depression near the critical speed. The data presented in Figure 6 6 illustrates that the maximum dynamic magnification factor is approximately 1.6 for the two deeper water locations and 2 2 for the shallow location Note that the shallow location, while having a larger dynamic magnification factor, had a smaller absolute deflection

From data presented in Figure 6 5, the maximum ice sheet uplift occurred at 32.5 km/h and was numerically smaller than the maximum depression

Other previous studies [Eyre 1977] have observed that the width of the depression in which the vehicle is travelling narrows near the critical speed As a measure of depression or bowl width, the distance between the negative peak and the point where the deflection crosses zero (prior to the peak) was measured To aid in comparison with other investigations, twice the observed half width is plotted.

These data are presented in Figure 6.7 for the three deflection stations for the constant speed tests. Variable speed tests were not included because the depression width is calculated from the time difference and the constant vehicle speed. There is a general decrease in width with speed near the critical velocity The width appears to be narrower for the station close to shore The width relative to the mean of data collected at 10 and 15 km/h are shown in Figure 6.8. These data indicate that the width is between 0.5 and 0 75 times the low velocity width at or above the critical velocity.

Test runs were also conducted when the approach speed of the vehicle varied The results of these tests are illustrated in Figure 6 9 From an inspection it can be seen that slowing down from 30 km/h to 5 km/h just prior to measurement station 1 provided a deflection (downward) greater than measured during the constant speed tests. Note that this speed reduction coincides with the posted speed limits approaching most portages Speeding up did not appear to cause greater deflections

When the vehicle is travelling faster than the critical speed, the vehicle is preceeding the hydrodynamic wave. By the vehicle slowing down it allows the wave to catch up with the vehicle, thereby leading to greater deflections Because of the finite number of measurement

FIGURE 6.7 : DEFLECTION TESTS
WIDTH OF "BOWL"

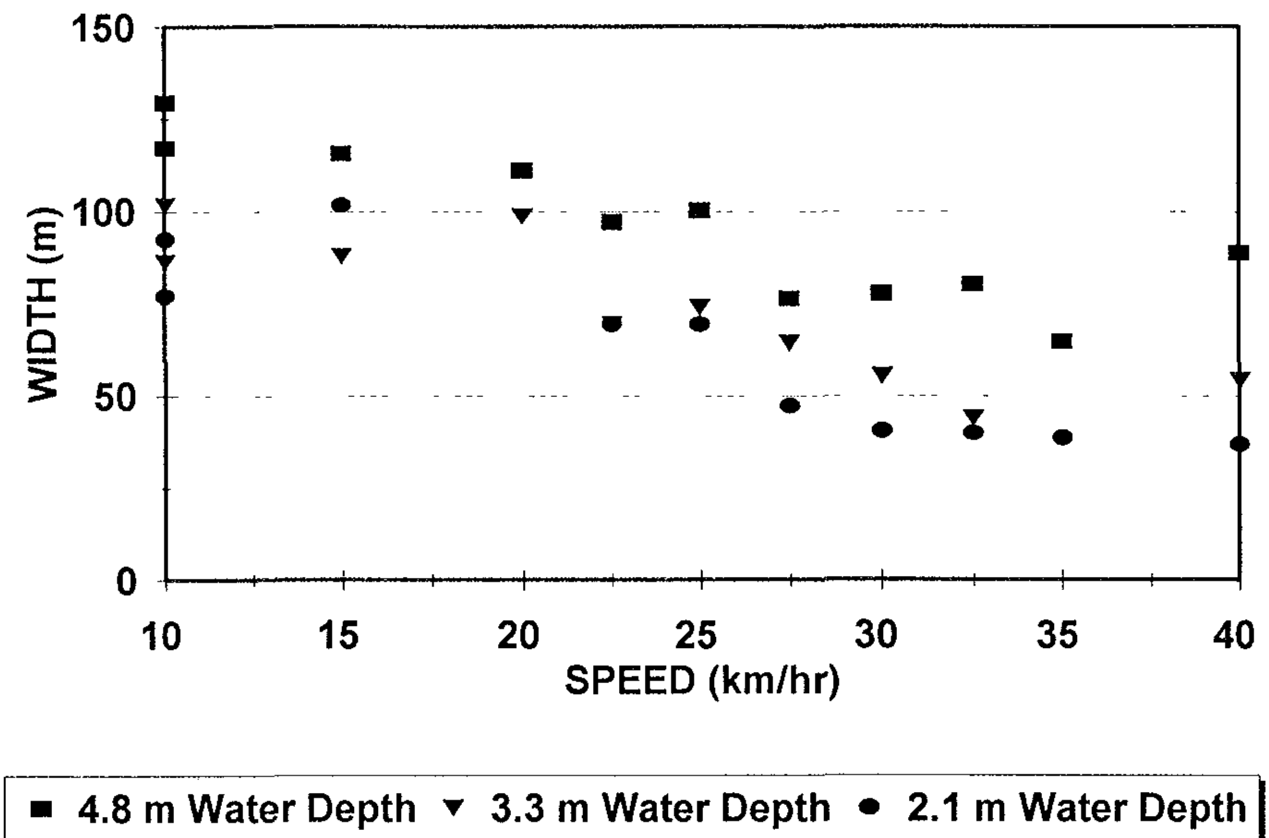


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FIGURE 6.8 : DEFLECTION TESTS
RELATIVE "BOWL" WIDTH

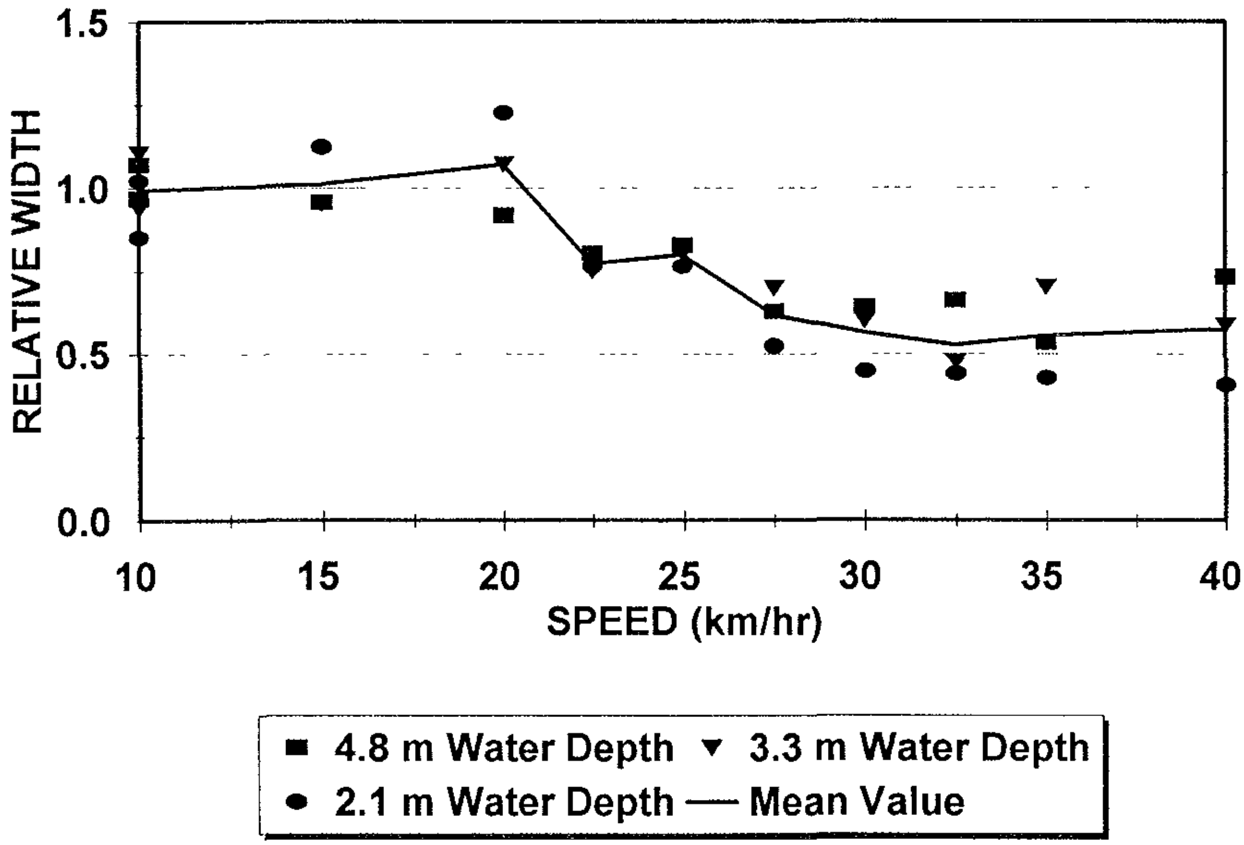
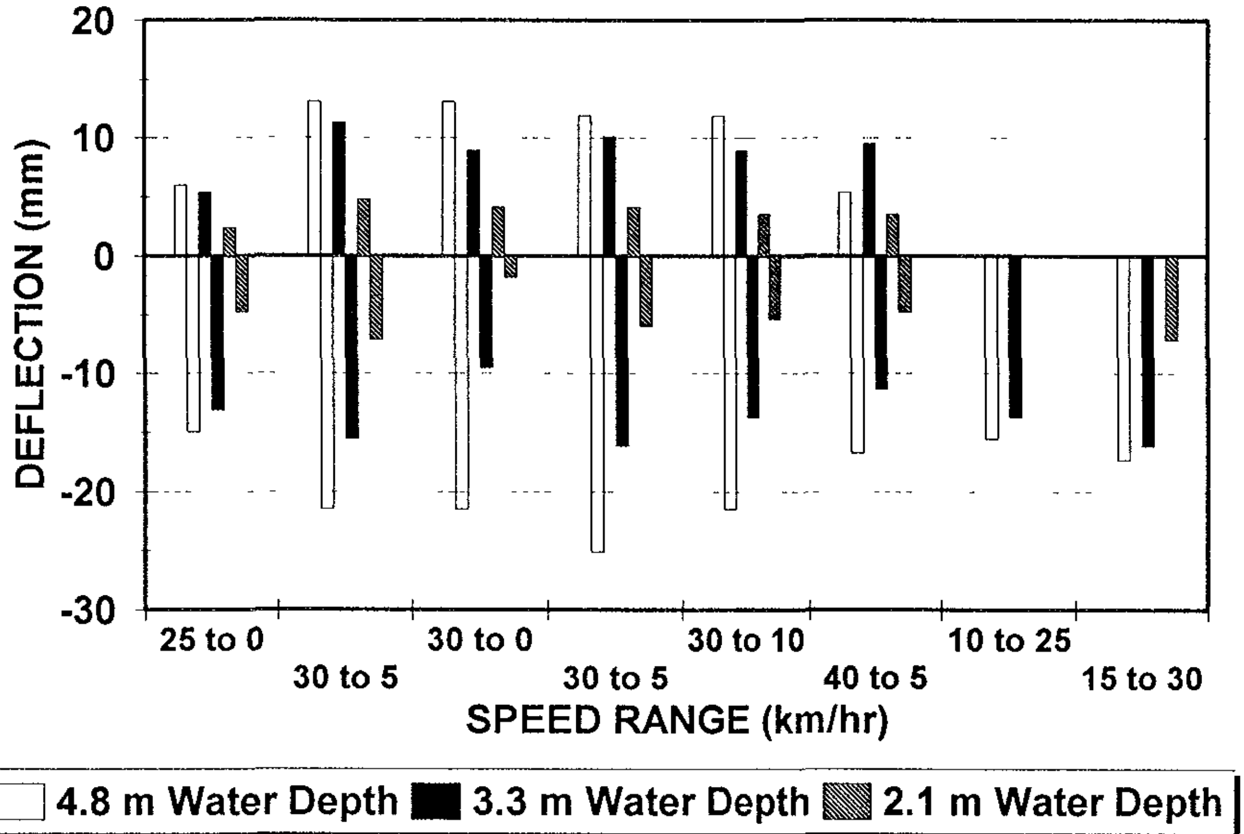


FIGURE 6.9 : DEFLECTION TESTS
AT VARIABLE SPEED



stations there is no guarantee that the maximum possible deflection was detected. However, the deflection at Station No 1, as the vehicle was slowed from 30 to 5 km/h, corresponded to a dynamic magnification factor of 1 95, 20 percent larger than the constant speed case of 1.6. It is also noted that this phenomena would also occur in deep water and is not just restricted to shallow water

6.7 Accelerometer Data

Assume for simplicity and to illustrate the principals, that the ice road can be treated as a beam with the following governing differential equation [Heteneyi 1946]·

$$EI \frac{\partial^2 w}{\partial x^2} = -M \tag{6.1}$$

When: E = *Effective Material Modulus*

I = *Section Modulus*

w = *Vertical Deflection*

x = *Horizontal Distance Coordinate*

M = *Applied Moment*

For a constant velocity of the vehicle

$$\frac{\partial^2 w}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 w}{\partial T^2} = \frac{1}{v^2} \ddot{w} \tag{6.2}$$

Furthermore the maximum fibre stress σ_{max} at a distance of Z from the neutral axis is given by

$$\sigma_{max} = \frac{Mz}{I} \quad (6.3)$$

Substitution 6 2 and 6 3 into 6 1 gives on re-arranging:

$$\sigma_{max} = \frac{zE}{V^2} \ddot{w} \quad (6.4)$$

Equation 6 4 indicates that the maximum fibre stress in the ice sheet is proportional to vertical acceleration. The other way of looking at the selection is to realize that the stress in the ice sheet is proportional to the curvature which is given by the vertical acceleration

Putting in values representative of the current situation.

$$\sigma_{max} = 500\ kPa$$
$$z = 1\ m$$
$$E = 5\ GPa$$
$$v = 10\ m/s$$
$$\text{Therefore } \ddot{w} = 10^{-2}\ m/s^2$$

Note that the expected vertical accelerations are only 0 1% of the acceleration of gravity even at the higher vehicle speeds. The noise level from the accelerometer was higher than anticipated and data were only obtainable at the higher vehicle velocities At 40 km/h and 27 5 km/h the estimated peak stresses, using 1 8 m ice thickness, were 250 and 265 kPa respectively. This approach does show promise as a field survey technique which is easily deployed on the ice surface

6.8 Critical Speed

When a vehicle is travelling at or near the velocity of the water wave dynamic effects are created. The critical velocity is, in general, a function of ice and water parameters. For constant water and ice parameters the critical velocity is given by [Haspel 1981]:

$$U_c = \left(\frac{2Hg}{1 + \sqrt{1 + (\mu H/\lambda)^2}}\right)$$

Where: H = *Water Depth* (m)

g = *Acceleration due to gravity* (m/s^2)

(6.5)

$$\mu = \frac{\rho_{ice} h}{\rho_{water} \lambda}$$

λ = *Characteristic Length*

$$= \left[\frac{Eh^3}{12(1-v^2)\rho_{water} g}\right]^{1/4} \quad (m)$$

For the current situation of shallow water Equation (6 5) can be written to good approximation as

$$u_c = \sqrt{H g} \qquad \textbf{(6.6)}$$

This last equation indicates that the critical velocity of the interaction is a function of the water depth only and is not a function of any ice parameters such as thickness or modulus Note that Equations 6 5 and 6 6 are for a constant water depth and not for a varying water depth.

Table 6 1 lists the theoretical and observed critical speeds at the depths of the three deflection measuring stations As indicated the theoretical critical speed decreases with decreasing water depth The observed critical speed does not show the predicted trend. Furthermore the observed critical speed is higher than the predicted from the measured water depth A critical speed of 26 km/h should correspond to a water depth of 5 3 (m). Because the dynamic phenomena take a

TABLE 6.1 CRITICAL SPEED

WATER DEPTH (m)	THEORETICAL CRITICAL SPEED (km/h)	OBSERVED CRITICAL SPEED (km/h)
4.8	24.7	27
3 3	20.5	25.
2.1	16 3	26.

finite amount of time to establish and to decay, the critical speed in the shoreline approach would be expected to reflect the water depth prior to the location of the measuring station.

In Figure 6 10 the critical speed is shown as a function of water depth for the range of ice thickness of the ice road. A second line is shown at 70% of the critical speed and represents the maximum vehicle speed in order to avoid dynamic effects. The value of 70% was chosen based on the characteristics of the observed dynamic region The value is also consistent with other investigations [Haspel et al, 1981, Eyre 1977]. The current speed limit for the ice road is 30 km/h for a loaded vehicle and 35 km/h for an unloaded vehicle.

Using the data presented in Figure 6 10, 30 km/h is appropriate if the water depth is greater than 15 m During the ice survey conducted during January 1995, some measurements of water depth were made Data for Gordon Lake are presented in Figure 6 11 along with the maximum speed in order to avoid dynamic effects As illustrated, the majority of the lake would suggest speeds at about 30 km/h would avoid dynamic magnification effects. However, there are likely to be locations in the overall ice road where water depths are less than 15 m These locations should be identified and the possibility of reducing the maximum vehicle speed be considered. Speed reductions have already been posted on the smaller lakes.

6.9 Comparison With Other Dynamic Magnification Measurements

In Table 6.6 other measurements of dynamic magnification factors are listed. The measurements reflect different measurement techniques and both from sea ice and fresh water ice. The measurements from this test program are broadly consistent with the other reported values.

FIGURE 6.10 : CRITICAL SPEED EFFECTS
ICE THICKNESS 0.5 to 2.0 m

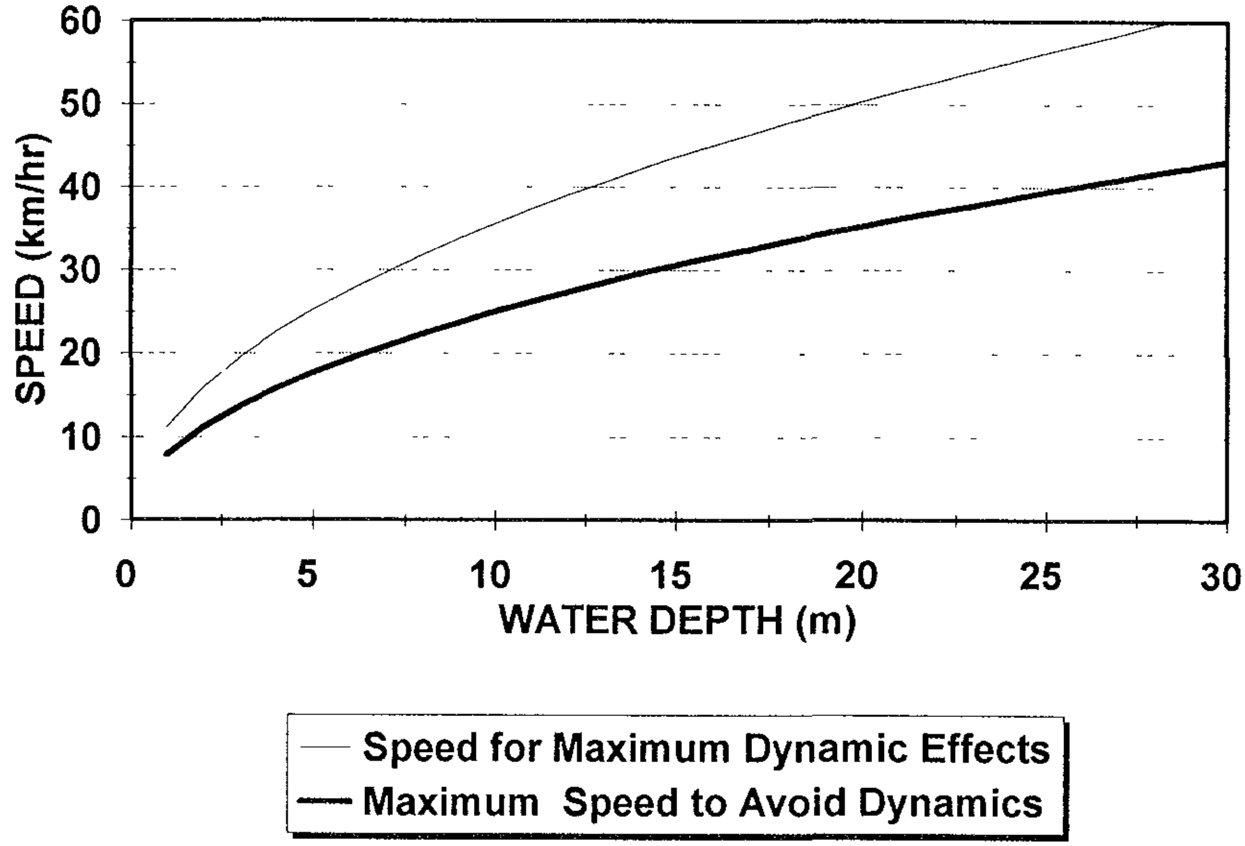


FIGURE 6.11 : CRITICAL SPEED EFFECTS
ON GORDON LAKE

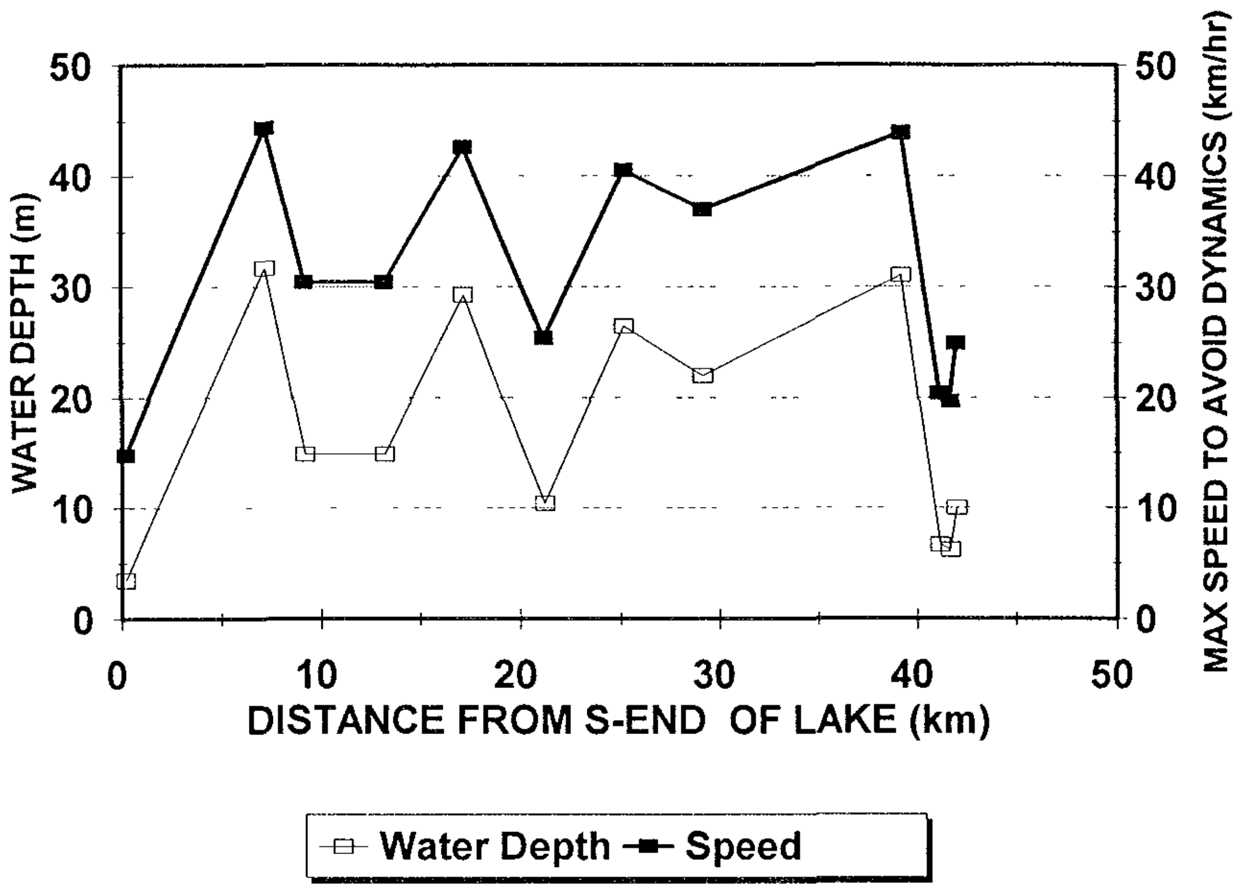


TABLE 6.2 CONSTANT SPEED TESTS DEFLECTIONS

SPEED	STATION 1		STATION 2		STATION 3	
(km/hr)	Max (mm)	Min (mm)	Max (mm)	Min (mm)	Max (mm)	Min (mm)
10 0	0 0	-13.1	0 0	-10 7	0.0	-4 2
10 0	0.0	-13.1	0.6	-10 1	0.0	-3.6
15 0	1.2	-12.5	1.2	-10 1	0.0	-3.0
20	3 0	-14.9	1.2	-10 1	0.0	-3.0
22 5	1 2	-16.1	2 4	-16.1	1 2	-6 6
25.0	5.4	-21.5	3 6	-16 7	0 0	-7.2
27 5	9 5	-20.3	9.5	-17 3	3.0	-7.8
30 0	10 7	-20 3	11.9	-11 3	3.6	-6.6
32 5	13 7	-17.3	7 8	-8.4	3.0	-3 6
35 0	7 8	-10.7	6.0	-11 9	2 4	-6 6
40 0	6.6	-13.7	8.4	-8 4	3.6	-3.6

TABLE 6.3 DYNAMIC MAGNIFICATION OF DOWNWARD DEFLECTION *

SPEED (km/hr)	STATION 1	STATION 2	STATION 3
10	1 02	1.04	1 17
10	1 02	0 98	1 00
15	0.97	0 98	0.83
20	1.15	0.98	0.83
22.5	1.25	1.56	1.83
25	1.66	1.62	2.00
27 5	1 57	1.67	2.17
30	1 57	1 10	1.83
32.5	1.34	0 81	1.00
35	0.83	1.15	1.83
40	1 06	0 81	1 00

* Relative to the average deflection at 10 and 15 km/hr

TABLE 6.4 VARIABLE SPEED TESTS DEFLECTIONS

SPEED RANGE (km/hr)	STATION 1		STATION 2		STATION 3	
	Max (mm)	Min (mm)	Max (mm)	Min (mm)	Max (mm)	Min (mm)
25 to 0	6 0	-14 9	5 4	-13 1	2 4	-4 8
30 to 15	13.1	-21.5	11 3	-15.5	4.8	-7 2
30 to 0	13 1	-21.5	8 9	-9 5	4 2	-1.8
30 to 5	11 9	25 1	10.1	-16 1	4 2	-6.0
30 to 10	11.9	-21 5	8.9	-13 7	3 6	-5 4
40 to 5	5.4	-16 7	9.5	-11.3	3 6	-4 8
10 to 25	0 0	-15.5	0.0	-13 7	0 0	0 0
15 to 30	0 0	-17.3	0.0	-16.1	0.0	-7 2

TABLE 6.5 TWO TIMES WIDTH OF INTERACTION

SPEED (km/hr)	STATION 1 Width (m)	STATION 2 Width (m)	STATION 3 Width (m)
10	117	86	93
15	116	88	102
20	111	99	111
25	100	74	69
30	78	56	41
35	65	65	39
40	89	54	37
27 5	76	65	48
22 5	97	69	69
32.5	80	44	40
10	130	102	77

TABLE 6.6 MEASURED DYNAMIC MAGNIFICATION FACTORS: FIXED SPEED

ICE TYPE	ICE THICKNESS (m)	WATER DEPTH (m)	DYNAMIC MAGNIFICATION FACTOR	MEASUREMENT TYPE	REFERENCE
First Year	2.0 to 2.9	3.2 to 8.0	1.5	Deflection	Haspel 1981
First Year	2.0 to 2.9	3.2 to 8.0	1.5	Stress/Strain	Haspel 1981
Fresh	0.53 to 0.73	36.4	2.1	Water pressure	Eyre 1977
First Year	0.15	6 - 12	~4	Deflection	Tabata 1956
Fresh	0.85	662	2.25	Strain	Squires 1985
First Year	2.05	~300	1.45	Strain	Squires 1985
Fresh	1.58 to 1.70	3.3 to 4 8	1 7	Deflection	This report
Fresh	1 70	2.1	2.2	Deflection	This report

7.0 SUMMARY AND CONCLUSIONS

Ice thicknesses were measured on the winter road to the Lupin Mine between the Ingrahm Trail and Lockhart camp in early December, 1994 by Echo Bay personnel. A more detailed survey was conducted by Sandwell in early January, 1995 to measure ice thickness both on and off the road, snow thickness, ice freeboard and the cross-sectional ice thickness profile of the road. It should be noted that this portion of the road is about 175 km in length and about 100 km of that length consists of floating ice road. In late March and early April of 1995, Sandwell rode with a fuel carrier from Yellowknife to the Lupin Mine Subsequently, Sandwell conducted a continuous electronic thickness profile of the ice road between the Ingrahm Trail and the Koala Mine site, a distance of about 400 km with about 300 km of ice road. As well, dynamic measurements of the near shore ice were made using a loaded water truck and other features of the road were investigated and recorded. The main results are as follows.

December, 1994 Measurements

The average ice thickness over the road between the Ingrahm Trail and Lockhart Camp in early December was 41 cm or 16 in The standard deviation was 8 cm or 3 in and the maximum and minimum thicknesses were 64 cm (25 2 in) and 20 cm (8 in) respectively

The December thickness measurements showed an apparent trend of thicker ice as one proceeded north from the Ingrahm Trail to Lockhart

The ambient temperatures, obtained from the Yellowknife Weather Office showed that November and December were 2° to 4° C warmer than normal and snowfall in this period was higher than normal Thus the ice thicknesses were less than normal but were greater than the 28 year minimum

January, 1995 Survey

The January survey indicated an average ice thickness for the over-ice portions of the road of

81 9 cm (32 2 in). The minimum measured thickness was 55 cm (21 6 in.), this minimum range being obtained only at two specific locations along the road The standard deviation of the thickness was about 10 percent of the mean, less than observed in December when it was about 20 percent of the mean

There was no apparent trend for average ice thicknesses to increase as one proceeded north from the Ingrahm Trail to Lockhart, contrary to the observation in December.

The ice north of Lockhart Camp in Wharburton Bay and Mackay Lake was thicker, being about 1 m thick.

The average ice thickness measured off-road in January in undisturbed snow covered areas was 65 6 cm (26 in.), indicating that the ice on the road right-of-way was 25 percent thicker than that where snow had not been removed. Thus snow removal resulted in a significant gain in ice thickness over a period of one month.

The average thickness measured at the edge of the 23 m right-of-way was 72 cm (28.3 in), 10 7 cm or 4 2 in less than measured in the road center portion This was a result of the fact that the road had originally been plowed to about an 8 m width and then widened later to the 23 m width

Thickness variation across the road section has an important effect on the flexural stress in the ice due to applied load. Uniform ice thickness was assumed for the stress calculations performed by Sandwell in August, 1994

The freeboard along the road centerline was normal isostatic while at the edges and off-road in the snow it was about zero The load carrying capacity of ice depends on positive freeboard and thus it is important to maintain a positive freeboard on the central portion of the road by keeping it free of snow. Also, it is important that heavy loads stay on the road centerline for safe passage

Spring, 1995 Survey

The trip with the fuel truck in late March provided the following major observations·

- Ice blowouts occur early in the season and always at the shore. They occur most often to the side of the road and result in no harm to the road. If they occur on the road, then repairs are required but since they occur in shallow water they do not present a dangerous situation whereby the truck could sink

- Observable ice dynamic effects are uncommon and flexural fatigue of the ice sheet resulting in failure has not been observed This is consistent with other ice roads which have experienced more loads at higher frequency.

- Surface cracks cause roughness, catch wheels and are a general nuisance Truckers will then often drive adjacent to a snowbank at the road edge to avoid the rough areas in the road center, placing them on thinner ice and sometimes near dangerous, wet cracks.

- Posted speed limits can be close to the speed where maximum dynamic effects occur However, limiting speeds is essential at shore approaches and over shallow water The safest practice is to reduce speed to below the critical velocity before reaching shallow water or the shore approach Otherwise, the vehicle is likely to pass through the critical velocity zone of the dynamic response curve and create maximum dynamic effects

- Effective snow removal is important and snow blowers help with snow removal It is important to maintain a road width of at least 25 to 30 m to avoid a "hogging" moment and tensile cracking of the road centerline

- Alternative routes for the road from Tibbitt Lake to Drybones Lake would be difficult to find. Thus the existing alignment may require widening if traffic is increased.

- Some ice "boils", which have thinner ice, are caused by underlying rocks, whereas some are not. Measurements were taken of one "boil" on McKay Lake which overlay 5 m of water.

The electronic ice thickness survey conducted in later March using ground penetrating radar (G.P.R.) was successful and quantified the ice thickness distribution over the complete length of the road. Approximately 1 8 x 10^6 thickness readings were obtained at a spacing of 0 2 m Minimum ice thicknesses in early April were generally 1 30 m (51.2 in) south of Lockhart Camp but only 1 25 m (49 2 in.) north of Lockhart Camp Maximum ice thickness were 1.58 m (62 2 in) north of Lockhart Camp and 1 80 m (71 in.) south of Lockhart Camp The lower minimum thicknesses north of Lockhart were due to the presence of naturally occurring snow drifts in the northern section of the road These drifts were established early in the winter and this northern section of the road was not opened until the second week of January

A model was generated to allow predictions of ice growth as a function of ambient air temperatures and snow cover. The model was calibrated against field data from Yellowknife, Baker Lake, Alert and measurements from the winter access road The road was modelled as two sections, the section south of Lockhart Camp using Yellowknife as a reference meteorogical station and the section north of Lockhart Camp using Lupin Mine as the reference station The model was then employed to predict ice thickness at the end of the season and to predict when sufficient ice is available for hauling Opening dates for reduced loads ranged from January 1 in a cold year to January 16 for a warm year. A cold year is based on the freezing degree days being 1 standard deviation greater than the long term mean The second major conclusion from the modelling is that even in a cold year the design 1 70 (m) (67 in) minimum ice thickness required for the heavy loads such as the mine shovel carbody may not be achievable for the whole road by April 1 It will be necessary to reexamine the method used to transport these heavy loads over the ice.

Tests were conducted on the dynamic effects in the ice sheet caused by vehicles approaching a portage. Constant velocity dynamic magnification factors of 1 6 to 2.2 were observed in the speed range of 25 - 30 km/hr The maximum observed deflection, however, occured when the vehicle slowed down from 30 to 5 km/hr just prior to the deflection measurement stations. The dynamic magnification factors measured were broadly consistent with other reported values.

8.0 RECOMMENDATIONS

From our study on the winter access road conducted during the 1994 - 95 season, there are a number of recommendations for further field evaluation.

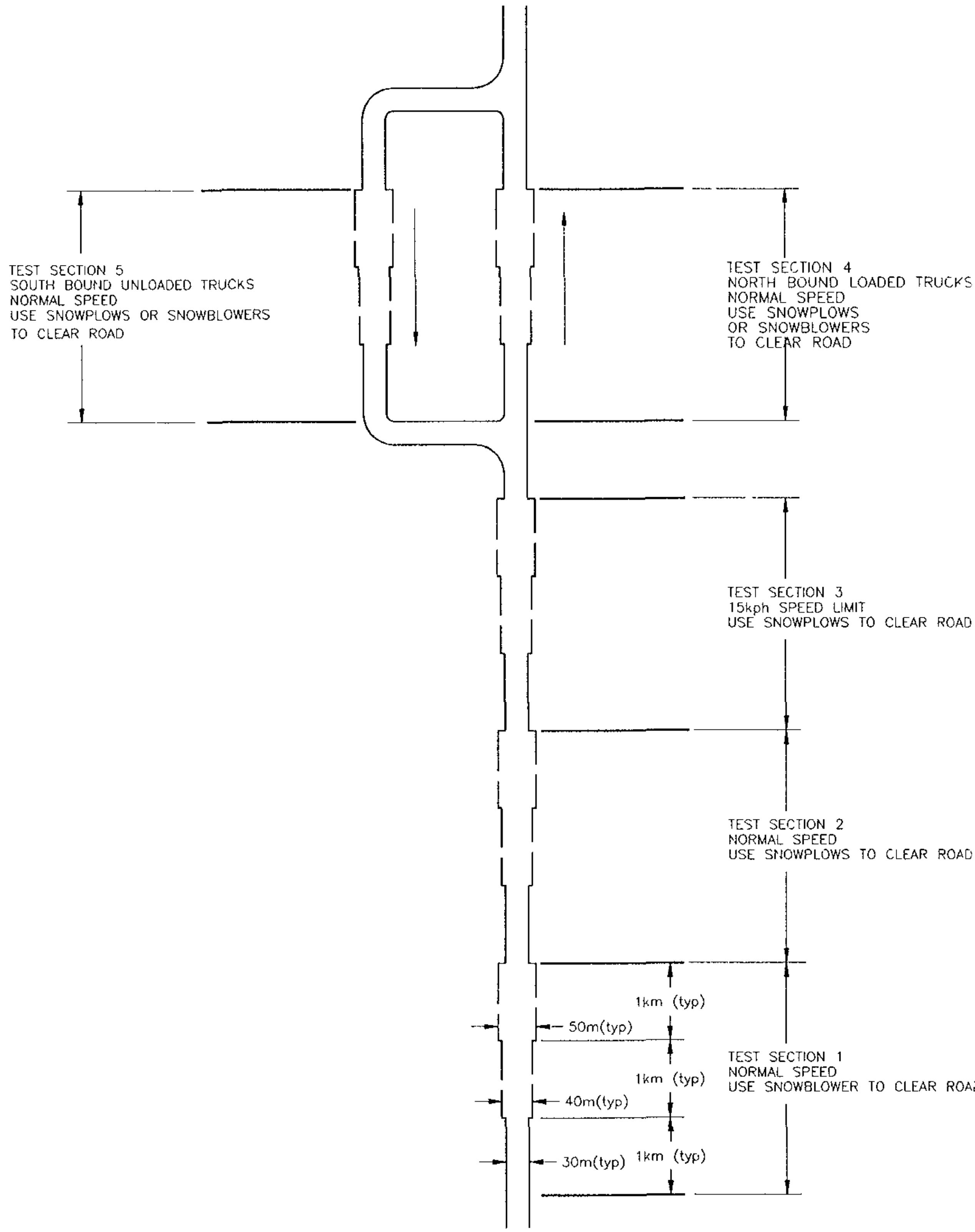
- Conduct an electronic thickness survey on a yearly basis Ideally, the survey should be done twice per season, once when the road is being opened and once near the end of the season. The electronic profile has been shown to be very effective and with the experience obtained this year, the cost can be kept very low. The data from the surveys will help in detecting thin areas in the road and provide documentation of the actual ice thickness This information is required for future planning purposes, especially for determining the feasibility of transporting heavier loads

- Conduct a survey once using the electronic profile system to quantify the water depth over the whole length of the road This data will be used to detect areas where speed limits may be appropriate in order to avoid dynamic effects. It will also put the current speed limits on a firmer engineering basis

- In order to determine a cost effective strategy for improving the serviceability of the road, particularly when increased traffic is anticipated, a set of road test sections should be established. These sections would evaluate the effect of road width, vehicle speed and loading and road maintenance method on the serviceability of the road. Also, the tests can be conducted using the existing road preparation equipment Thus, except for the monitoring, the incremental cost is negligible The proposed test sections are illustrated in Figure 8.1 The basic test section might consist of a 1 km segment 30 m wide, a 1 km segment 40 m wide and a 1 km section 50 m wide, although the widths of these sections would need further scrutiny At present, the road is generally plowed to a 25 to 30 m width although it is often much narrower on the northern sections where drifting snow makes it difficult to maintain the width.

  This will principally evaluate the centerline and edge cracking of the road as a function of road width Observations indicate a generally reduced amount of cracking with increased road width The other factors to be investigated would be the effect of using snow blowers as opposed to snow ploughs in road maintenance and in road clearing. The effect of vehicle speed would be evaluated by having one test section with a 15 km/hr speed limit The last aspect would be to evaluate the effect of loaded vs unloaded trucks by having a test section which had northern traffic only and a parallel section which has southern traffic only

It is suggested that such a road test arrangement be selected on the northern part of Gordon Lake and one on the southern part of MacKay Lake. These two locations would evaluate the test measures in the qualitatively different sections of the road south and north of the tree line The chosen locations would also be relatively close to Lockhart Camp A crack, ice thickness, ice freeboard and snow bank thickness survey would be conducted two or three times during the season to quantify the effect of the various test measures.



ROAD TEST SECTION

FIGURE 8.1

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9.0 ACKNOWLEDGEMENTS

We wish to thank B.H.P. and Echo Bay Mines personnel for their assistance during this project We also would like to acknowledge the co-operative attitude and help of the winter road maintenance personnel, and especially that of Wilf Kallihoo Randy Turlock, an independent trucker, is also thanked for his assistance. Uve Embacher of Elgin Drilling is thanked for supplying data on snow densities.

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