COGLA Program Number 9233-A4-3E

"Airborne Airtrace Surveys over the Peel Plateau, Northwest Territories"

an Airborne Geochemical Survey

of the

Peel Plateau area, Northwest Territories

August 1987

prepared for

Amoco Canada Petroleum Company Limited

by

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Barringer Research Limited

November 1987

David B. Grass

Geologist

Amoco Canada Petroleum Company Limited

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W.D. #1972D/0445A

AIRBORNE AIRTRACE SURVEYS OVER PEEL PLATEAU, NORTHWEST TERRITORIES

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AIRBORNE AIRTRACE SURVEYS OVER PEEL PLATEAU, NORTHWEST TERRITORIES

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TABLE OF CONTENTS

BARRINGER

TABLE OF CONTENTS

BARRINGER

TABLE OF CONTENTS

BARRINGER

LIST OF FIGURES

BARRINGER

LIST OF TABLES

LIST OF PLATES

(in back pockets)

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1. ABSTRACT

This report describes the methodology and results of airborne AIRTRACE[R] surveys carried out by Barringer Research Limited over the Peel Plateau area, Northwest Territories for Amoco Canada Petroleum Company. The AIRTRACE technology is the culmination of a joint venture between Barringer Resources Inc. and British Petroleum International Limited. The AIRTRACE system was developed to enable mapping of the observed effects of marine thermogenic hydrocarbon seeps with the intention to relate the results to underlying hydrocarbon reserves. The surveys described herein were intended to test the application of the system in the Canadian muskeg environment.

The AIRTRACE survey system was mounted in a Britten-Norman Islander BN2A and surveys were flown over an area of approximately 19,900 square kilometres northwest of Norman Wells, Northwest Territories. Initially, reconnaissance lines were flown over the entire area with a five kilometre line spacing and detailed (one kilometre spaced) survey lines were flown over areas where previous workers had observed hydrocarbon seepage. Finally, infill survey lines were interlocated between existing lines in the western part of the survey area to provide further detail over anomalous areas. In addition to the AIRTRACE data, video imagery was acquired along survey lines which allowed corroboration of oil slick sightings. A total of 5,605 line kilometres were flown over a period of thirteen days between August 10 and 22, 1987. The highest quality data was selected from the total flown and data for 4,506 line kilometres are presented in this report.

Except for a few days, when fog and rain were encountered, propitous weather conditions were encountered during survey operations. Overall AIRTRACE data quality is excellent, although data obtained along small portions of the western-most lines was ntaminated by persistent forest fires.

(R) AIRTRACE is a registered trade mark of Barringer Research Ltd.

The report describes logistics of the operations, data acquisition and reduction methods and presents survey results.

Repeat flying, at the end of each survey flight, over the Norman Wells oil field and production facilities demonstrated that the equipment was operating satisfactorily on productive flights. Three of four detailed surveys over documented hydrocarbon seeps showed evidence of leakage; the fourth survey, over the Rond Lake Seep, showed no AIRTRACE response, probably because of the low API gravity of the exuding hydrocarbons.

AIRTRACE data acquired over the reconnaissance area clearly shows a region of high frequency of responses over outcropping Middle Cambrian to Upper Devonian source rocks in the eastern half of the area. Location of AIRTRACE responses is not correlated with location of larger water bodies suggesting that permafrost does not exert a strong control over seepage of longer chain hydrocarbons. Trends are apparent in the AIRTRACE data, for the most part aligned NE-SW, some of which are coincident with structural trends.

A cluster of high and low amplitude AIRTRACE responses was obtained over presumed Cretaceous cover in the western part of the area. This cluster of responses is not obviously related to the NE-SW fabric of the data. This, together with the probable presence of Cretaceous cover, suggests this may be the highest priority exploration lead generated by the survey.

2. INTRODUCTION

This report describes AIRTRACE surveys conducted over an area of approximately 19,900 square kilometres, northwest of Norman Wells, Northwest Territories by Barringer Research Limited for Amoco Canada Petroleum Company during a period between August 10 and 22, 1987.

The AIRTRACE survey equipment used is unique, the equipment and data interpretation techniques for which have been developed over a five year period in a technological Joint Venture between Barringer and British Petroleum plc. The initial field trials of these systems were carried out in 1983 offshore California in the Santa Barbara Channel. Subsequently, they were evaluated in large scale surveys in the North Sea, U.K. in 1984 and 1985; offshore Egypt in 1985; and the Gulf of Mexico, offshore Mozambique, and the Atlantic Margins, U.K in 1986. Following release of the AIRTRACE system from joint venture constraints, the extensive tests described in this and a number of subsequent reports * were carried out.

The AIRTRACE data provides a map of zones of hydrocarbon seepage which were active at the time of overflight. The identification of zones of hydrocarbon seepage is generally not in itself adequate to provide accurate locations for drilling, since often the leakage can take place along faults adjacent to the main oil accumulation, or the leakage may occur over source rocks where there has been no trap to form a commercial accumulation. Thus, geochemical methods are normally supported by other techniques such as seismic surveys or the detailed interpretation of well logs from pre-existing drilling. However the presence of geochemical anomalies is a direct indication of oil whereas other techniques such as seismic surveys, gravity surveys or magnetics are indirect. The juxtaposition of promising geochemical data and good seismic structures is therefore a much more encouraging indication of a good prospect than either approach when used on its own. The only restriction on acquiring AIRTRACE data is that it cannot be obtained during periods of heavy precipitation.

*(TR87-304,TR87-305,TR87-306)

3. SURVEY SYSTEMS

3.1 AIRTRACE

The AIRTRACE method is based on rapid collection of particulate aerosols close to the surface and subsequent in-flight chemical analysis for total adsorbed hydrocarbon content, with the intention to relate the results to underlying geology and generation or accumulation of oil. Successful operation of the AIRTRACE system depends on the existence of vertical fracture networks within sedimentary basins that provide pathways for the upward migration of fluids that include thermogenically produced hydrocarbons.

Many oil fields contain substantial amounts of natural gas which leaks in trace amounts through even relatively impervious strata along with oil and formation fluids. When the gas, carrying trace quantities of long chain hydrocarbons, reaches the sediment water interface a bubble is formed with the trace oil constituents lining the bubble's inner wall. When bubbles that are lined with an oil film burst at the water surface they generate an aerosol in which the water droplets become coated with the oil that was previously inside the bubbles (Figure 3.1). During the drying process in the atmosphere above the surface, water is evaporated from the droplets and the residual solid particles, coated with the oil which was previously in the droplets, rise to considerable heights. The rate of drying is dependent upon relative humidity of the surrounding atmosphere. Under optimum conditions the drying process takes place in less than a second and the ambient evaporative flux and turbulence can carry the fine dry particles to heights of 50-300 metres.

The phenomena which allow airborne detection of terrigenous gas and oil seeps are not well understood, particularly in well drained areas. Empirical results obtained over producing oil fields on land show that a mechanism does exist: most probably related to rise of particles carrying adsorbed hydrocarbons in turbulent or thermal updrafts; or to uptake and rejection of compounds by vegetation.

SIMPLIFIED MODEL FOR AIRBORNE PARTICULATE PLUME GENERATION BY BURSTING BUBBLES

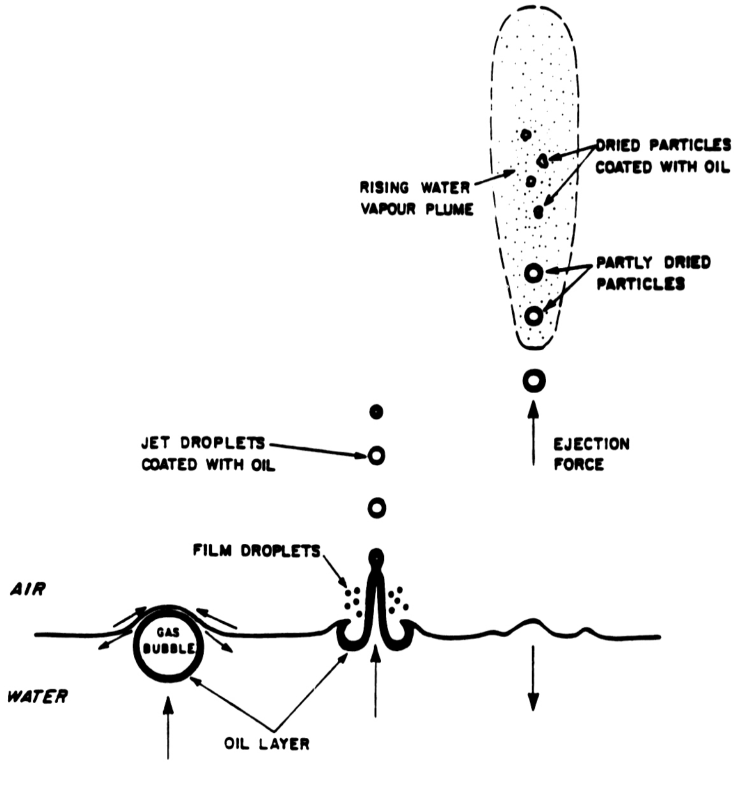


FIG. 3.1

The AIRTRACE aircraft intercepts these rising plumes of oil rich aerosols at the survey height of approximately 50 metres.

The AIRTRACE instrumentation consists of an aerosol collecting and concentrating system that scoops four cubic meters of air per second and passes this through devices that provide an increase in concentration of the aerosols in the air stream by a factor of approximately 1 million. The intake system is mounted on the nose of the aircraft in such a way as to provide minimum aerodynamic drag (Figure 3.3).

A specially developed in-board analytical detector (modified Varian flame ionization detector) is employed to extract, at elevated temperature, the volatile organic fraction from the inorganic components in the particulate stream and to analyze and display the quantities of hydrocarbon released, within fractions of a second. The detector provides two output signals; one responding to the instantaneous changes in hydrocarbon concentrations due to intercepted aerosol plumes formed by discrete seeps, and the other, monitoring slow changes due to gradual build-up of background hydrocarbon levels.

A new AIRTRACE MKIIA unit Figure 3.4 was recently built on the basis of the experience gained during the previous operations. This unit is more rugged and contains a number of additional features including a built-in calibration system for the detector and improved signal processing electronics. The overall sensitivity of the detector to hydrocarbon compounds has been improved almost 10 fold. The system is now able to detect 2.5×10^{-12} grams of hydrocarbon present in solid aerosols in 1 cubic meter of sampled air. Figure 3.5 shows AIRTRACE flow patterns in diagram form. A block diagram of the signal flows is given in Figure 3.6.

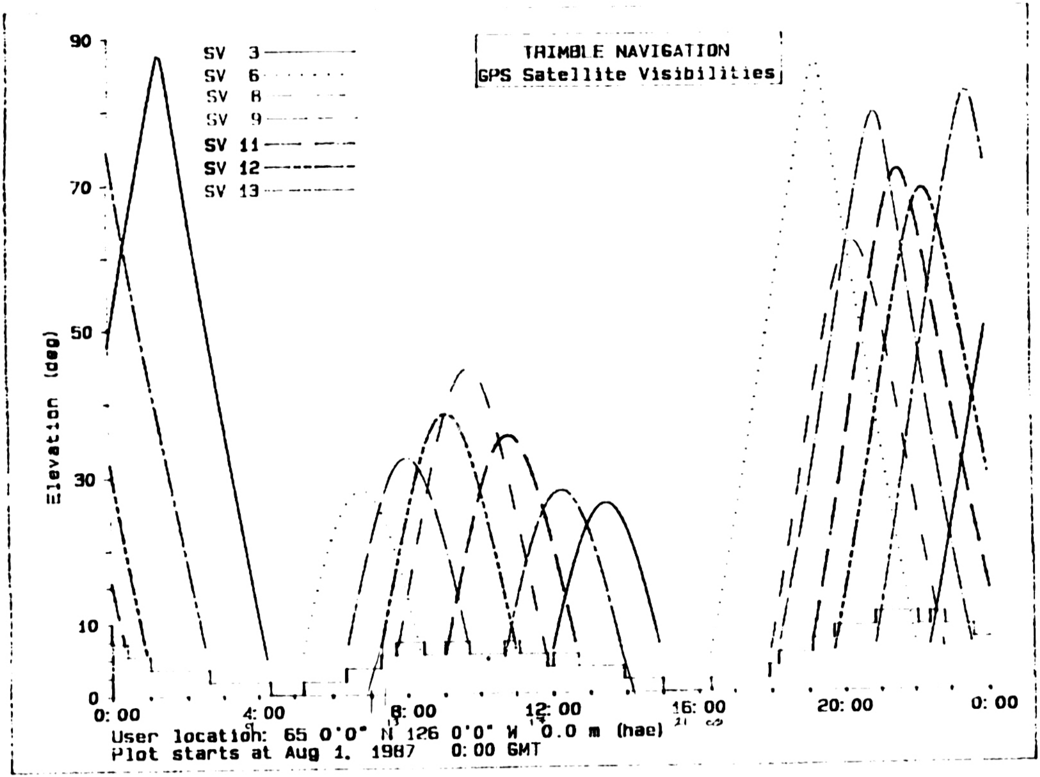

TRIMBLE NAVIGATION
GPS Satellite Visibilities
SV 3
SV 6
SV 8
SV 9
SV 11
SV 12
SV 13
Elevation (deg)
90
70
50
30
10
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
User location: 65 0'0" N 126 0'0" W 0.0 m (hae)
Plot starts at Aug 1. 1987 0:00 GMT

FIG. 3.2

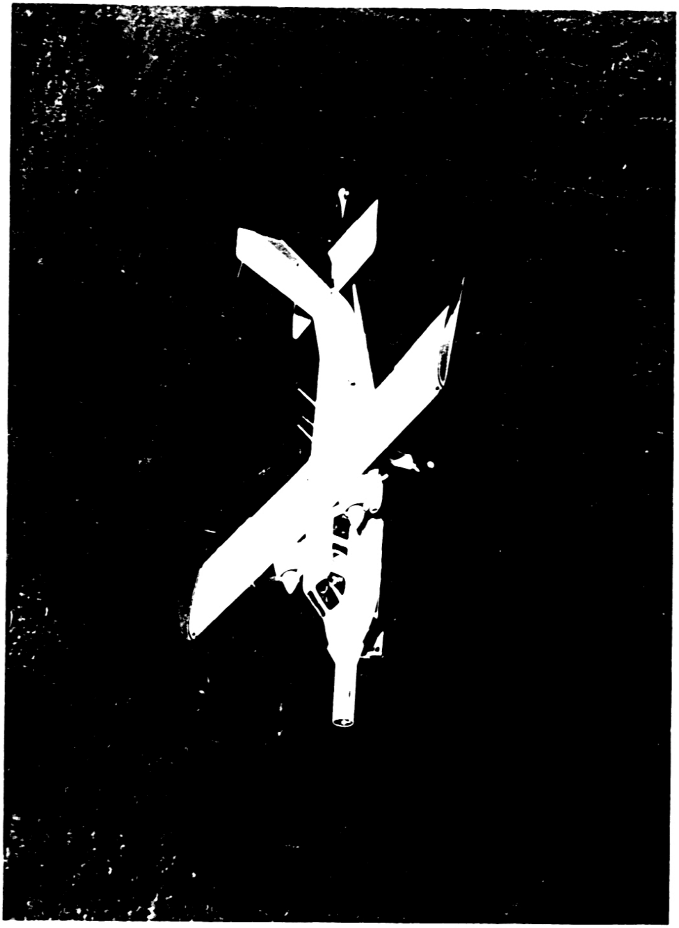


FIG 3 3

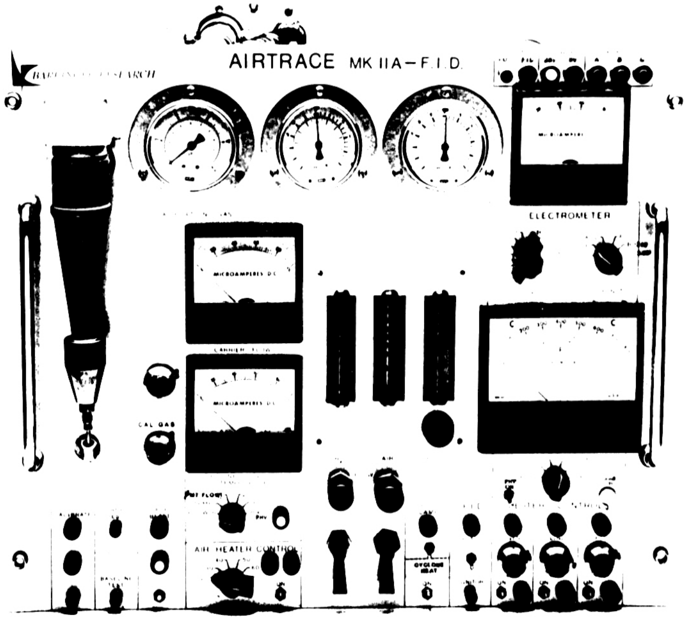

AIRTRACE MK IIA—F.I.D.
ELECTROMETER
MICROAMPERES D.C.
MICROAMPERES D.C.
CAL GAS
AIR HEATER CONTROL
CYCLONE HEAT

FIG. 3.4

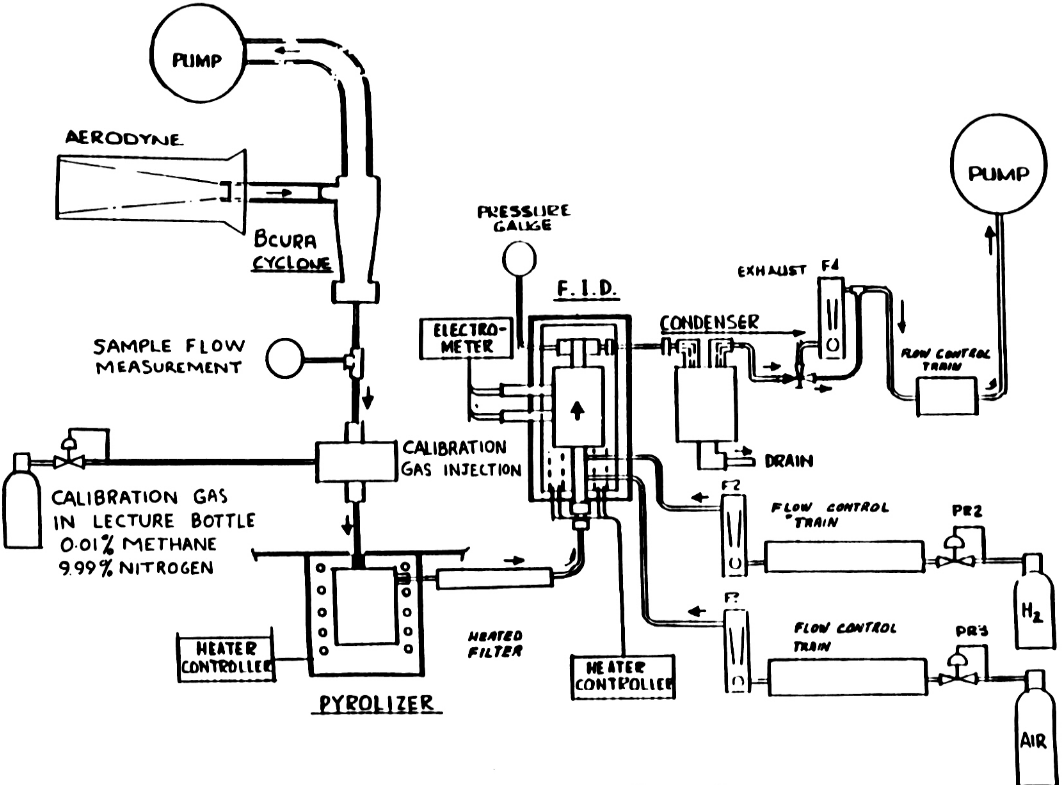
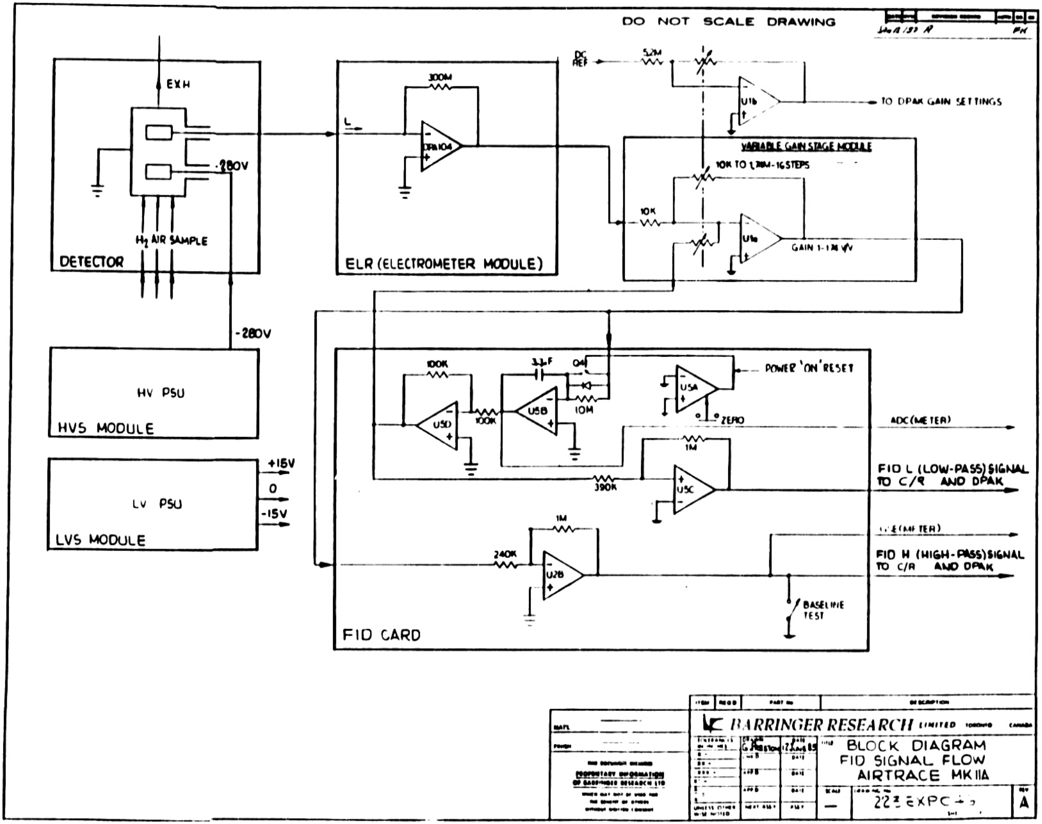


FIG. 3.5

AIRTRACE MK. IIA FLOW DIAGRAM



DO NOT SCALE DRAWING
EXH
-280V
H_2 AIR SAMPLE
DETECTOR
300M
OPA104
ELR (ELECTROMETER MODULE)
DC REF
5.2M
U1b
TO DPAK GAIN SETTINGS
VARIABLE GAIN STAGE MODULE
10K TO 1.78M - 16 STEPS
10K
U1a
GAIN 1-178 V/V
-280V
HV PSU
HVS MODULE
+15V
0
-15V
LV PSU
LVS MODULE
100K
U5D
100K
U5B
10M
U5A
POWER 'ON' RESET
ZERO
ADC (METER)
1M
390K
U5C
FID L (LOW-PASS) SIGNAL TO C/R AND DPAK
1M
240K
U2B
FID H (HIGH-PASS) SIGNAL TO C/R AND DPAK
BASELINE TEST
FID CARD
BARRINGER RESEARCH LIMITED TORONTO CANADA
BLOCK DIAGRAM
FID SIGNAL FLOW
AIRTRACE MK IIA
A

FIG. 3.6

3.2 FLIGHT VIDEO SYSTEM

An on-board video and audio system is employed for recording surface images below the aircraft and crew communication in flight. The purpose of this system is as follows:

1. To enable continuous visual in-flight and post-flight observation of the surface sampled by AIRTRACE.

2. To aid flight path recovery and accurate registering of the aircraft position over navigation reference targets.

3. To provide visual display of flight information and AIRTRACE data in relation to the surface overflown.

4. To allow audio recording of the operator's and pilot's comments on the flight events and overflown targets and accurately annotate anomalous data.

For the above purpose two Panasonic CCD colour video cameras (CD100) were installed in a specially designed gimbal mounted in an external pod attached to the door of the aircraft. One camera was positioned such that it recorded a view looking ahead of the aircraft the other was mounted vertically. Both cameras were fitted with 4.8 mm lenses.

The video output was recorded on 1/2" video cassettes with audio soundtrack recorded on the forward looking camera.

3.3 NAVIGATION

For the purpose of this survey the standard aircraft IFR navigational equipment was supplemented with a GPS system for high accuracy and two LORAN-C systems. The GPS receiver model 10X made by Trimble Navigation of Sunnyvale, California also contained one of the Loran units as an integral part. The primary Loran C was a model AVA1000 made by Arnav Systems, Inc. Salem, Oregon.

The output from the GPS was continuously recorded by the DATAPAK for post time processing and simultaneously displayed on the video monitor. Real time navigation was facilitated by a Course Deviation Indicator (CDI) driven by the GPS system and a "Hi-Lo" indicator with the radar altimeter as input.

Expected positioning accuracy for the GPS is ±25 metres and spot checks using the video system over topographical features confirmed this accuracy. The survey area was outside Loran C coverage although when used on extended range the system would "Lock on" but with very poor positioning accuracy.

The appropriate constellation of GPS satellites during the survey is shown in Fig. 3.2.

3.4 ANCILLARY SENSORS

To aid in interpretation of the survey data a number of ancillary sensors monitoring environmental and flight conditions have been mounted in the aircraft. These include: 1) Vaisala environmental probe HMT-14 for monitoring of ambient air temperature and relative humidity; 2) King radar altimeter Model KRA-10 for precision flight altitude measurement (±5 ft.); 4) true air speed indicator Penny and Giles Model 41566; 5) orthogonal rate gyros for measurement of turbulence at aircraft altitude (in order to define mixing conditions).

3.5 DATA ACQUISITION

The survey data is recorded in flight by two independent data acquisition systems in both analogue and digital form. The analogue recorder (RMS Model GR-33) provides a hardcopy of the AIRTRACE, altimeter, air temperature, relative humidity and system gain data in profile form along with time printed in 20 second intervals. The profiles are displayed in real time allowing the operator continuous monitoring of the system performance and evaluation of the data. The analogue hardcopy is also used extensively during final data processing to verify recorded responses and for detailed data interpretation.

The digital recorder employed (DATAPAK MK-I) is a custom-made system developed by Barringer specifically for the AIRTRACE survey applications. The system is based on the Zilog 8761 microprocessor and contains a Memodyne 765-8EP cassette tape drive for recording of survey data on standard 3M type cassettes. The following data is recorded in 60 second data blocks: time, position coordinates, high and low frequency AIRTRACE response, radar altimeter, rate gyros, directional gyro, air temperature, relative humidity, air speed and event marker.

3.6 FIELD COMPUTER STATION

The airborne operations are supported by a field computer facility for checking the data quality and preliminary processing to allow data evaluation in the field shortly after each flight. The field computer station is equipped with an IBM XT personal computer with peripherals allowing retrieval of survey data from DATAPAK cassette, filtering, plotting and listing of data at a reduced spatial resolution and transfer of data to high density floppy tape for shipping to Barringer's computing facilities in Toronto.

In addition, a separate video cassette recorder and a video monitor is used to replay the video tapes to evaluate image quality and examine locations where high AIRTRACE response was obtained for the presence of surface oil slicks or anthropogenic contamination.

3.7 AIRCRAFT

The AIRTRACE, video and ancillary systems were installed in a Britten-Norman Islander BN2A aircraft Registration No. C-FGAQ (Fig. 3.3). This STOL aircraft was selected because it provided a stable airborne platform with adequate cabin dimensions for the survey equipment racks. It also possesses good characteristics for low altitude operations and the fuel efficiency required for long range surveys. All external equipment was mounted without the necessity for major structural changes to the aircraft. An airscoop was incorporated into the aircraft nose to facilitate aerosol collection with minimum aerodynamic drag. This replaced the standard aircraft nose cone. The video cameras were mounted in a pod on the outside of the cabin door which in this aircraft is a replaceable item. Long-range wing-tip fuel tanks were an additional item that enable survey operations to be carried out at ranges of up to 200 miles. Full avionics instrumentation was provided for all weather IFR flying.

4. SURVEY SUMMARY AND STATISTICS

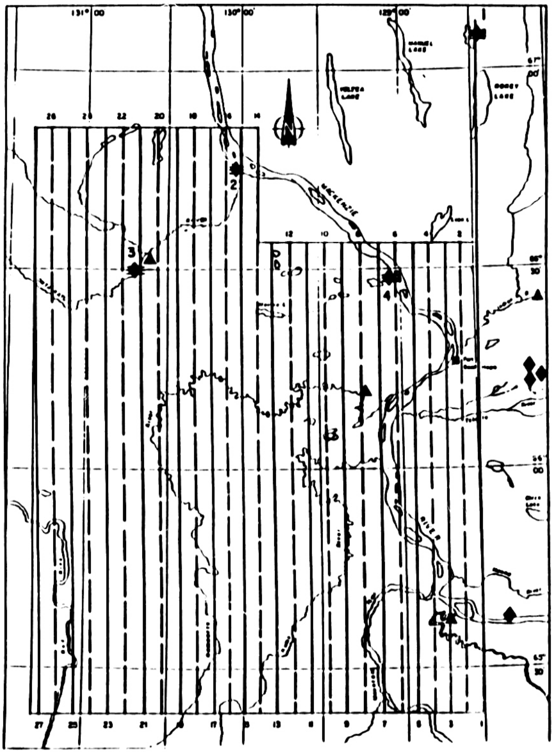
Location of the survey area flown from Norman Wells is shown in Fig. 4.1. A summary of the number of line kms flown and survey statistics are given in Tables 4.1 through 4.4.

The survey operations were conducted by a six man field crew consisting of a Geochemist, Crew Chief, Field Technician, Data Person and two pilots.

Regular flights occurred almost daily with only 4 days interrupted due to poor weather conditions in 13 days on location. Surveys in Norman Wells were completed by August 22. On August 23 the aircraft left for Ft. Nelson to undergo a 100 hour aircraft inspection. A summary of daily progress is presented as Table 4.1, which also lists climatic conditions. Table 4.2 is a description of daily aircraft operations as a breakdown of the flight time allocated to each aspect of the survey. Table 4.3 is an accumulation of statistics over the complete survey.

Navigation in the N.W.T. areas was primarily by GPS. A significant restriction on the survey time was caused by the limited availability of satellites in the still incomplete GPS constellation. A sufficient satellite constellation was available from approximately 11:30 a.m. to 4:00 p.m. (local).

Overall 4506 line kilometres of high quality AIRTRACE survey lines were flown. Propitous weather conditions considerably aided the execution of the survey activities and allowed acquisition of excellent AIRTRACE data. Approximately 61% of flight time was spent in the actual acquisition of survey data.



SURVEY LOCATION AND FLIGHT LINES

PEEL PLATEAU

NORTHWEST TERRITORIES

1 - ROND LAKE
2 - ONTARATUE/MACKENZIE RIVERS
3 - ONTARATUE RIVER
4 - MACKENZIE RIVER

◆ OIL SEEP

▲ GAS SEEP

0 20 40 Kilometres

0 10 20 30 Miles

FIG. 4.1

TABLE 4.1 DAILY SURVEY STATUS

Location	Date	Flight Number	Lines Flown	Line km	CLIMATE DATA Mean Air Temp	R.H. (%)	Weather	Remarks
	8/08/87							Crew & A/C arrive NW
	9/08/87						Heavy Rain	No flying set up base station
Peel Plateau	10/08/87	06			7	85	15 OVC, 70 OVC wind 390/12	Turb Mod. Viz 0/0 at area. Video U/s
	11/08/87	07	01-06 100	751	12	45	10 sct, 3/10 200/10	Line 06 short 6 mi. mtns
	12/08/87	08	07-12,100	829	16	23	/sct, wind 120/08	dwn video. Blckge at start cleared
	13/08/87	09	100-106, 13-15	610	16	41	1/100 sct, 110/08	Turb Mild/Mod
	14/08/87	10	16-19,100 201-205	722	17	43	/sct, 100/08	
	15/08/87	11	20-23,100 301-307 315-316	629	15	40	40 ovc, 150/03	
	16/08/87	12	23-27	577	14	54	clr, 240/10	
	17/08/87	13	601-607 501-514	302	14	59	3/10, 5000' 210/10	Flight called for rain
	18/08/87	14	16,100,422 401-405 411-415	342	15	54	2000 ovc 100/05	Turb Mild, Rain showers in areas
	19/08/87	15	82,100 201-202 211-212 221-222 231,241-242	471	16	48	sct 2/10, /sct,160/2kts	
	20/08/87						low overcast	
	21/08/87						rain	
	22/08/87	16	100,222 241,242,251 252,261-262	372	17	34	/sct, 3/10 160/02	
	23/08/87							GAQ left NW for 100 hr insp.
	24/08/87							Crew & equip left NW and arrived Ft. Simpson

Summary of Abbreviations

aprt	= airport	clm	= calm	flt.	= flight
Lt.	= light	lftg	= lifting	Md	= Mild
Mod	= mild	ovc	= overcast	/ovc	= high overcast
sct	= scattered	/sct	= high scattered	sml	= small
Sv	= severe	T-shwrs	= thundershowers	U/s	= unserviceable
var	= variable	whi	= white	NW	= Norman Wells

TABLE 4.2: SUMMARY OF AIRCRAFT OPERATIONS

Location	Date	Flight #	Line Kms	Survey Hours	Ferry Hours	Turn Hours	Daily Total Hrs.	Running Hours
Peel Plateau	10/08/87	06			0.80		0.80	0.80
	11/08/87	07	751	4.22	1.16	0.45	5.38	6.18
	12/08/87	08	829	4.65	1.37	0.39	6.02	12.20
	13/08/87	09	610	3.50	2.94	0.37	6.43	18.63
	14/08/87	10	722	4.51	1.66	0.75	6.16	24.79
	15/08/87	11	629	3.55	2.35	0.35	5.90	30.69
	16/08/87	12	577	3.30	1.99	0.35	5.28	35.97
	17/08/87	13	302	2.13	2.44	0.50	4.56	40.53
	18/08/87	14	342	2.16	2.66	0.41	4.82	45.35
	19/08/87	15	471	2.70	2.69	0.30	5.38	50.73
	22/08/87	16	372	0.94	2.87	0.33	3.81	54.54
Totals:			5605	31.64	22.92	4.20	54.54	54.54

TABLE 4.3: SURVEY STATISTICS FOR PEEL PLATEAU

	Days	% of Total Days	Flight Hours	% of Total Flt. Hours	Line Km.
Survey Total	14		57.1		5605
Production Days	10	71.4			
Days lost to Eqpt. failure	0				
Days lost to weather	4	28.6			
Production Survey Time (incl. turn time)			31.6	58.0	4506
Ferry Time			22.9	42.0	
Turn Time			4.2	7.7	

TABLE 4.4: SURVEY AVERAGES

Average Survey Flight Time	5.0 Hours
Average Ferry Flight Time	2.1 Hours
Turn Time Per Flight	0.4 Hours
Production[1] Per Productive Flight	480.6 kms/flt.
Production[1] Per Productive Day	480.6 kms/day
Production[1] Per Day in field	369.7 kms/day
Production[1] Per Flight Hour (Ferry Excluded)	151.9 kms/hr
Production[1] Per Flight Hour (Ferry Included)	88.1 kms/hr

1 High Quality AIRTRACE.

Topographical considerations led to incomplete coverage in the region. In particular the Mackenzie mountains in the western edge of the Peel Plateau survey restricted flying due to rapid rise in the terrain and the corresponding inability to maintain a terrain clearance of 50 $\pm$10 metres.

5. DATA PROCESSING

5.1 PRELIMINARY FIELD PROCESSING

The purpose of the preliminary field processing is three-fold:

(A) to retrieve survey data from the DATAPAK cassettes, store it on the IBM-XT unit and write the data to high density floppy tape for subsequent shipping to BRL, Toronto;

(B) to review the survey data, checking for data quality and system failures and to evaluate the results for immediate feedback in subsequent flying;

(C) to plot the survey data in order to allow flexible and strategic response to discovered anomalous areas (i.e. fly more detailed lines over the area).

Preliminary maps, produced in the field base computer station consist of AIRTRACE response, plotted at reduced resolution, in profile form over flight lines recovered from the navigational system. All data were plotted within 24 hours of the survey flight and facsimile copies were transmitted to Amoco at intervals throughout the survey operations.

This regular communication allowed maximum cost effectiveness during operations as additional survey lines at closer spacing could be authorized by Amoco without causing costly delays in survey operations.

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5.2 FINAL DATA PROCESSING

All final data processing was carried out at BRL's in-house computer facilities in Toronto. Processing was preceeded by data transfer from floppy tapes via IBM-XT to the Gould SEL 32/77 computer, data verification and editing and establishment of a data base.

5.2.1 Data Verification and Calibration

Apart from checksum comparison, data verification involves comparison of the analogue chart record with recovered and plotted digital record together with the flight logs (see Appendix 1). Discrepancies are noted and corrected and the operator's written comments regarding high amplitude AIRTRACE responses, abnormal system behaviour, turbulence, potential anthropogenic contamination or the presence of visually sighted oil slicks are also noted and either corrected or accounted for during data interpretation.

It is common procedure for the system operator to vary the pulse width of the calibration injection of methane in relation to the selected system gain. The (electronic) pulse width and observed amplitude of each (digitized) calibration pulse (at the start and end of each survey line) together with the system gain are used to convert digital units to ng $m^{-3}s^{-1}$ of methane equivalent total particulate hydrocarbons. The AIRTRACE data is calibrated at the raw 40 Hertz resolution (approximately one analysis per 1.3 metres of ground track). The end portions of each line, containing the calibration peaks and detector baseline sections are truncated.

5.2.2 Data Reduction

The Peel Plateau AIRTRACE survey resulted in just over 4.5 million total particulate hydrocarbon chemical analyses. It is not feasible to represent such a large number of analyses in graphical form and consequently the raw data must be considerably reduced in resolution prior to interpretation. A four stage procedure was used to reduce data resolution; the affect of this on the appearance of the data is discussed below.

Data resolution was reduced from 40 Hertz (profile A, Figure 5.1) to 10 Hertz using an 11 point (0.27 second) low pass Hanning (cosine squared function) filter in order to minimize aliasing during reduction. A high pass 145 point (14.5 second) Hanning filter was then applied to the 10 Hertz data (profile B, Figure 5.1) which removed wavelengths longer than approximately 30 seconds of flight time (ca: 1500 metres of ground track). This last filter results in data at 5 Hertz lying along the trace of the flight line, but with negative excursions due to the high pass filter (profile C, Figure 5.1) which are then removed by truncation of non-zero values (profile D, Figure 5.1). The data are then reduced to 1 Hertz using a 5 point (1 second) low pass Hanning filter (profile E, Figure 5.1). Lastly, data are normalized by flight line to a common survey mean for presentation purposes.

5.2.3 Effect of Data Reduction on Interpretation

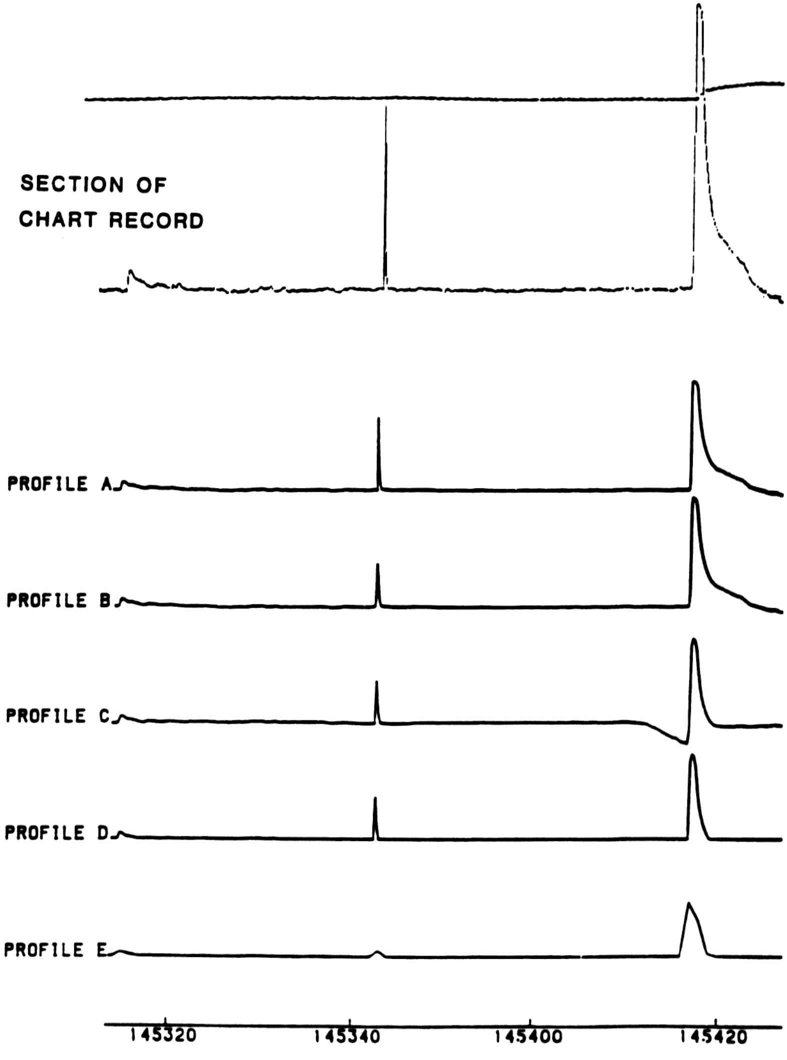
Examination of the raw AIRTRACE data showed that three broad classes of responses are present in the data. Typical examples of these three types of responses are shown in Figure 5.2. The type A response is considered a "normal" response from active hydrocarbon seepage, type B responses are considered to be larger, or more prolific, seeps. Type C responses tend to occur in broad clusters and show little or no line-to-line coincidence.

Type C responses are usually between 25 to 100 milliseconds (representing one to five metres of ground track) wide and show no trailing edge (cf. types A and B). Type C responses were often observed around airports and towns, particularly in areas with a high atmospheric dust load. The empirical interpretation of type C responses (over muskeg anyway) is that they represent single particles carrying adsorbed hydrocarbons rather than the clusters of particles commonly found over hydrocarbon seeps. As a consequence of this interpretation, the data reduction process described above was designed with a bias towards enhancing type A and B responses at the expense of type C responses. The effect of this enhancement is clear on Fig. 5.1 where the original type C response is almost completely removed whereas the type A response is only slightly diminished in amplitude. Figure 5.1 is plotted at much larger scale than the final survey data.

5.2.4 Specialized Data Processing Methods

The detailed AIRTRACE surveys over documented seeps and over the Mackenzie River at Norman Wells were processed slightly differently from the bulk of the data since the flight lines were very short. Consequently the data for these short lines was brought to base level by removing a 2nd degree polynomial fit to the data. The final result of this technique appears very similar to the high pass filtered data except that longer wavelengths are preserved. The regression technique is particularly applicable to the long wavelength responses at Norman Wells and over the Ontaratue-Mackenzie River seep.

The regression technique was not used for all survey lines because long wavelength AIRTRACE responses are most commonly associated with either changes in combustion gas flows or radical changes in altitude. Both of these types of responses were easily differentiated from true hydrocarbon responses since the gas flow rates and altitude are digitized and stored by the on-board microprocessor and recorded on the analogue chart record.



SECTION OF
CHART RECORD
PROFILE A
PROFILE B
PROFILE C
PROFILE D
PROFILE E
145320
145340
145400
145420

FIG. 5.1

TYPES OF AIRTRACE RESPONSES

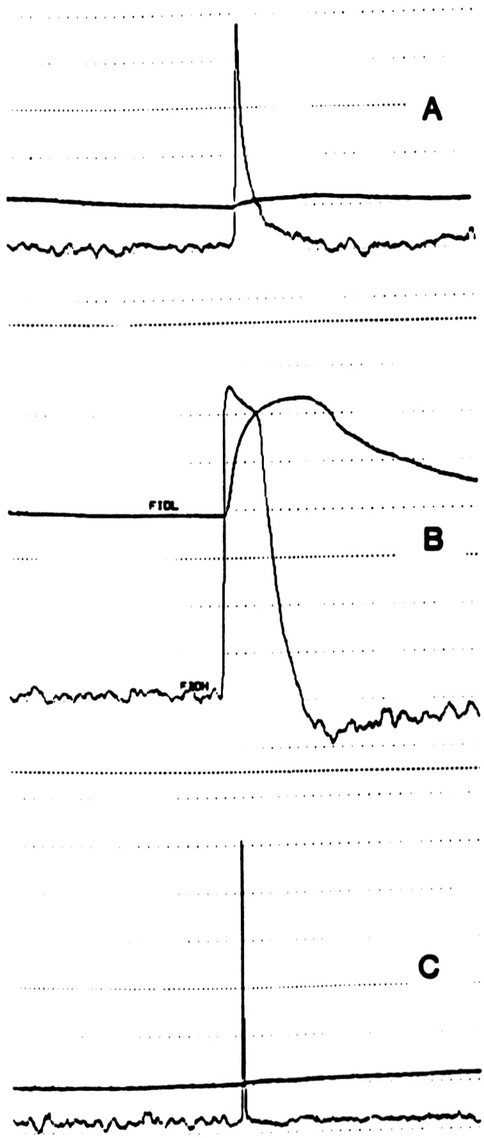


FIG. 5.2

A number of other, specialized data processing methods were used to produce thresholded and colour contoured maps of the AIRTRACE data. These techniques are discussed in more detail in secton 6.4.2 of this report.

5.3 ANCILLARY SENSORS

The Vaisala environmental probe was regularly calibrated during survey operations and the raw data was converted from digital units to degrees Celsius and percent relative humidity based on the manufacturers specifications. The temperature and humidity responses were digitized at one Hertz. Output from the rate gyros (to monitor turbulence) was converted to a deviation about zero by subtracting 128 from the digitized values.

6. SURVEY RESULTS

6.1 AREA DESCRIPTION

6.1.1 Location

$65^{o}15'N$ to $65^{o}50'N$
$128^{o}30'W$ to $131^{o}15'W$

6.1.2 Geography

The survey area can be geographically divided into 5 physiographic regions. Peel Plain is the area north of the Lichen Syncline and west of the Mackenzie River. Peel Plateau is south of the Lichen Syncline. The Mackenzie Plain Synclinorium is a wedge south of the Lichen and north of the Imperial Synclin-e. The Franklin Mountains are north and east of the Mackenzie and south of the Snafu Creek. Peel Plain is perhaps best described as a monotonous expanse of swamp. It is nearly level ground largely covered with glacial drift, bogs, swamps, slow meandering streams and innumerable small lakes. Forested areas when seen at low sun angles commonly revealed a wet surface layer. The many small lakes of the northern section originate from thermokarst action in the ice rich pre-glacial clays. Peel Plateau is a gently rolling upland. It shows a record of Laurentide glaciation with extensive areas of hummocky moraine, outwash deposits of sand and gravel and northwest trending meltwater channels. Most of the major features of the topography and drainage are preglacial in origin. Mackenzie River occupies part of a broad flood plain of pre-Quarternary age that has been extensively buried by Quarternary deposits. The Mackenzie Plain Synclinorium is a broad expanse of nearly flat topography at low elevations. The northern Franklin Mountains are a series of narrow, linear to arcuate bedrock ridges, rather widely separated by broad valleys.

6.1.3 Geology

The Norman Wells area has been a known source of oil for 67 years and was a district of intensive investigation associated with the Canol project in 1944. In addition Operation Norman was conducted by the GSC in 1968-1971. Despite all this activity only fragmentary knowledge has been obtained about the lithology of the survey region. Access to the region by land transport is all but impossible, and only a few of the rivers are navigable. Outcrops are rare in this muskeg covered area and delineation of lithological boundaries has been largely unattempted in published maps.

Peel Plateau and Peel Plain are known to cap a single, regional, deep basin filled with Cretaceous and older sediments. Because both lower and upper Cretaceous series thicken toward the basin it appears to have originated as a depositional marine trough. The rock structure has been accentuated by mild Laramide folding, as seen in the Lichen Syncline. Peel Plateau and Plain are structurally a single deformed unit. The Plateau is an erosional remnant capped and protected by upper Cretaceous sandstones. The southern limit of the Plateau is truncated by en echelon mountain front flexures. The northern Franklins are narrow, linear to arcuate ridges that are separated by broad, flat bottomed synclines. The Mackenzie Synclinorium shows a common style with the Franklin Mountains and is essentially a depressed region of the same structure.

A summary of several geological maps have been placed on Figure 6.1 (Aitken and Cook 1975, 1982). Geological boundaries available on the original maps are repeated on this figure, as are the location of symbols identifying geological units.

6.2 DESCRIPTION AND DISTRIBUTION OF PERMAFROST

It is the intention of this section to summarize previous permafrost studies in order to examine its likely effects on AIRTRACE response to hydrocarbon seepage.

Permafrost is the thermal condition of soil or rock of temperature below 0°C persisting over at least two consecutive winters and the intervening summer. Because it is defined thermally, water is not necessarily present. Permafrost is an extraordinarily complex phenomena with several environmental controls.

6.2.1 Aerial Zonation of Permafrost Distribution

Permafrost is dominantly a phenomena of land masses with mean annual air temperatures below 0°C, it does also occur on the shallower polar sea floors of the Beaufort and Laptev Seas. It is widespread in Canada, China and the USSR. The three principle zones of division are based on percentage of area underlain (Harris, 1986). The continuous zone has 80% or greater covered. Thicknesses vary from over 500 metres in the arctic archipelago to 60-90 metres depth at the southern boundary. Taliks (thawed zones within or above the permafrost) become larger in thickness and extent further south. In the discontinuous zone 30-80% is underlain. The permafrost thins to 12 metres in the southern limit. The sporadic zone has less than 30% permafrost by area with frozen regions reduced to isolated islands of a few acres in size.

6.2.2 Zonation of Permafrost in the Peel Plateau Area

The distribution of permafrost in the Norman Wells region is mostly unmapped. Heginbottom (1977) mapped permafrost in close proximity to the Mackenzie River. He found that "Frozen ground is widespread everywhere in the valley north of 60 degrees and its proportion gradually increases from south to north... The proportion of frozen ground is greater than 50% in all areas and all genetic classes except for lacustrine soils in the area around Fort Simpson...". Norman Wells is at the northern limit of the discontinuous Zone and has permafrost depths from 45 to 65 metres.

6.2.3 Vertical Zonation in Permafrost Soils

Northern soil profiles are simple reflecting their recent deposition since glaciation. After the retreat of the continental ice sheets ca. 12,000 years B.C., there was a complex sequence of glacial lakes depositing lacustrine sediments of clay and silt onto the local bedrock and the occasional morainal deposits. The muskeg closely followed the retreating ice sheet. Muskeg ecology demands the net accumulation of organic soils in the form of peat. One sample cited as typical by Walmsley (1977) was made up of humic acids (41%), bitumen (12.9%), hemicellulose (22.5%), lignin (10.5%), cellulose (5.6%), water soluble material (5%) and others (2%).

The distribution of ground ice can vary substantially with depth. Two of the main types are Pore Ice and Taber Ice. Pore ice that fills or partially fills pore spaces is generated from water freezing in situ, with no addition of external water. Taber ice includes ice films, seams, lenses, pods, or layers ranging from hairline thickness to 10 metre thickness. Taber ice is one of the most extensive forms of ground ice and can represent 75% of ground volume in some places. In general between 0.5 and 3 metre depths Pore and Taber ice fill 61% of ground volume, and between 3 and 9 metres they fill 41% of ground volume.

6.2.4 Controls on Permafrost Distribution

As noted above the permafrost layer is a thermal phenomena, so factors affecting the temperature balance affect its distribution. The permafrost base is where the geothermal gradient intersects the 0°C isotherm. The upper surface is the maximum penetration of solar energy, which is rarely more than 2 metres in depth. Above this the ground is thawed in summer, and frozen in winter.

There are many controls on permafrost thickness. If the bedrock has a higher thermal conductivity the geothermal gradient is decreased, lowering the permafrost base. Permafrost on south facing slopes is thinned or eliminated, depending on the local thicknesses. Along permeable fractured and faulted zones which become favoured routes for fluid migration, the relatively warm ground waters emerging from them may thaw a linear zone to the ground surface.

Bodies of water, lakes, river and the ocean have a profound effect on permafrost distribution. A deep lake that does not freeze to the bottom during the winter will be underlain by a zone of thawed material. As one moves southward the size of the lake necessary to penetrate the permafrost layer fully to the base decreases. This is due to decreasing thickness of the layer at southward latitudes. Only major rivers in the continuous zone are thawed completely below whereas smaller rivers and creeks completely penetrate in the discontinuous zone.

Vegetation acts as an excellent thermal insulator for permafrost from solar energy. In the coniferous forests that cover the Northwest Territories, only an estimated 10% of solar energy penetrates to the ground. Snow pack also acts as an insulator and prevents heat from leaving the ground in the winter, promoting thinner permafrost. The timing and thickness of snow falls are critical controls on permafrost thickness.

6.2.5 Permafrost on the Microscopic Level

Anderson (1985) writes "The freezing of water in porous particulates involves several complex processes. Ice nucleation, the movement of water to enlarging ice crystals and the rejection and segregation of solutes and mineral particles. It has been shown that when water freezes in porous particulate matter the ice crystals remain separated from mineral surfaces by an unfrozen, fluid-like interfacial layer of water. The fluidity of this water layer persists as low as -10^{o}C, apparently diminishing as the temperature is lowered."

Ice dominantly exists in the larger pores. The unfrozen water exists almost entirely in the liquid phase as films on the pore ice and particle surfaces and in the smaller diameter capillaries between pores. The film water is not entirely liquid but instead exists as structured water aligned according to the polarized mineral and ice surfaces for up to 40 molecular film thicknesses (Harris, 1986; Akimov, 1983), Akimov reported low mobility for this film water.

6.2.6 Groundwater Aspects of Permafrost

One worker (North, 1985) reported that "The only rocks truly impermeable to water are evaporites and permafrost." Any fractures that develop in the permafrost are healed by the freezing of water that moves into the void from the thawing active layer. No fracture will likely persist continuously into permafrost with thicknesses in the tens of metres. The extensive coverage of ground surfaces by muskeg marshes, and the thousands of small ponds is in large part due to the impermeability of ground layers to water.

That groundwater mobility is of critical interest to AIRTRACE interpretation can be seen by a review of hydrocarbon secondary migration mechanisms. While no rock is impermeable to fluid motion through them, it is an established fact that gaseous or liquid hydrocarbons, probably in solution in ground water, will favour higher permeability pathways. The higher permeability routes from source rock to reservoir, known as carrier systems (including unconformities, faults, fractured zones, or old weathered horizons) will be the main zones of hydraulic flow lines (North, op.cit.) along the hydraulic pressure gradient.

Taking this concept of carrier systems to permanently frozen ground it is reasonable that thawed zones will be favoured routes for transport of hydrocarbons critical for AIRTRACE detection of hydrocarbon seeps.

While permafrost beds may not be absolutely impermeable to fluid motion, the decrease in porosity caused by pore ice, the structuring of film water and the presence of Taber ice beds will act to reduce this permeability to minimal values in comparison to subsurface thawed (taliks). It should be noted that one of the world's largest supergiant gas fields (North, op.cit.) exists in the West Siberia Basin due to the impermeability of its permafrost cap.

6.2.7 Observed Hydraulic Gradients in Permafrost Areas

Kane and Slaughter (1973) studied an Alaskan lake in the discontinuous zone to determine if it was connected by a thawed zone to a subpermafrost aquifer. The lake was 0.18 square kilometres in area, and had a maximum depth of 4.5 metres. Well logs indicated a permafrost layer present with a depth of 40 to 70 metres with an active layer as shallow as 0.2 metres. Piezometric readings below lake bottom indicated a hydraulic head directing flow upward into the lake. This increase in potential with depth, among other evidence, indicated an unfrozen conduit extending down to a subpermafrost network. This shallow lake, much thinner than the surrounding permafrost did not freeze to the bottom during winter, despite seasonal low temperatures as low as -46^{o}C.

"It is suggested that the thousands of lakes found in central Alaska give evidence of a great lack of continuity of permafrost, even in low lying, poorly drained sites. Existence of such a network of thawed zones also suggests that groundwater systems are extremely complex and that even local groundwater situations may have unsuspected inter-relations." (Kane and Slaughter, op.cit.).

6.2.8 AIRTRACE Interpretation with Respect to Literature

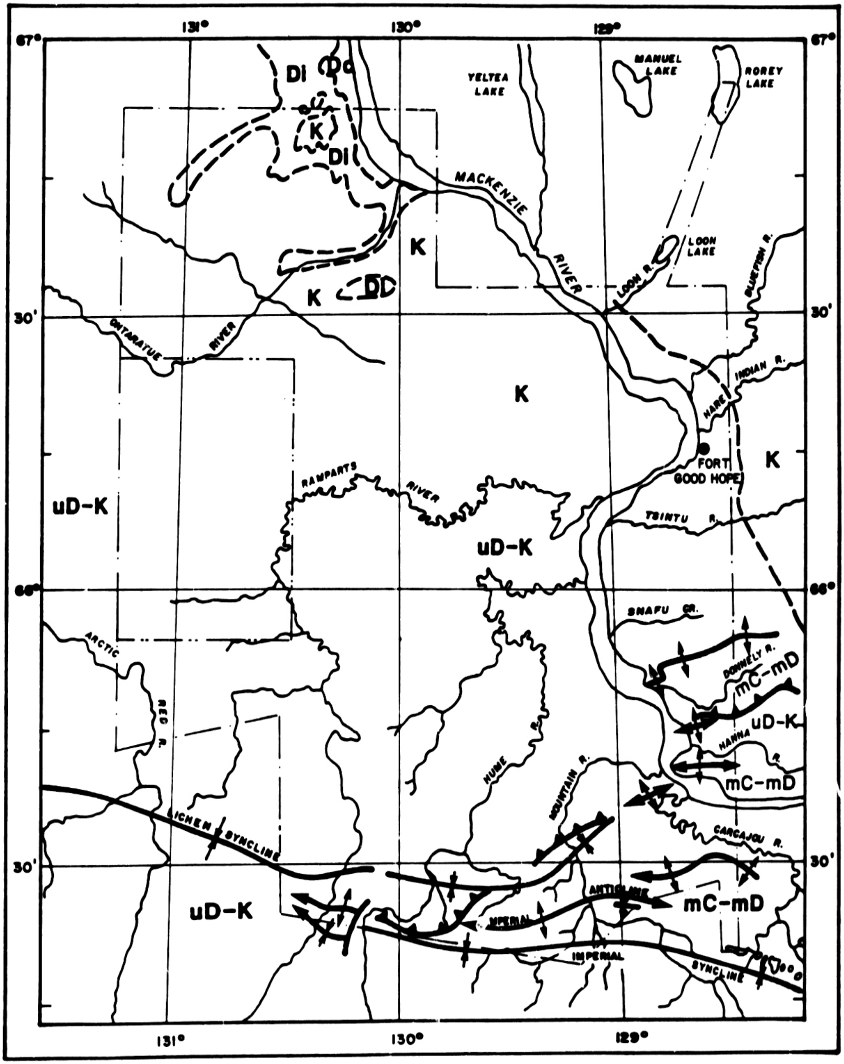
The high ground surface moisture levels being coincident with suspected petroliferous geological conditions was one of the major factors in choice of the survey area. While moist soils are thought to promote aerosol production, the permafrost layer causing it would seem to inhibit gas transport to the surface. The previously discussed literature review would suggest specific avenues for interpretation in the Peel Plateau region. As large lakes appear to act as groundwater conduits to the surface, isolated bodies of water and larger streams would be favourable locations for hydrocarbon migration. Other areas favourable to migration are south facing slopes which can be determined from topographic maps. Finally, although largely undetectable from aerial photographs, permafrost may be reduced in areas of geothermally warmed groundwater seepage from fractured bedrock.

6.3 AIRTRACE RESULTS

AIRTRACE data was obtained over the Peel Plateau areas on flights 7 through 16. Weather conditions encountered during surveying are detailed in Table 6.1. The flight mean air temperatures gradually increased during operations although (excepting the aborted flight 6) the range is only 5°C. The flight mean relative humidity values show much more variation, and there is considerable variation in range of relative humidity by flight. Previous work has shown that humidity range is a useful measure of the effects of weather variations on AIRTRACE response for offshore surveys. The extension of this relationship to overland AIRTRACE surveys requires further work.

The variation of the rate gyro data (a measure of turbulence) was compared with the location of AIRTRACE responses. Although some relationships are apparent in very localized areas there is not a good general correspondence, even for periods of less than 50 to 100 seconds of flight time.

Geology and Drainage of the Peel Plateau Survey Area



THRUST FAULT (teeth on upthrust side)

SYNCLINE } arrows indicate plunge

ANTICLINE }

FORMATIONAL BOUNDARIES

BOUNDARY OF AIRTRACE SURVEY REGION

K LOWER CRETACEOUS

Di UPPER DEVONIAN IMPERIAL FORMATION

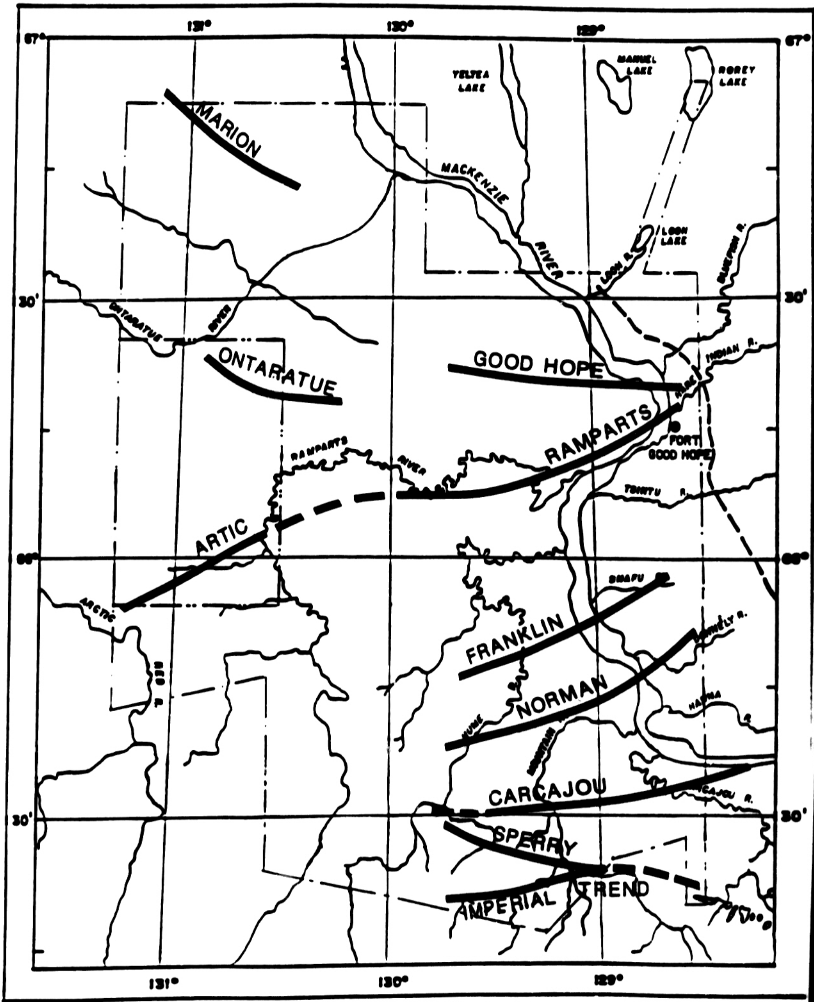
Dc UPPER DEVONIAN CANOL FORMATION

C CAMBRIAN

m,u PREFIXES FOR MIDDLE, UPPER

FIG. 6.1

FIGURE 6.2: PRINCIPAL AIRTRACE TRENDS



—·—·— BOUNDARY OF AIRTRACE SURVEY REGION

TABLE 6.1: SUMMARY OF WEATHER CONDITIONS DURING SURVEY FLIGHTS

DATE	FLT. NO.	CLOUD COVER	MEAN TEMP (° C)	MEAN R.H. (%)	R.H. RANGE (%)	WIND VELOCITY (Deg. & Knots)	LINES FLOWN	TURBULENCE
10/08/87	6	1500' scattered 7000' overcast	FLIGHT SCRUBBED			20° @ 12	Fog in area	Moderate
11/08/87	7	37% scattered	12	45	31	200° @ 10	01-06	Mild/Moderate
12/08/87	8	High scattered	16	23	36	120° @ 8	7-12	Light
13/08/87	9	12% high scattered	16	41	32	110° @ 8	Rond Lake 13-15	Mild/ Moderate
14/08/87	10	60% high scattered	17	40	28	100° @ 8	Seep #2 16-19	Mild
15/08/87	11	100% at 4000'	14.7	40	44	150° @ 3	Seep #3 20-23	Mild
16/08/87	12	Clear	13.7	54	38	240° @ 10	23-27	Mild/Moderate
17/08/87	13	Showers 37% @ 5000'	12.1	68	36	210° @ 6	Rond Lake	Mild
18/08/87	14	100% @ 2000' showers	15.5	49	39	100° @ 5	Seep #4 16	Mild
19/08/87	15	25% @ 4000'	15.4	47	16	160° @ 4	Infill Lines	Mild
22/08/87	16	25% high Scattered	17.3	34.4	14	160° @ 2	Infill Lines	Moderate/ Heavy

TABLE 6.2: SUMMARY OF INVALIDATED AIRTRACE DATA SECTIONS

SURVEY LINE	START TIME OF INVALIDATION	END TIME OF INVALIDATION	REASON FOR DATA INVALIDATION
11	15:50:25	15:51:10	Checksum Error
14	16:15:10	16:16:20	" "
14	16:16:52	16:17:45	" "
16	15:34:32	15:34:34	Data Misrecorded
25	13:33:36	13:35:08	Forest Fire
26	14:31:18	14:32:16	" "
26	14:35:07	14:36:29	" "
26	14:40:56	14:40:59	" "
27	14:52:36	14:59:20	" "
27	15:01:36	15:01:39	" "
27	15:04:00	15:10:12	" "

TABLE 6.3: TOTAL NUMBER OF PEAKS OBSERVED IN EACH SECTOR (ALL CO-ORDINATES GIVE THE NORTHWEST CORNER OF SECTOR)

Longitude \ Latitude	131 30'	131 00'	130 30'	130 00'	129 30'	129 00'	128 30'
67 00'	5	4	5	1	NL	0	0
66 45'	0	4	3	5	5	5	0
66 30'	6	12	3	16	17	24	9
66 15'	9	19	3	12	27	26	6
66 00'	15	9	4	11	38	29	11
65 45'	0	0	4	12	42	17	7
65 30'	NL	NL	2	7	26	1	8

NL = No lines flown in sector

Wind velocity varied considerably between flights, although it did not exceed 10 knots.

6.4 NORMALIZED FILTERED AIRTRACE

Following data reduction and processing (cf. section 5) the AIRTRACE data was normalized by factoring the mean of each survey line to a common survey mean. The factors used are given in Appendix 2. Normalization is used to substantially remove the differential effects of weather conditions on the amplitude of background AIRTRACE responses. The processed data are presented in Plates 1-8 in back pockets. The survey data acquired over known seeps are described first followed by those acquired over the main, reconnaissance area. All data are plotted at the same vertical scale (50 ng $m^{-3}cm^{-1}$).

6.4.1.1 Norman Wells Area

At the end of each survey flight a short line was flown close to oil production facilities, near Norman Wells, in the Mackenzie River. For a few flights the test line was not flown due to lack of sufficient GPS satellites or equipment malfunction. Data acquired along six of these short test lines are presented as Plate 1 (back pocket). Higher amplitude data are posted under the flight lines on Plate 1.

Two broad areas of high amplitude AIRTRACE responses are evident: over Goose Island; and south of Rader Island. The former group are most probably related to hydrocarbon production facilities. The latter group, near Rader Island, may be responses to geological seepage, although there is considerable atmospheric contamination in the general area of the production and refinery facilities.

In addition to the lines shown on Plate 1 a number of others were flown, but unfortunately lack of sufficient GPS satellites above the horizon prevented accurate navigation. Every line flown along the trend in Plate 1 showed anomalous responses, attesting to the AIRTRACE system performance during the surveys described below.

6.4.1.2 Rond Lake Seep

The Rond Lake seep is documented by Patterson and Kirker (1958) who gave the approximate location 128° 27' W, 67° 5' N. The seep is situated (Patterson and Kirker, op. cit.) "on the side of a west facing hill about one mile from the east shore of the lake. The seep covers an area of about one acre and occurs as four separate seeps. The oil comes to the surface in small springs and runs down the hillside forming a residuum of organic matter, clay and residual oil". Patterson and Kirker (op. cit.) do not mention the presence of associated gas seepage, although this is not surprising in view of its low API gravity (17.7°). Cretaceous sandstone approximately 0.8 kilometres to the south is also reported to be oil stained.

Amoco personnel visited the seep site following conclusion of AIRTRACE survey activities (Grass, D., pers. comm., 1987) which allowed identification of the seep on the flight path video. The seep is currently located at 67° 5.64' N, 128° 25.93' E, over a mile from the location given by Patterson and Kirker (op. cit.). Only one pool of oil is visible on the video for line 102 and the aircraft passed slightly to the north of it.

AIRTRACE data acquired over the general area of the seep are shown as Plate 2 (back pocket). Selected data are posted under the flight lines on Plate 2. Two sets of survey lines were acquired, lines 101 through 106 on August 13 and lines 601 through 607 on August 17. Neither data sets show anomalous responses over the seep location. Although a slight increase in background levels is apparent on line 103, this is not repeated on either line 101 or 602. Low level but nevertheless anomalous responses occur some distance to the north and also to the east of the seep location.

The lack of AIRTRACE response to the seep is difficult to reconcile with responses seen over the Norman Wells field (see 6.4.1.1) and over three other documented seeps (see discussion below).

The most likely reason for the lack of response over the Rond Lake seep is the very low API gravity of the oil and the consequent absence of any related gas seepage which would allow generation of airborne particulates. The area is also better drained than most of the areas overflown which may also have influenced the production of airborne particulates carrying adsorbed hydrocarbons.

6.4.1.3 Ontaratue-Mackenzie River Seep

The Ontaratue-Mackenzie River seep is reported by DIAND report no. 246-1-6-3 and Geological Survey of Canada paper 74-11 as located near 130° 2' W, 66° 46' N and is described as an oil seep. The AIRTRACE survey results (Plate 3, back pocket) show only very minor responses at the exact location given above, but a large, broad anomaly is present almost 1.5 kilometres to the west. The anomaly is coincident on three survey lines. The data was processed using a second order polynomial regression technique (cf. section 5.2.4) instead of a high pass Hanning filter in order not to segment the long wavelength AIRTRACE responses. The displacement of the anomaly to the west of the location given above may be explained by the inaccurate original coordinates and the prevailing east wind during the survey flight. Selected data are posted under the flight line, for higher amplitude responses.

6.4.1.4 Ontaratue River Seep

The Ontaratue River oil seep is reported by Geological Survey of Canada paper 74-11 as located at 130° 45' W, 66° 30' N on a meander of the Ontaratue River. A gas seep is also reported to be located approximately 2 miles to the northeast on a tributary of the Ontaratue River.

The survey results (Plate 4, back pocket) clearly identify both seeps, suggesting that oil is also present in trace quantities in the gas seep. A very light (3 knot) southeasterly wind was observed during survey activities. Selected (higher amplitude) data are posted under the flight line.

The moderate amplitude AIRTRACE responses are present at the junction of lines 306 and 316 and suggest further seepage is present in the area. The juxtaposition of these two responses, which are separated in time by several minutes, is particularly compelling.

6.4.1.5 Mackenzie River Seep

The Mackenzie River seep is reputed to be primarily an oil seep, although no published reference in the literature could be located. The location of the seep is not known exactly to the prospector, but is assumed to be at approximately 129° 2' W, 66° 28' N and located on, or near, the west bank of the Mackenzie River.

The normalized AIRTRACE data (Plates 5, back pocket) reveal two more or less parallel lines of responses trending NE. The easternmost linear is particularly striking as it is clearly coincident across four survey lines. A lone high amplitude response was obtained at the centre of the western edge of the detailed survey area. The data was acquired under a light (5 knot) easterly wind. The amplitude of higher responses is posted, under the flight lines, on Plate 5.

6.4.2 Reconnaissance AIRTRACE Data

Filtered AIRTRACE data for the reconnaissance area is presented as plate 6 (back pocket). Visually, the area appears separated into two halves, separated by line 12. Cenerally, the data to the east of line 12 shows frequent high amplitude responses. In the area to the west of line 12 anomalous values are of similar amplitude to those in the east, but are much less frequent. Even in the western portion of the area responses are clustered in specific areas. Selected (higher amplitude) data are posted below the flight lines in Plate 6.

Although the geology is known only poorly (cf. section 6.4.1) there is a consistent relationship between areas showing many AIRTRACE responses and formation age. Middle-Cambrian to Middle Devonian rocks are generally associated with a high frequency of AIRTRACE responses, as is the Upper Devonian Imperial Formation. The association of AIRTRACE responses with the Imperial Formation is particularly interesting in the extreme northwestern portion of the survey area where all the high amplitude responses occur southwest of the outcrop of this formation. The observed general association between areas of intense hydrocarbon seepage and the, albeit poorly known, outcrops of Middle Cambrian to Upper Devonian lithologies is in good agreement with the distribution of hydrocarbon source rocks with age, as inferred by Patterson and Kirker (1958). The outcrop of known source rocks are also associated with pilot reported visible slicks. In the eastern portion of the area such slicks are often associated with high amplitude AIRTRACE responses.

Detailed, fill-in survey lines were flown in the western part of the area in order to provide more detailed information on clusters of medium to low amplitude responses in this area (see Plate 6, back pocket). This area is probably more prospective in terms of exploration since there is probably Cretaceous cover which may have allowed trapping of migrating hydrocarbons.

The available geology is not sufficient to assess whether the clusters of AIRTRACE responses represent inliers of older source rocks or fracturing above or near trapped hydrocarbons.

The AIRTRACE profile plot (Plate 6) provides the best way of subjectively examining duration and amplitude of individual responses as well as of assessing the adequacy of navigation (i.e. line straightness, etc.). However, it is difficult to assess trends in the data as the eye tends to be directed to trends at right angles to the survey line axis. In order to obviate this problem a threshold AIRTRACE plot (Plate 7, back pocket) has been prepared on which data values have also been posted.

The threshold plot was prepared by plotting AIRTRACE responses above a defined threshold as solid triangles. The distribution of triangles was observed as the threshold was increased and at some threshold value the clustering of anomalous values reaches a maximum. Beyond this optimum threshold level the clustering of anomalous values decreases. Although this procedure is currently subjective and places emphasis solely on response amplitude, it does allow assessment of trends within the data. The optimum threshold for the Peel Plateau reconnaissance data was selected at 83 ng m^{-3} s^{-1} (Plate 7, back pocket).

Examination of the threshold plot and comparison with profile plotted and coloured contoured data (Plate 8) allows delineation of ten trends apparent in the AIRTRACE data. The trends were named after topographical features and are presented on Figure 6.2. Seven trends are evident in the eastern portion and three in the western half of the area.

The Imperial Trend crosses six flight lines (ca. 30 kilometres). It incorporates four high and six lower amplitude AIRTRACE responses. The trend follows the crest of the Imperial Anticline and at its eastern end coincides with a large offset in position of the Mountain River.

The Sperry Trend cross cuts the Imperial Trend and closely follows the crest of the Imperial Anticline at its eastern end. It is represented by eleven medium to high amplitude AIRTRACE responses. These responses are of long duration and, except for four, do not appear on the threshold map due to their slightly lower amplitude.

The Carcajou Trend is not strongly defined, except at the southern ends of lines five and six, but is nonetheless traceable across nine survey lines. A gas and an oil seep are aligned with and east of the trend on the southern and northern banks of the Mackenzie River respectively. The Carcajou Trend corresponds fairly closely with an unnamed thrust fault and, at its eastern end, with an anticlinal structure.

North of the Carcajou is the Norman Trend which is well defined across eight or nine flight lines (forty to forty-five kilometres) and consists of seven AIRTRACE responses above the 83 ng m^{-3} s^{-1} threshold. The eastern end of the trend corresponds to an anticline just north of the Donnely River, although the structure was apparently not mapped west of the Mackenzie River. A visible slick was reported by the pilot just north of the Donnely River. The trend thickens near the Sans Sault Rapids - Bat Hills area with two high amplitude responses at each of these locations.

The Franklin Trend parallels the Norman and Carcajou Trends and persists over a similar strike length. There is no reported geological structure along the trend. A cluster of high amplitude responses occurs north of the trend at Snafu Creek along survey lines 3, 4 and 6. The pilots reported two visible slicks in the vicinity of this cluster, on lines 3 and 5. It is of note that this cluster is in two parts, each of which appears to be associated with areas of high frequency of lakes (cf. section 6.5).

The Ramparts Trend is clearly evident on both Plate 6 and 7 and consists of eight high amplitude responses together with many of lower amplitude and with one reported gas seep (DIAND report number 246-1-6-3). An AIRTRACE response just to the northeast of Fort Good Hope of very long duration is part of the Ramparts Trend and is associated with a pilot reported slick. The Ramparts trend is associated with a major deflection of the Mackenzie River caused by the Ramparts and is also aligned with the confluences of both the Hare Indian River and the Ramparts River with the Mackenzie River. These topographic features suggest a major structural trend is present. There is some evidence on lines 14, 16, 17 and 19 that the Ramparts Trend continues west under presumed Cretaceous cover and becomes the Arctic Trend (discussed below).

Just north of the Ramparts Trend and oblique to it is the Good Hope Trend (GHT). The GHT consists of only five high amplitude responses which span seven survey lines, although numerous lower responses extend it five lines (25 kilometres) to the west. There is no reported geological structure coincident with the AIRTRACE trend and, apart from the previously mentioned slick north of Fort Good Hope, no pilot reported oil slicks. The GHT does line up with the Ontaratue Trend, to the west, although there is no evidence for such a continuation on the intervening survey lines which are presumed to be over Cretaceous cover.

It is of note that the extension line 101 showed no AIRTRACE responses although Patterson and Kirker (op.cit.) inferred a fault through Rond Lake and Rorey Lake. If such a fault exists there is no evidence of hydrocarbon seepage associated with it, although if the seepage were of the heavy oil found at Rond Lake (cf. section 6.4.1.2) the AIRTRACE sensor may not detect it.

In the western part of the area there are fewer responses and responses that do occur are of lower amplitude than those in the east. Three trends are, however, present within the AIRTRACE data.

The furthest north is the Marion Trend which includes five high amplitude and six lower amplitude AIRTRACE responses. The trend may be associated with the outcrop of the Upper Devonian Imperial Formation although the trend is displaced to the south and is over an area of presumed Cretaceous cover.

The Ontaratue Trend occurs further south and runs parallel with the Marion Trend. The Ontaratue Trend consists of only four high amplitude responses although all four are of wider than normal duration (i.e. Type C responses). The Ontaratue Trend may represent a western extension of the GHT discussed above although there is no evidence of this over the intervening Cretaceous cover.

Finally, the Arctic Trend consists of four rather widely spaced high responses and numerous lower responses. The trend cuts the southern part of the fill-in survey lines (spaced at 1.7 kilometres) and is well represented across the detailed grid. It is possible that the trend is related to a structural element which plunges beneath the Cretaceous cover, as the Ramparts and Arctic Trends are arguably connected by AIRTRACE responses on lines 13, 16, 17 and 19.

Midway between the Arctic and Ontaratue trends and roughly in the center of the fill-in detailed survey lines is a rather loosely clustered group of three high and fifteen lower amplitude AIRTRACE responses. The cluster forms an east-west elongated ellipse with a pilot reported slick at the west end and is devoid of responses in the center. It is unclear from available geological mapping whether the cluster is in an area of Cretaceous cover or Upper Devonian lithology. The cluster, especially since it does not appear to follow the dominant structural trend, may represent the highest priority exploration lead generated by the survey. Although the Marion Trend does follow the structural fabric it also is of some interest since the responses occur southwest of the mapped Devonian, over Cretaceous cover.

TABLE 6.4: PERCENTAGE OF PEAKS IN EACH SECTOR DETECTED NEAR* SURFACE WATER BODIES

Longitude	Latitude 131 30'	131 00'	130 30'	130 00'	129 30'	129 00'	128 30'
67 00'	0	0	100	0	NL	m	m
66 45'	m	25	33	0	60	80	m
66 30'	66	58	66	38	24	42	44
66 15'	11	11	100	92	74	38	16
66 00'	66	11	0	18	63	48	18
65 45'	m	m	0	82	26	71	29
65 30'	NL	NL	0	14	12	0	0

m = Percentage in regions of zero peaks undefined.

* 'near' means within 500 metres.

6.5 COMPARISON OF AIRTRACE RESPONSE AND LAKE DISTRIBUTIONS

Research was performed to determine the control of permafrost on the AIRTRACE hydrocarbon response signal. As indicated above (section 6.2) there are a multitude of controlling factors on permafrost distribution. Considering the general homogeneity of the topography, and the practically continuous coverage of vegetation, the largest apparent control would be the observed inhomogeneous distribution of surface water. If the majority of AIRTRACE responses were seen over surface water bodies then permafrost could then be inferred to act as a strong control. A survey response map was superimposed on an acetate NTS topographic map of the region. The map was divided into 49 sectors of 15 minutes latitude by 30 minutes longitude. A count of responses above background noise was performed by inspection. In addition a count of which anomalies were found within 500 metres of a water body of sufficient size to create a talik deep enough to penetrate to the permafrost base was also done. These water bodies included the Mackenzie and Carcajou rivers and larger creeks and ponds. A range of 300 metres of the 500 metre range was chosen as the maximum distance over which aerosol plumes could be deviated from their site of emission before being intercepted at the aircraft's altitude. The remaining 200 metres was allowed for differences in map scale, small mis-alignments, errors in recorded position of anomalies inherent in the GPS navigation, and the possibility that thawed zones occur for a small extent beyond shore boundaries. Thus the counting method will slightly favour permafrost control of AIRTRACE data. Table 6.3 displays the total number of responses observed in each of the sectors and table 6.4 shows the percentage of these which occur close to water bodies, as defined above.

If the distribution of surface water correlated well with the distribution of AIRTRACE responses then Table 6.4 would display percentages close to one hundred. The observed values do not support this interpretation. High numbers of peaks shown in Table 6.3 are sometimes correspondent with the amount of line-km flown in each sector, but the percentage of Table 6.4 is independent of this parameter. Table 6.3 is a useful summary of sample size for each sector.

Regions with high numbers of anomalies are not necessarily correlated with high percentage of responses over water. There are cases where high percentage sectors occur with high peak counts, but the opposite also occurs, even taking into account zones with fill-in lines.

In the total of 469 responses observed, 182 were associated with water (38.8%) which shows that the AIRTRACE system when flown overland detects anomalous hydrocarbon concentrations independent of the surface water distribution. There are two possibilities for interpretation of this fact. The first is that there may exist unknown sub-surface controls on permafrost distribution creating taliks for gas percolation routes. The second is that gas is able to penetrate the permafrost layer by some unknown mechanism.

The second possibility contradicts the literature review discussed earlier. This is not so extreme. Permafrost occurs in remote areas that are difficult to access, awkward in terms of mobility, and are a challenge for removal of intact soil samples, especially one not thermally disturbed. Most on location studies have been more qualitative than quantitative. Permeability studies have either been with two dimensional mathematical models, or on processed soil samples in highly controlled laboratory environments. The phenomena of gas transport in permafrost is basically unstudied and unknown mechanisms must surely be occurring, because AIRTRACE anomalies were observed.

It is of note, with respect to the above discussion, that Patterson and Kirker (1958) report that when they excavated with a power auger to a depth of fifteen feet, permafrost was encountered and the one foot diameter hole filled with oil and water overnight. The authors do not, however, comment on whether the oil and water flowed principally from the sides or bottom of the auger hole. Their work certainly confirms the ability of heavy oil to permeate the active layer even though leaving uncertainties about the permeability of permafrost with respect to oil and gas migration.

6. CONCLUSIONS

An AIRTRACE survey was carried out over approximately 20,000 square kilometres of muskeg terrain northwest of Norman Wells, Northwest Territories. Detailed surveys were carried out over four areas known to be associated with hydrocarbon seepage and one area of production facilities. In addition, a stategic approach was used to map the distribution of hydrocarbon seeps over a larger reconnaissance area. This approach involved: rapid, field processing of data acquired along survey lines at five kilometre spacing; telecopy of the plotted data to Amoco's Calgary office at intervals during surveying; a decision by Amoco's personnel on areas to be covered by more detailed fill-in survey lines. This strategic method allowed optimum surveying of a large area with minimum delays, and hence in a cost-effective manner.

The AIRTRACE survey resulted in a total of over 4.5 million geochemical analyses spread along 4500 survey line kilometres. The survey equipment and aircraft performed superbly during survey activities with no days lost to production for these reasons. A total of four days were lost due to poor weather conditions (rain and fog).

At the end of each AIRTRACE survey flight a line was flown over petroleum production facilities in the Mackenzie River, off Norman Wells. Large responses were obtained over these facilities on every flight, indicating that the AIRTRACE system was working and able to detect hydrocarbons adsorbed on airborne particulates on each operational flight.

Closely (one kilometre) spaced survey lines were flown over four documented seeps within the larger reconnaissance area, although in each case the seep location was only known to the nearest nautical mile. Anomalous responses are evident on three of the four detailed surveys located, for the most part, near to the assumed hydrodarbon seep location. Anomalous AIRTRACE responses were not observed over the Rond Lake Seep. A likely reason for the lack of geochemical response at Rond Lake is the low API gravity of the exuding organic material.

In addition to the detailed surveys over known seeps a larger reconnaissance grid was also surveyed. Lines were spaced at five kilometres, except for fill-in lines over the western portion of the area where they were spaced at 1.7 kilometres.

The frequency of high amplitude AIRTRACE responses is markedly related to outcrop (but not exposed) lithologies with the most intense activity associated with Middle Cambrian to Upper Devonian strata and quiescent areas over Cretaceous cover. A number of linear trends are apparent, particularly over areas of Middle Cambrian to Upper Devonian outcrop. A maximum of ten trends were observed, the more outstanding of which show coincident responses over a strike length of thirty to fifty kilometres. One of the observed trends shows some evidence of persisting beneath Cretaceous cover. A number of the observed trends, in the eastern part of the reconnaissance area, coincide with fold hinge zones. This coincidence may persist across the area but the dearth of published structural mapping prevents comparison.

In addition to the trends noted above, numerous AIRTRACE responses occur in a cluster in the western part of the area. The responses are of mid to low amplitude but do, nevertheless, show good line to line coincidence. It is possible the group of anomalies occurs over an area of Cretaceous or Upper Devonian cover and therefore may overlie commercial accumulation of hydrocarbons. A second, linear anomaly in the extreme northwest of the area is also of some interest since it occurs over Cretaceous cover just south of an outcrop of the Devonian Imperial Formation.

The poor quality of the published geology for this area prevents further assessment of AIRTRACE anomalies by the prospector, however, the western anomaly is considered the higher priority geochemical target because of its location over probable cover rocks. Most of the major geochemical anomalies in the area occur over uncapped source rock. It is recommended that the structure in the western part of the area be further evaluated by geophysical techniques such as seismic or magnetics.

7. REFERENCES

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BARRINGER

APPENDIX 1

(Survey Flight Reports)

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau FLIGHT No.: 6 DATE: 8/10/87

JOB No.: 34841 TAKE OFF TIME: 1207 LAND TIME: 1255

PILOT: Randy NAVIGATOR: Jeff OPERATOR: Bob

MAIN BASE: Norman Wells FERRY TIME: 0.8

TRANSIT BASE: — SURVEY TIME: ___

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 7°C DEW POINT: ___ R.H. %: 85%

CLOUD COVER: 1500' o'cast 7000' o'cast WIND: 290° @ 12 kts

TURBULANCE: Moderate SEA STATE: —

NOTES: ___

POSITION FIX: Using GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT	LAT.	
	LON	LON.	
2.	LAT.	LAT.	
	LON	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT.	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: Down Video u/s

SUMMARY OF PERFORMANCE: Fog in Survey Area.

FLIGHT No. 6

PAGE ____ OF ____
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS

9223-A4-3E

FLIGHT REPORT

PAGE ____ OF ____
REV. OCT 1985

AREA: Peel Plateau **FLIGHT No.:** 7 **DATE:** 11/08/87

JOB No.: 348-11 **TAKE OFF TIME:** 11 52 **LAND TIME:** 1715

PILOT: Randy **NAVIGATOR:** Jeff **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 1.2

TRANSIT BASE: — **SURVEY TIME:** 4.2

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 14° C DEW POINT: ____ R.H. %: 64 %

CLOUD COVER: 3/8 @ 10,000' scattered WIND: 200° @ 10 kts

TURBULANCE: mild / moderate SEA STATE: —

NOTES: ____

POSITION FIX: using GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN		COMMENTS	
AIRTRACE				44			
SEASCAN				X			
MAG							
RAD							

EQUIPMENT / AIRCRAFT STATUS: ____

SUMMARY OF PERFORMANCE: ____

FLIGHT No. ______ PAGE ______ OF ______
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
001	N	1230	1231	19	44	SCRUB - GPS
101	N	1238	1321			
002	S	1326	1400			
003	N	1404	1442	016		BREAK AT 1404 FOR HILL
004	S	1446	1522			
005	N	1524	1601	018		ADJ H_2
006	S	1605	1644			

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 8 **DATE:** 12/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 1155 **LAND TIME:** 1756

PILOT: Randy **NAVIGATOR:** Jeff **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 1.5

TRANSIT BASE: ___ **SURVEY TIME:** 4.5

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 10°C DEW POINT: ___ R.H. %: 50%

CLOUD COVER: OCC. HIGH SCATTERED WIND: 120° @ 8kts.

TURBULANCE: LIGHT SEA STATE: ___

NOTES: ___

POSITION FIX: USING GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE				44	
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: A/C VERT VIDEO CLEARED FID AT START

SUMMARY OF PERFORMANCE: ___

FLIGHT No. 8

PAGE ____ OF ____
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
007	N	1242	1322	17	44	CLEARED FID
008	S	1333	1416		121	WIND LIGHT
009	N	1419	1500	05		
010	S	1504	1546			
011	N	1548	1630	26		
012	S	1634	1715			
100	E	1748	1754			RIVER - PUMPERS WIND 180° @ 2K[illegible] TEMP 19°C

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 9 **DATE:** 13/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 1146 **LAND TIME:** 1812

PILOT: Randy **NAVIGATOR:** Jeff **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 2.0

TRANSIT BASE: ___ **SURVEY TIME:** 4.4

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 10°C **DEW POINT:** ___ **R.H. %:** 70%

CLOUD COVER: 1/8 High Scattered **WIND:** 110° @ 8 kts

TURBULANCE: Mild / Moderate **SEA STATE:** —

NOTES: ___

POSITION FIX: using GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN		COMMENTS	
AIRTRACE							
SEASCAN				X			
MAG							
RAD							

EQUIPMENT / AIRCRAFT STATUS: Recal Rhum New Celesco

SUMMARY OF PERFORMANCE: Rond Lake Seep Area & Peel Plateau Lines

FLIGHT No. 9

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
101	N	1250	1310	06	22	D'PAK ALARM AFTER EOL
102	E	1318	1322	33	44	
103	W	1325	1330			
104	E	1332	1336			
105	W	1338	1341			
106	E	1343	1346			ACT FLOWS
013	S	1421	1502			READT FLOWS
014	N	1518	1521	08	121	SCRUB - BURN AREA - SMOKE
014	N	1532	1619		44	
015	S	1623	1715	09	88	
100	E	1806	1808			RIVER

9238-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau FLIGHT No.: 10 DATE: 14/8/87

JOB No.: 348-11 TAKE OFF TIME: 1135 LAND TIME: 1745

PILOT: Randy NAVIGATOR: Jeff OPERATOR: Bob

MAIN BASE: Norman Wells FERRY TIME: 1.9

TRANSIT BASE: ___ SURVEY TIME: 4.3

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 14 °C DEW POINT: ___ R.H. %: 64%

CLOUD COVER: 5/8 High Scattered WIND: 100° @ 8 kts

TURBULANCE: Mild SEA STATE: —

NOTES: ___

POSITION FIX: GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: New Celesco, Diak Software V2.3.2

SUMMARY OF PERFORMANCE: Sect Area #2 and Survey Lines

FLIGHT No. 10

PAGE ____ OF ____
REV. OCT 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
016	N	1230	1318	22	44	
201	E	1326	1329			
202	W	1331	1336		88	
203	E	1338	1342			
204	W	1346	1349			
205	E	1351	1354			
017	S	1408	1458	31		
018	N	1501	1502	32		SCRAB DIPAK RESET
118	N	1507	1555			
019	S	1600	1650	33		
100	E	1733	1741			RIVER
						FIRE AT 66°37N 130°23 W

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 11 **DATE:** 15/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 1123 **LAND TIME:** 1717

PILOT: Randy **NAVIGATOR:** Jeff **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 2.1

TRANSIT BASE: — **SURVEY TIME:** 3.8

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 10°C DEW POINT: ___ R.H. %: 45%

CLOUD COVER: 8/8 @ 4000' WIND: 150° @ 3 kts

TURBULANCE: MILD SEA STATE: —

NOTES: ___

POSITION FIX: G.P.S

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT.	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE				1.2'	
SEASCAN				X	
MAG					Project #
RAD					

EQUIPMENT / AIRCRAFT STATUS: ___

SUMMARY OF PERFORMANCE: Seep Mun #3 And Survey Lines

FLIGHT No. 11

PAGE ____ OF ____
REV OCT 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
020	N	1230	1320	35	121	
021	S	1322	1359	29		
022	N	1401	1440			
301	E	1453	1456	31		
302	W	1458	1504			
303	E	1506	1509			WIND FROM N-NW
304	W	1511	1515			
305	E	1517	1521			
306	W	1523	1526			D'ARK ALAM AFTER EOL
307	E	1531	1535	34		LINE EXTENDED TO COVER POSS. ANOM
316	W	1537	1540			
315	E	1541	1544			
023	S	1556	1622			START SHORT - TIME
100	E	1711	1716			RIVER AT NORMAN WELLS.

9233-A4-3E

FLIGHT REPORT

PAGE ____ OF ____
REV. OCT. 1985

AREA: Peel Plateau FLIGHT No.: 12 DATE: 16/8/87

JOB No.: 348-11 TAKE OFF TIME: 1109 LAND TIME: 1626

PILOT: Randy NAVIGATOR: Jeff OPERATOR: Bob

MAIN BASE: Norman Wells FERRY TIME: 2.1

TRANSIT BASE: — SURVEY TIME: 3.2

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 11°C DEW POINT: ____ R.H. %: 60%

CLOUD COVER: Clear WIND: 240° @ 10 kts

TURBULANCE: Mild / Moderate SEA STATE: ____

NOTES: ____

POSITION FIX: GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT.	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: ____

SUMMARY OF PERFORMANCE: ____

FLIGHT No. 12

PAGE ___ OF ___
REV. OCT 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
024	N	1212	1257	44	44	WIND LIGHT FROM WEST
023	N	1310	1322			NORTH END
025	S	1325	1403	43		
026	N	1406	1447			
027	S	1448	1524	42		
100	E	1619	1624		88	WIND 320° @ 15kts RIVER.

9233-A4-3E 1

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 13 **DATE:** 17/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 1134 **LAND TIME:** 1608

PILOT: Jeff **NAVIGATOR:** Randy **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 4.0

TRANSIT BASE: ___ **SURVEY TIME:** 0.6

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 10°C DEW POINT: ___ R.H. %: 83%

CLOUD COVER: 3/8 @ 5000' Scattered WIND: 210° @ 6 kts

TURBULANCE: Mild SEA STATE: —

NOTES: Scattered showers in area.

POSITION FIX: GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: ___

SUMMARY OF PERFORMANCE: Flight aborted due to rain
Rond Lake Seep Area

FLIGHT No. 13 PAGE ___ OF ___

REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
601	S	1252	1256	39	44	
602	N	1257	1302			
603	S	1304	1307			NO VIZ SLICKS
604	N	1309	1312			
605	W	1314	1318			
606	E	1319	1320			
607	SW	1323	1326			
401	W	RAIN				
CHECKED OTHER SEEP AREAS — RAIN						

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau FLIGHT No.: 14 DATE: 18/08/87

JOB No.: 348-11 TAKE OFF TIME: 1156 LAND TIME: 1645

PILOT: Jeff NAVIGATOR: Randy OPERATOR: Bob

MAIN BASE: Norman Wells FERRY TIME: 1.7

TRANSIT BASE: — SURVEY TIME: 3.1

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 12°C DEW POINT: ___ R.H. %: 67%

CLOUD COVER: 8/8 @ 2000' WIND: 100° @ 5kts

TURBULANCE: MILD SEA STATE: —

NOTES: Rain Showers

POSITION FIX: GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS:

SUMMARY OF PERFORMANCE: Rain Showers

FLIGHT No. 14

PAGE____ OF____
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
405	W	1250	1254	36	32	
402	E	1255	1259			
404	W	1300	1304			
401	E	1306	1310			
403	W	1311	1315			LINE HEATER OPEN CIRCUIT
411	E	1400	1403		63	SCRUB NAV - GPS DROPPED OUT
413	W	1409	1413		63	SCRUB
415	E	1420	1424		44	
413	W	1426	1430			
411	E	1431	1435			
414	W	1437	1441			
412	E	1442	1445			
422	W	1447	1450			
						SET 1? ENTAREUE RAIN
016	S	1515	1602	35		MODERATE TURBULENCE
100	E	1640	1644		63	STON. WEST WIND

9233-A4-3E

FLIGHT REPORT

PAGE ___ OF ___
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 15 **DATE:** 19/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 1130 **LAND TIME:** 1653

PILOT: Randy **NAVIGATOR:** Jeff **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 2.5

TRANSIT BASE: — **SURVEY TIME:** 2.4

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 10°C DEW POINT: ___ R.H. %: ___

CLOUD COVER: 7/8 @ 4000 scattered WIND: 160° @ 4kts

TURBULANCE: mild SEA STATE: —

NOTES: ___

POSITION FIX: GPS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT	LAT.	
	LON	LON.	
2.	LAT	LAT.	
	LON	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT.	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE					
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS: ___

SUMMARY OF PERFORMANCE: ___

FLIGHT No. 15

PAGE ____ OF ____
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
201	N	1230	1248	41	44	
202	S	1249	1306			
211	N	1308	1327			
212	S	1329	1345			
221	N	1347	1406			
222	S	1409	1426	44		RMS BREAK
231	N	1429	1447			WEST WIND 5-8kts / SLICK AFTER EOL
232	S	1449	1506			
241	N	1508	1519			RAIN
242	S	1522	1524			SCRUB - RAIN
332	S					SCRUB - RAIN
082	N					SCRUB - RAIN
100	E	1647	1651			WIND 240 @ 10kts RIVER.

9233-A4-3E

FLIGHT REPORT

PAGE ____ OF ____
REV. OCT. 1985

AREA: Peel Plateau **FLIGHT No.:** 16 **DATE:** 22/8/87

JOB No.: 348-11 **TAKE OFF TIME:** 12 14 **LAND TIME:** 1833

PILOT: Jeff **NAVIGATOR:** Randy **OPERATOR:** Bob

MAIN BASE: Norman Wells **FERRY TIME:** 2.3

TRANSIT BASE: ____ **SURVEY TIME:** 4.0

BASE WEATHER AND FLIGHT CONDITIONS:

TEMP.: 11°C DEW POINT: ____ R.H. %: 48%

CLOUD COVER: 2/8 High Scattered WIND: 160° @ 2 kts

TURBULANCE: Mild / Moderate to Very Turbulent SEA STATE: —

NOTES:

POSITION FIX: G.PS

REFERENCE TARGET	ACTUAL POSITION	LORAN FIX	TIME
1.	LAT.	LAT.	
	LON.	LON.	
2.	LAT.	LAT.	
	LON.	LON.	

SURVEY STATUS:

SURVEY TYPE	STATUS	FLT. HGHT	LINE SPAC.	SENS/GAIN	COMMENTS
AIRTRACE				63	
SEASCAN				X	
MAG					
RAD					

EQUIPMENT / AIRCRAFT STATUS:

SUMMARY OF PERFORMANCE: Infill Lines & Seep #2

FLIGHT No. 16

PAGE ____ OF ____
REV. OCT. 1985

SURVEY LOG

LINE	DIR'N	TIME START	TIME END	TAPE No.	FID GAIN	REMARKS
222	N	1325	1329	33	63	SCRUB NAV WIND SW 10kts MODERATE TURBULENCE
322	N	1334	1352			
242	S	1357	1415			
251	N	1417	1435			VERY TURBULENT
352	S	1437	1455			
261	N	1501	1516	25		
262	S	1518	1536			
241	N	1545	1555			
712	E					SCRUB NAV.
722	E	1614	1618			
708	W	1620	1626			
704	E	1627	1631			
701	W	1633	1638			
705	E	1639	1644			
709	W	1645	1651			
711	E	1653	1658			
706	W	1700	1701	32		SCRUB - GPS
716	W	1706	1711	04		
702	E	1713	1717			
707	W	1718	1724	~~1724~~		
703	E	1725	1727			LINE SHORT - GPS
100		1828	1829			WIND 150° @ 34kts.

BARRINGER

APPENDIX 2

(AIRTRACE normalization factors by flight line)

SUMMARY LISTING OF NORMALIZATION FACTORS REQUIRED TO BRING MEAN AIRTRACE VALUES TO MEAN FOR LINE 5

FLIGHT	LINE	NORMALIZATION FACTOR
RECONNAISSANCE SURVEY LINES		
7	101	0.793
7	2	1.207
7	2	1.415
7	3	1.360
7	4	1.002
7	5	1.000
7	6	0.875
8	7	1.108
8	8	0.377
8	9	0.382
8	10	0.339
8	11	0.416
8	12	0.503
9	13	0.991
9	14	0.574
9	15	1.186
14	16	0.624
10	17	0.913
10	118	0.674
10	19	1.730
11	20	0.676
11	21	0.396
11	22	1.189
11	23	1.144
12	23	0.202
12	24	0.489
12	25	0.255
12	26	0.937
12	27	0.720
Fill-In Survey Lines		
15	201	0.553
15	202	0.400
15	211	0.405

BARRINGER

SUMMARY LISTING OF NORMALIZATION FACTORS REQUIRED TO BRING MEAN AIRTRACE VALUES TO MEAN FOR LINE 5

FLIGHT	LINE	NORMALIZATION FACTOR
FILL-IN SURVEY LINES		
15	212	0.622
15	221	0.376
16	322	0.967
15	231	1.008
15	241	0.437
15	242	0.453
16	242	0.997
16	251	1.042
16	252	1.088
16	261	1.017
16	262	1.104
16	241	0.973
Rond Lake Seep		
9	101-106	0.396
13	601-607	0.485

BARRINGER

SUMMARY LISTING OF NORMALIZATION FACTORS REQUIRED TO BRING MEAN AIRTRACE VALUES TO MEAN FOR LINE 5

Mackenzie River Seep

Normalization factor for all lines is 0.600

Ontaratue-Mackenzie River Seep

Normalization factor for all lines is 0.600

Ontaratue River Seep

Normalization factor for all lines is 1.0

Norman Wells (Production Facilities)

Normalization factor for all lines is 1.0