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BMR RECORD 1992/45

CARNARVON BASIN (BARROW SUB-BASIN)
GEOCHEMICAL CALIBRATION SURVEY

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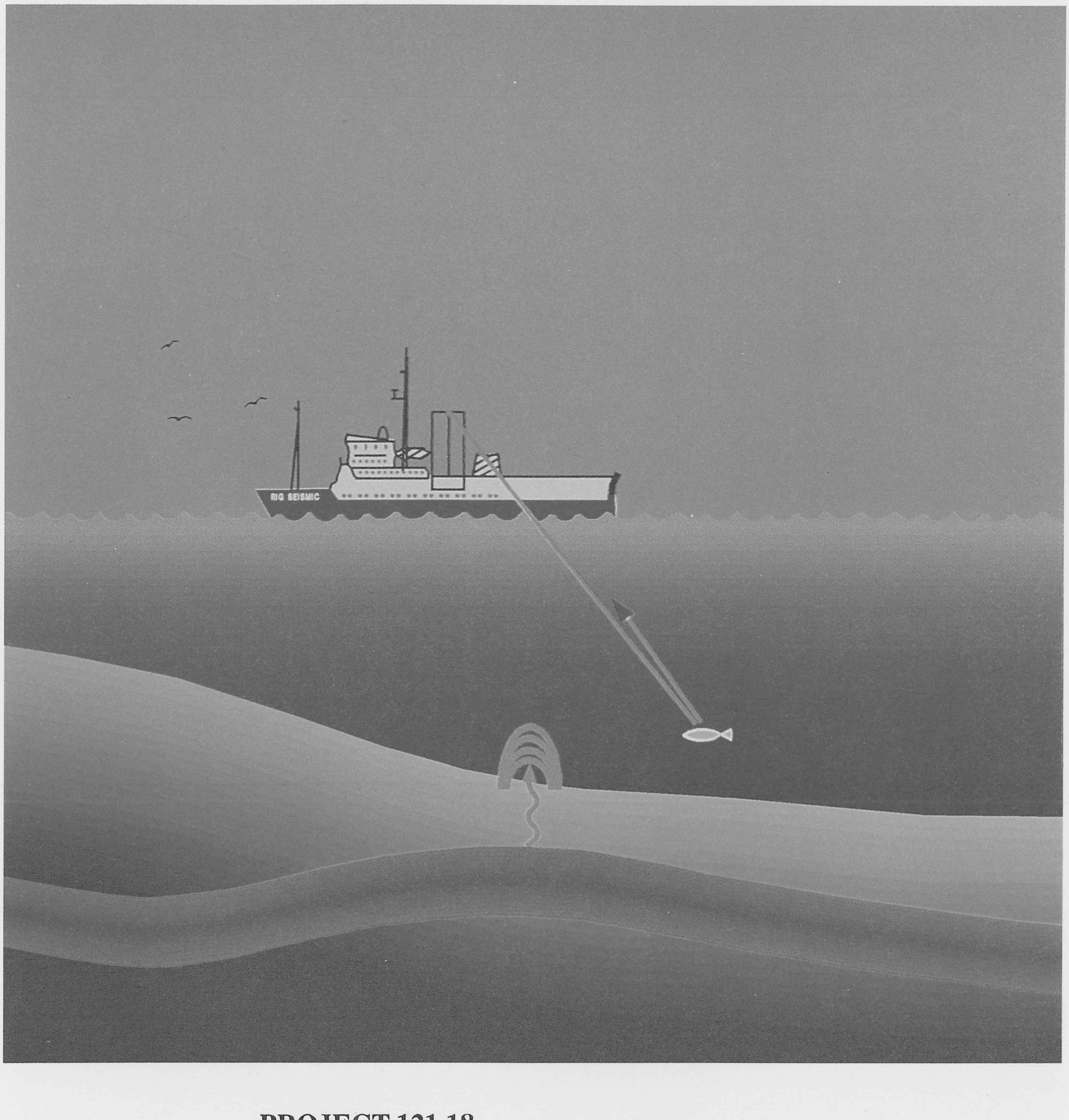

PROJECT 121.18

G.P. Bickford, D. Heggie, B. Hartman and J. Bishop

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MARINE GEOSCIENCE AND PETROLEUM GEOLOGY PROGRAM

BMR RECORD 1992/45
CARNARVON BASIN(BARROW SUB-BASIN) GEOCHEMICAL CALIBRATION SURVEY

R9204501

PROJECT 121.18

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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister: The Hon. Alan Griffiths

Secretary: G.L. Miller

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Executive Director: R.W.R. Rutland AO

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EXECUTIVE SUMMARY

Transglobal Environmental Geosciences (TEG) and the Bureau of Mineral Resources, as part of the Joint Research Agreement into hydrocarbon seepage around the Australian Continental margin, conducted a calibration survey over some known hydrocarbon accumulations in parts of the Barrow Sub-basin and the Rankin Platform during 1989. This survey was conducted at the end of a larger and proprietary geochemical 'sniffer' survey conducted by TEG (for Amoco Production Co., USA) in the Perth Basin.

Approximately 220 line km of Direct Hydrocarbon Detection (DHD) data were collected during the survey in the vicinities of known hydrocarbon accumulations, Saladin, South Chervil, Chervil, North Herald and South Pepper in the inshore part of the Barrow Sub-basin. Additional survey lines were run in the deeper water part of the basin, on the landward side of the rift, in the vicinities of Chinook and Griffin, and further to the north, on the southern extension of the Rankin Platform (Alpha Arch) over the Gorgon gas/condensate field.

Light hydrocarbon anomalies were detected in bottom-waters in the vicinities of Saladin, Chervil, South Chervil, North Herald and South Pepper, although the anomalies were generally weak (< five-fold background). No anomalies were detected near Chinook and Griffin, nor Gorgon, although problems with the tow-cable and tow-fish resulted in the tow-fish being too high above the seafloor to detect any significant seepage.

INTRODUCTION

Surface geochemistry and offshore exploration for hydrocarbons

The aim of surface geochemical techniques in offshore petroleum exploration is: (a) to detect direct evidence for thermogenic generation of hydrocarbons in a sedimentary basin, (b) to assist in locating sub-surface hydrocarbon accumulations, and (c) to provide information on the likely composition of hydrocarbon accumulations within a given geologic province. The most common technique used to detect hydrocarbon seepage offshore involves towing a submerged 'fish' close to the seafloor which continuously pumps seawater into a geochemical laboratory in the tow-vessel. There, hydrocarbons are extracted and measured by gas chromatography. This equipment, commonly known as a geochemical 'sniffer' (Schink et al. 1971; Sigalove and Pearlman 1975) - or what we refer to as Direct Hydrocarbon Detection (DHD) - has been widely used overseas for offshore petroleum exploration. InterOcean Systems Inc., a US-based corporation has collected over 1.5 million line kilometres of data from about 140 surveys around the world. However, most of the data gathered by contractors for clients remains proprietary and the opinions expressed publicly, about surface 'sniffer' geochemical techniques, by the petroleum exploration community remain divided. Schiener et al. (1985) have commented about the use of the geochemical 'sniffer' in the North Sea.

Within Australia, the 'sniffer' has been a relatively under-utilised tool in offshore hydrocarbon exploration, with only four surveys being carried out prior to 1988. Those surveys were all located in southeastern Australia, specifically in: (1) the Duntroon Basin, for Getty Oil Development Company Ltd. in 1983, (2) the Otway Basin (Sprigg 1986) for Ultramar Australia in 1981, and (3) two small surveys in the Gippsland Basin for Esso Exploration and Production, Australia Inc., in 1983.

The Bureau of Mineral Resources (BMR), as part of the Continental Margins Program, and a joint Agreement with Transglobal Environmental Geoscience (TEG) of Leucadia California (Heggie et al., 1990), has been conducting surface geochemical (bottom-water DHD and sediment [hydrocarbon-headspace] geochemistry) surveys on parts of the Australian continental margin since 1989. Part of this work includes research into:

- the origins (biogenic or thermogenic?) of bottom-water light hydrocarbons
- light hydrocarbon 'sources' (liquids, condensate or gas?)
- bottom-water and seafloor expressions of seepage
- the relationships of seepage to the surface and sub-seafloor geology, including hydrocarbon accumulations and source rock types and distributions.

BMR Surface geochemistry overall program objectives

The overall objective of the BMR offshore surface geochemistry program is to evaluate the application of surface geochemical techniques (both direct hydrocarbon detection (DHD) and sediment [hydrocarbon-headspace] techniques) to hydrocarbon exploration around the Australian continental margin. Specific objectives include:

- To collect, via reconnaissance surveys, new information on the thermal generation of hydrocarbons in under-explored Australian basins.
- To test the application of both bottom-water DHD and sediment geochemical techniques to hydrocarbon prospect ('target') evaluations in both known hydrocarbon provinces and frontier basins.
- To test, develop and refine criteria to recognise thermally generated migrated hydrocarbons from background biogenic hydrocarbons in both seawater and sediments.

- To examine the relationship between hydrocarbon generation and migration by relating the surface and sub-seafloor expressions of hydrocarbon seeps to the sub-seafloor geology and probable locations and type(s) of source rocks.
- To relate the chemical and isotopic compositions of seeps to 'source' characteristics, i.e. gas, condensate, liquids, and to predictions from geohistory and maturation modelling of different source rock types.
- To test bottom-water DHD and sediment geochemistry techniques in the search for hydrocarbons sealed by stratigraphic traps.
- To examine the biogenic processes influencing the concentrations, distributions and chemical compositions of hydrocarbon seeps in bottom-waters and the near surface sediments.
- To examine oceanographic dispersal processes of seeps.

To achieve this, multi-disciplinary programs involving the simultaneous collection of bottom-water DHD, seismic reflection, gravity, magnetic and side-scan sonar data have, and will be, carried out by the BMR's research vessel "Rig Seismic" (and occasionally on other vessels) around the Australian continental margin. These data are both integrated with each other, and also with sediment geochemical data which may sometimes be collected during the surveys.

The geochemical analysis system (Direct Hydrocarbon Detection or DHD) that has been installed aboard the Rig Seismic as part of the Agreement is shown schematically in Figure II-1 of Appendix II. The laboratory system analyses a variety of gases extracted from seawater, including C1-C8 hydrocarbons with facilities to collect gases for shore-based isotopic analyses. Complete details of both the DHD system and the interpretative methodologies used are given in Appendices II and III.

This BMR Record presents the geochemical data obtained during a very short and very constrained 'calibration' exercise in the Barrow Sub-basin of the Carnarvon Basin

(Fig.1) during July of 1989. These data were obtained by TEG aboard the 'M.V. Mermaid Searcher', at the completion of a larger, proprietary 'geochemical sniffer' survey conducted for AMOCO Production Co., in the Perth Basin.

BARROW SUB-BASIN: BACKGROUND AND OBJECTIVES

Hydrocarbon accumulations in the Barrow/Dampier Sub-basins had been, until recently considered to fall into two trends. There existed an inner trend of oil-prone hydrocarbon discoveries e.g., Barrow Island and associated accumulations, such as Saladin, Chervil, North Herald, South Pepper, Harriett, Bambra and Rosette on the eastern flank of the Barrow Sub-basin, while an outer trend of predominantly gas/condensate accumulations were associated with the western side of the Barrow Sub-basin along the Rankin Trend e.g., Gorgon, West Tryall Rocks. However, more recently, there have been oil/gas discoveries in the what had previously been considered gas/condensate-prone areas, eg Griffin and Chinook, Wanaea and Cossack.

Given the occurrences of gas/condensate and oil/gas accumulations within the Barrow Sub-basin and the distinction between the inner oil-prone and outer gas/condensate trends becoming blurred, it was considered that surface geochemical techniques, specifically DHD (geochemical 'sniffer'), could be a useful complementary exploration tool that may be used to distinguish gas from oil prone accumulations, and hence reduce exploration risk in this part of the North West Shelf.

The objectives of this survey therefore were to; (i) measure the concentrations of light hydrocarbons in the bottom-waters of the Barrow-Sub-basin, in areas of known hydrocarbon (both gas/condensate and oil/gas discoveries) accumulations, hence (ii) to evaluate the potential application of bottom-water geochemical data in new exploration on the North-West Shelf.

BARROW SUB-BASIN: DHD RESULTS

Bottom-water geochemical data were collected along five survey lines (Figs. 1 and 2). These lines (Carn 1, Carn 2, Carn 3, Carn 4, Carn 5) are presented in this record as both the individual lines and also as a composite line in Figure 13. The corresponding shot-point numbers and line numbers of the composite data set are shown in Table 1.

The geochemical analysis system used to acquire the bottom-water light hydrocarbon data is identical to that installed on the Rig Seismic and is described in Figure II-1, Appendix II.

Eastern sector of the Barrow Sub-basin (survey lines Carn 1-3)

Line summary plots of light hydrocarbons are shown in Figures 3 through 9. Line summary plots of total hydrocarbons (THC; Fig. 3), sum C1-C4 (Fig. 4) and the individual saturated hydrocarbons methane (Fig. 5), ethane (Fig. 6) and propane (Fig. 8) show similar trends: bottom-water anomalies were found on survey lines Carn 1 and Carn 2, in the eastern part of the survey area.

All anomalies are weak (generally less than five-fold typical background concentrations), but nevertheless are clearly distinguishable from the local background hydrocarbon concentrations. Methane concentrations are highest in the anomalies on line Carn 2, and increase from background of about 3.5 ppm to about 9 ppm (Fig. 5).

Similarly, ethane concentrations increase about five-to-ten-fold above background levels in the anomalies measured on lines Carn 1 and 2 (Fig. 6). Maximum ethane was measured at about 0.1 ppm, typically, 0.04 - 0.08 ppm (typical background about 0.01 ppm). The increases in ethane are not accompanied by corresponding increases in the unsaturated biogenic hydrocarbon (ethylene) (Fig. 7). Propane concentrations varied similarly to ethane, but propane only showed minor increases above local background. For example, in the strongest anomaly on line Carn 2, propane increased to levels typically 0.025 to 0.05 ppm, and the local background was about 0.015 ppm (Fig. 8). Propylene concentrations (biogenic hydrocarbons) were relatively high on lines Carn 1 and Carn 2 (Fig. 9).

The anomalies are also reflected in the line summary plots of the Bernard parameter (methane/(ethane+propane) Fig. 10); the ratio of methane/ethane (Fig. 11), variations in the ethane/propane ratio (Fig. 12), and variations in the % hydrocarabon wetness (Fig. 14). It should be noted that the sudden increase in wetness on survey line Carn 5 results from the rapid appearance of iso-butane and trace levels of propane, but no increases in methane and ethane, and is not believed to be seepage from the seafloor (see below).

The positions of the anomalies are summarised in Table 2. The anomaly on survey line Carn 1 (Appendix I), corresponds closely to the location of the Saladin 1 oil and gas field. The anomalies on line Carn 2 (Appendix I), correspond closely to the accumulations of South Chervil and Chervil oil and gas fields, while the northernmost, and very weak anomaly corresponds to the North Herald and South Pepper oil and gas condensate accumulations.

At a ship speed of about 5 knots, the anomalies measured on Carn 1, near Saladin (Appendix I) could be detected over distances of about 17 km, those anomalies near South Chervil and Chervil, over distances of about 5 km each, while that near North

Herald and South pepper, about 6 -7 km (Appendix I). During this part of the survey, the tow-fish was consistently at an altitude of about 10 m above the seafloor (Fig.13).

At the end of the survey line Carn 2, a transit line (Carn 3) was run westward toward the Chinook and Griffin oil and gas/condensate accumulations (Fig. 2). No anomalies were found on this line although it did not pass near any known accumulations, and the tow-fish altitude was more than 20 m above the seafloor (SP 324 to 462; Fig.13).

Western sector of the Barrow Sub-basin (survey lines Carn 4, 5).

Survey line Carn 4 was designed to test for seepage near Chinook and Griffin. No anomalies were found possibly because the tow-fish (due to mechanical problems with the winch and cable) was at an altitude of 30 - to - 40 m above the seafloor for much of this line (sp 463 to 529; Fig. 13), at a total water depth of about 140 to 168m. Geochemical data collection was commenced again further to the north near Spar 1, and passed over the Gorgon gas/condensate field, and continued to survey near to West Tryall Rocks. No anomalous concentrations of C1-C3 hydrocarbons were detected, although elevated iso-butane concentrations were found (SP 38-90; Appendix I), which persisted for a distance of about 12 km, near Central Gorgon and North Gorgon. These result in a sudden increase in wetness values on Carn 5 (Fig. 14). However, for much of this part of the survey, continued mechanical problems with the winch (App. IV) resulted in the tow-fish being more than 40 m above the seafloor (Fig.13), and these instantaneous appearances of anomalous levels of i-butane (which are not accompanied by increases in methane or ethane although trace increases in propane were found, Figs. 5, 6 and 8), are probably not related to seepage. Time constraints meant these survey lines could not be re-run. Because of the unusual elevation of the tow-fish above the seafloor in these sectors (Carn 4 and 5) of the survey, the lack of bottom-water anomalies is inconclusive as a calibration exercise.

Hydrocarbon 'source'

The molecular compositions of the anomalies may provide some clues to the potential 'source' (liquids, condensate or 'dry' (biogenic or thermogenic) gas). According to the cross-plot model of Figure III-1, Appendix III, potential liquid-prone accumulations are indicated by increasing hydrocarbon wetness values with increasing methane concentrations. Gas/condensate sources are reflected in near constant hydrocarbon wetness values with increasing methane while 'dry' gas is indicated by decreasing wetness values with increasing methane.

In the anomalies found during this survey, methane co-varies with both ethane (Fig. 15) and propane (Fig. 16), although the propane increases above background represent only trace amounts. In the plot of percent hydrocarbon wetness versus line number (Fig. 14), typical background wetness values are < 1%. Increases in wetness values (up to about 2%) are associated with the anomalies near Saladin, S. Chervil, Chervil and N.Herald/S.Pepper. Wetness values increases rapidly to above 2 % in the southern part of line Carn 5, but these are associated with the unexplained appearance of i-butane when the tow-fish was high in the water column (above).

The cross-plot of methane versus percent wetness (Fig. 17) shows two trends of increasing wetness with increasing methane. The trend of increasing wetness at background methane (3 ppm, closed squares) is associated with the iso-butane increases on Carn 5 (propably not related to seepage). However, the trends on increasing wetness with increasing methane are associated with the bottom-water anomalies near Saladin, South Chervil, Chevil and North Herald/South Pepper. These are expanded in Figure 18, which shows the data separated by survey line. Background data are indicated by the transit line (Carn 3, closed squares); data from Carn 1, near Saladin (closed diamonds) and data from Carn 2 (S.Chervil, Chervil and N.Herald/S.pepper, open squares). The data from line Carn 2 are shown in Figure 19, and indicate separate trends for South Chervil (sp 1-35, closed squares); Chervil 1-3 (SP 36-98, open squares and closed diamonds), and for N.Herald/S.Pepper (SP 99-182, open diamonds). However, because of the generally low concentrations of all hydrocarbons measured during the survey (methane increases only about two-fold above background) and wetness values increase about twice background, these trend-lines are not strongly developed. However, they do indicate trends of varying wetness with increasing methane, which are at least qualitiatively consistent with the oil/gas nature of these accumulations.

SUMMARY

Approximately 220 line km of bottom-water light hydrocarbon data were collected from the Barrow Sub-basin of the Carnarvon Basin during July 1989. The survey was limited in scope, and intended as a brief calibration exercise only, to test the potential application of DHD ('geochemical sniffer') techniques to new exploration in this area. The survey was conducted by TEG (with BMR participation) aboard the vessel M.V. Mermaid Searcher.

Light hydrocarbon C1-C3 anomalies were detected in bottom-waters in the vicinity of the Saladin, South Chervil, Chervil and N.Herald/S.Pepper oil and gas/condensate accumulations. Because these anomalies were detected close to the seafloor, they probably represent hydrocarbon seepage from the subsurface into the overlying bottom-waters. These anomalies were weak, but could be detected over distances of about 5 - 20 km.

A cross-plot of methane versus percent hydrocarbon wetness indicates small increases (about double) in wetness for increases (about threefold) in bottom-water methane concentrations. At these low hydrocarbon concentrations this cross-plot model, used

as a rapid guide to potential hydrocarbon 'source', is not very sensitive. However, the model does distinguish the Saladin, South Chervil and Chervil, and the N.Herald/S.Pepper accumulations. The cross-plot model suggests the anomalies are sourced from liquids, or gas/condensate hydrocarbon accumulations.

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LIST OF TABLES

Table 1. Shot-point numbers and survey line names refering to the composite data set shown in Figure 13.

Shot-point	Line name
1-140	Carn 1
140-322	Carn 2
323-462	Carn 3
463-529	Carn 4
530-767	Carn 5

Table 2. Bottom-water anomalies and locations of hydrocarbon accumulations.

Survey line	Anomaly (sp:lat;long)	Accumulation (lat;long)	Name
Carn 1	sp 74: 21.4605; 115.1540	21.4416; 115.0531	Saladin-1
	sp125:21.4775;115.0830		
Carn 2	sp 37: 21.3745;115.2100	21.3444;115.2033	S.Chervil1
	sp 50: 21.3487;115.2063		
Carn 2	sp 69: 21.3319;115.2297	21.3036;115.2258	Chervil-1
	sp 84: 21.2733;115.2250		
Carn 2	sp 122: 21.1330;115.2605	21.1762;115.2674	N.Herald-1
	sp 140: 21.0687;115.2365	21.1249;115.2747	S.Pepper-1

LIST OF ENCLOSURES

Enclosure 1: Floppy disk with ASCII files of geochemical data

Enclosure 1 data has been made available as a separate download file.

Enclosure 2: Map showing DHD survey lines

LIST OF FIGURES

Figure 13. Fish altitude versus shot-point.

Figure 14. Percent hydrocarbon wetness versus survey line number.

Figure 15. Methane versus ethane, all survey lines.

Figure 16. Methane versus propane all survey lines.

Figure 17. Methane versus percent hydrocarbon wetness for all survey lines.

Figure 18. Methane versus percent hydrocarbon wetness for survey lines Carn-1, 2,3.

Figure 19. Methane versus percent hydrocarbon wetness for survey line Carn-2.

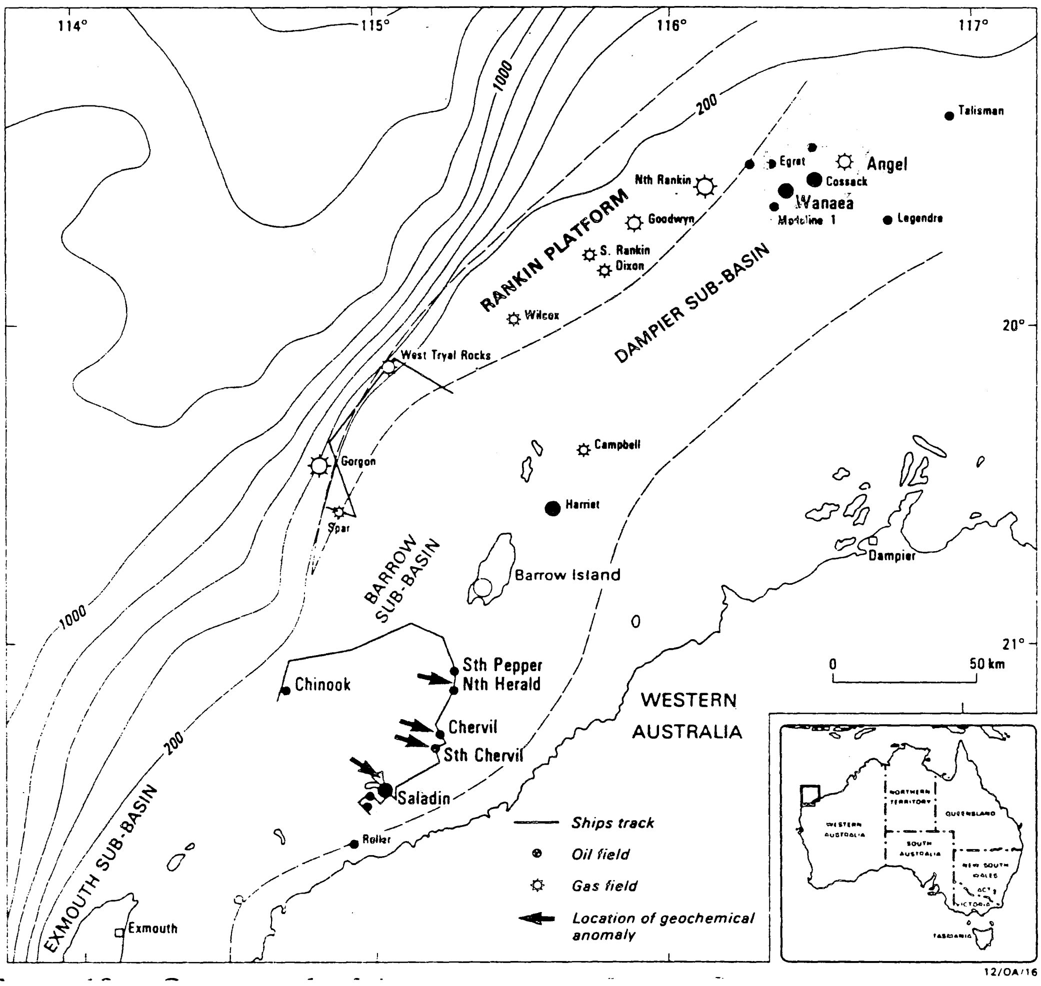


Figure 1 - Cruise track of the calibration survey in the Barrow Sub-basin also showing (arrows) the approximate location of anomalies.

CARNARVON BASIN

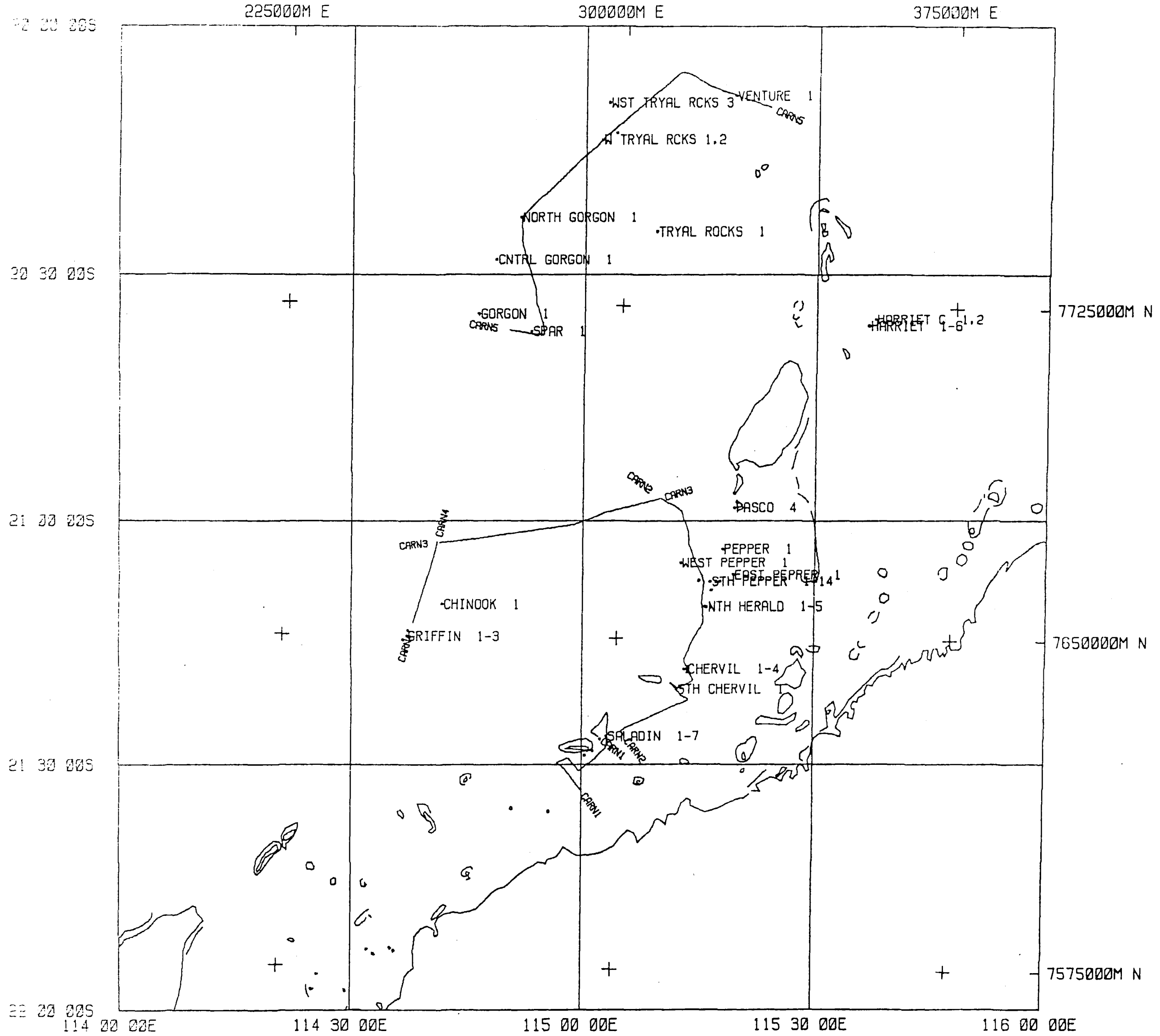


Figure 2 - Cruise track of the calibration survey in the Barrow Sub-basin.

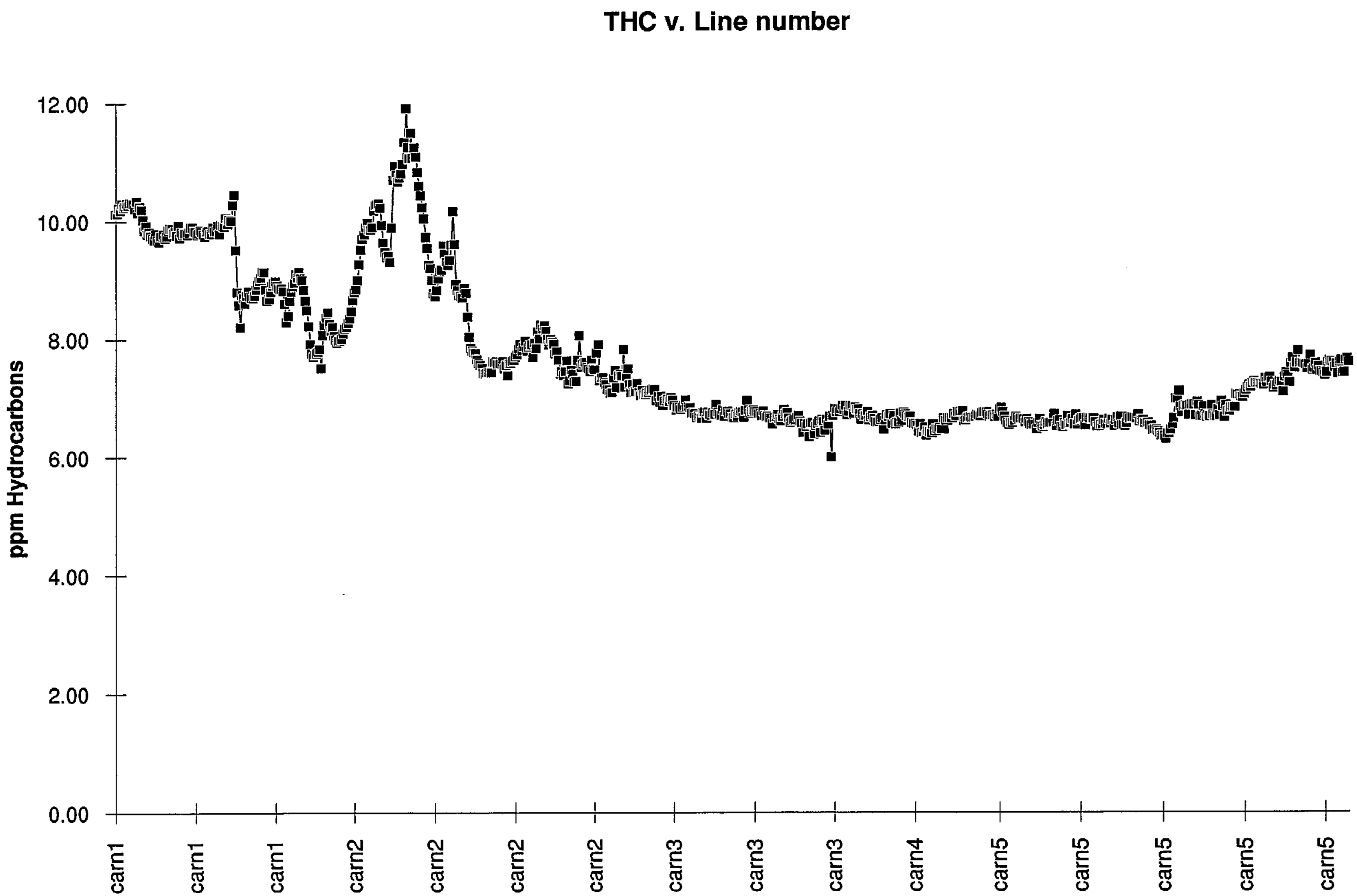


Figure 3. THC versus survey line number.

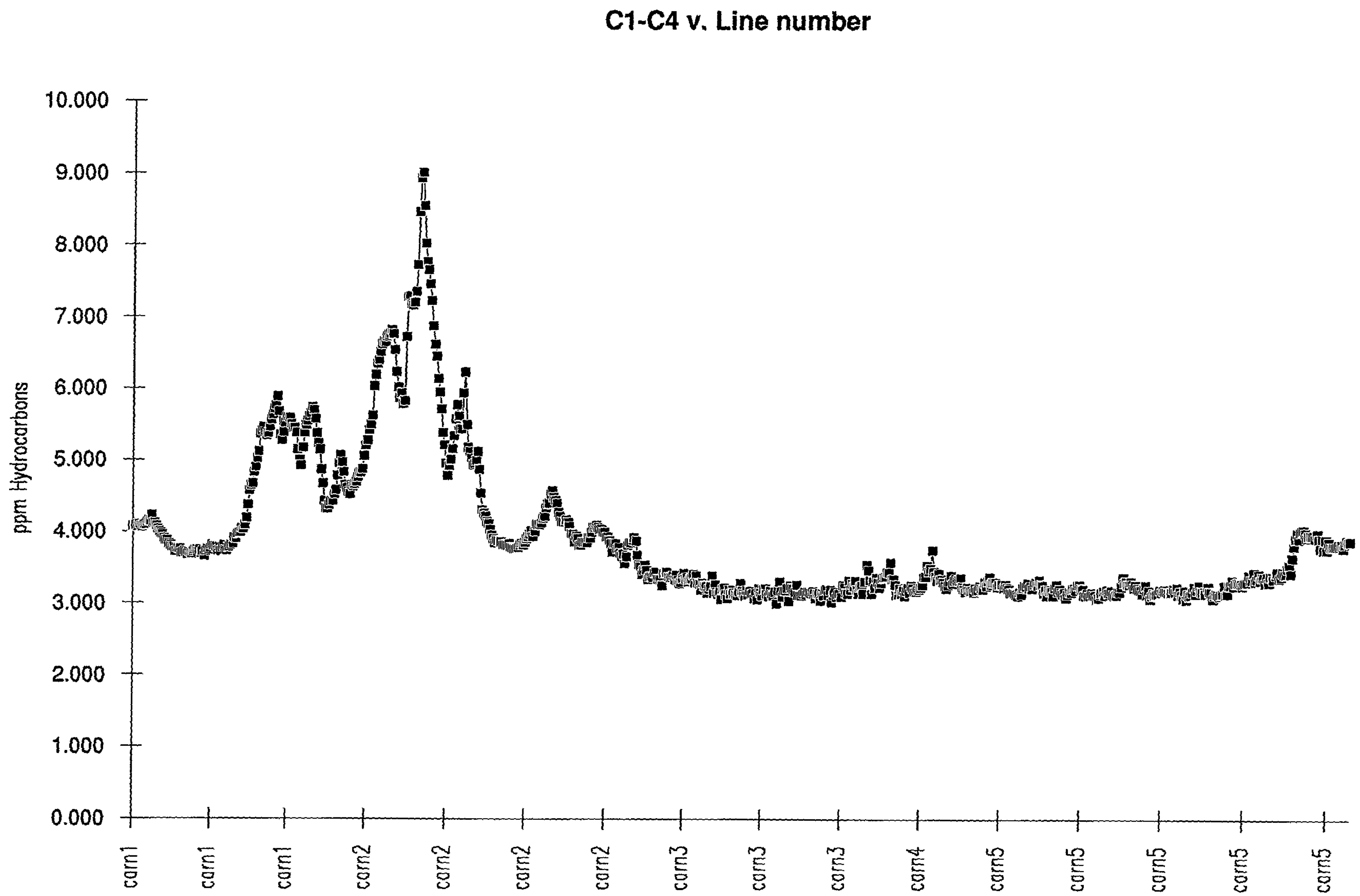


Figure 4. Sum C1-C4 saturated hydrocarbons versus survey line number

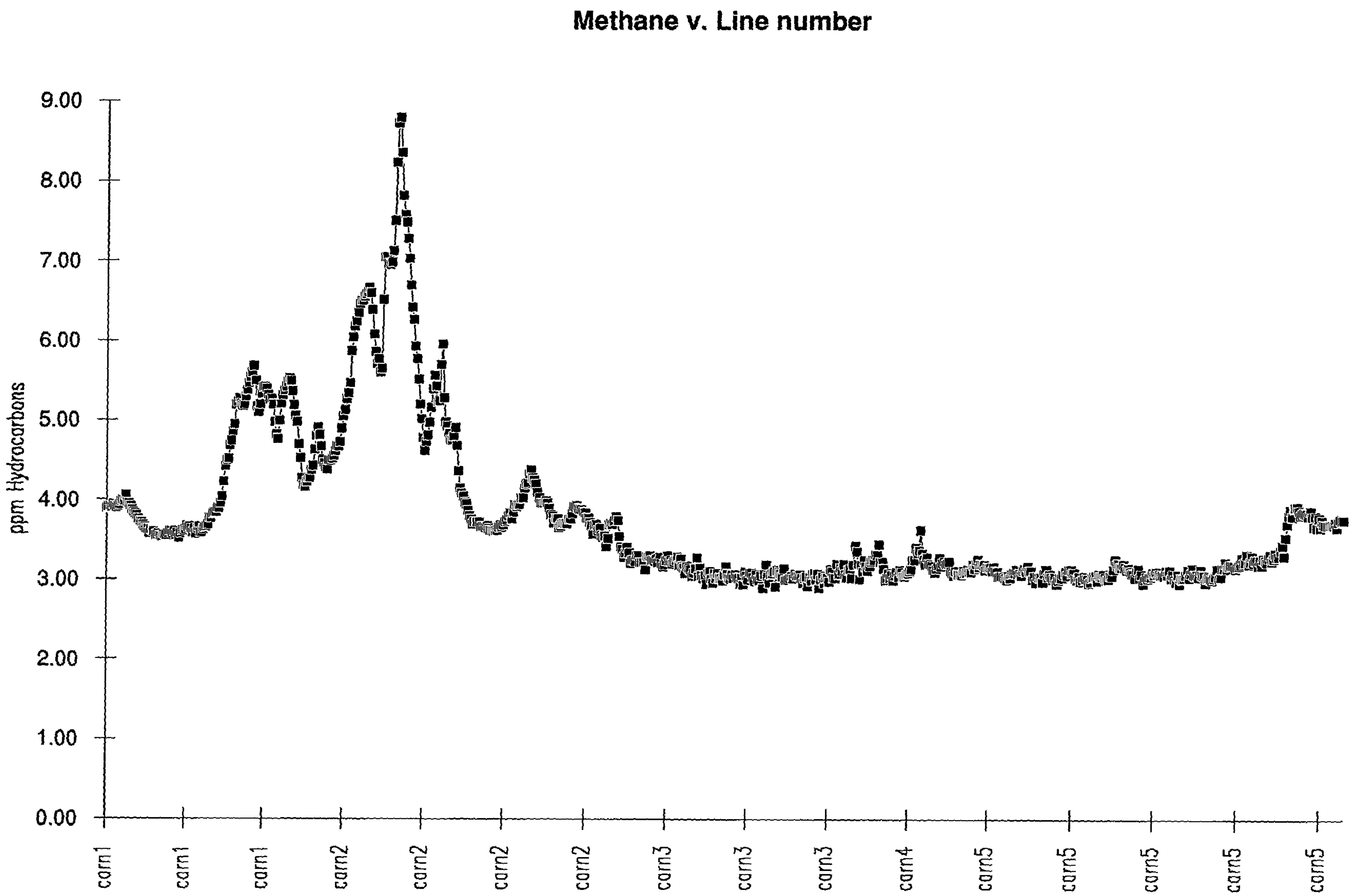


Figure 5. Methane versus survey line number.

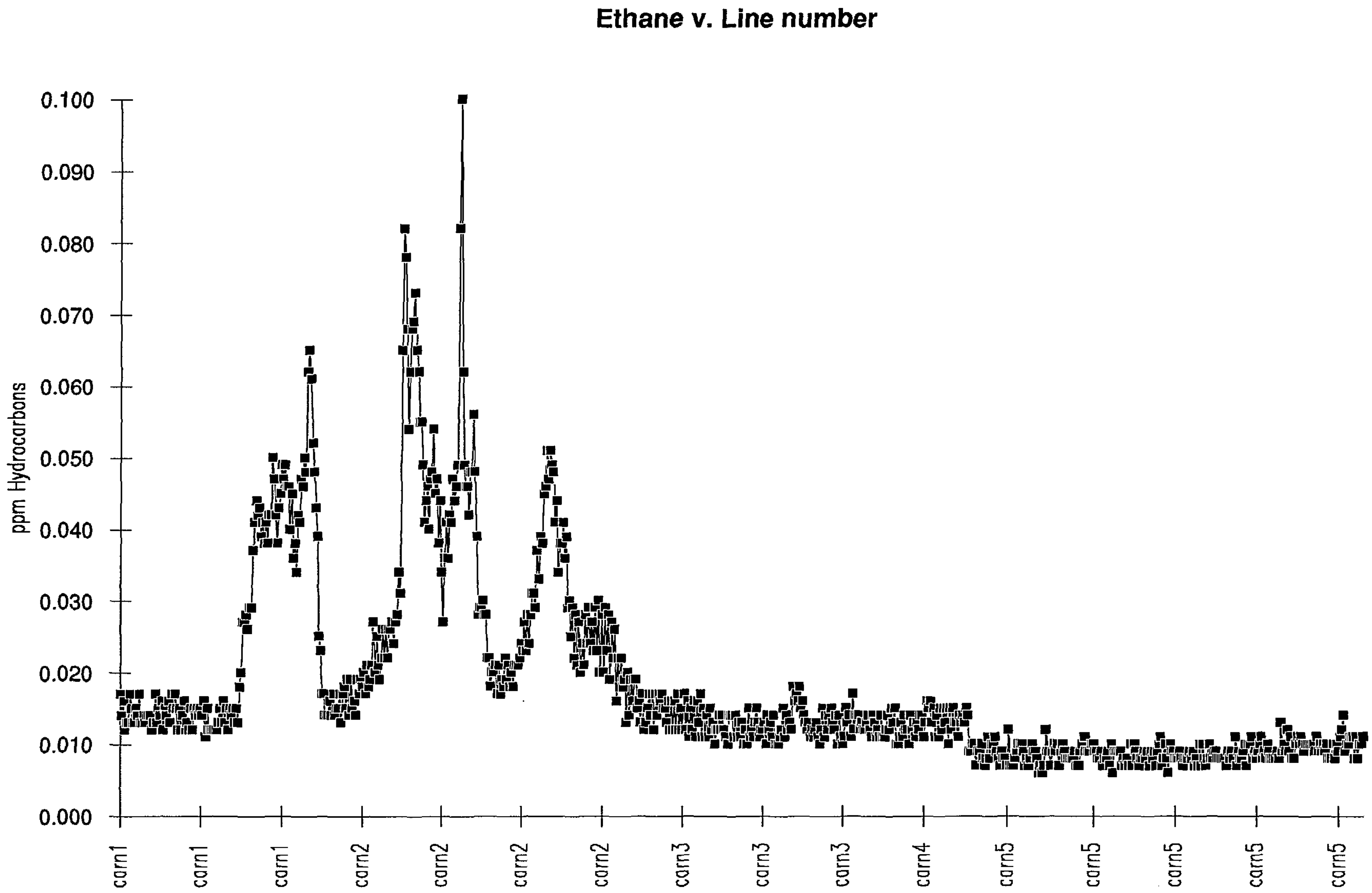


Figure 6. Ethane versus survey line number

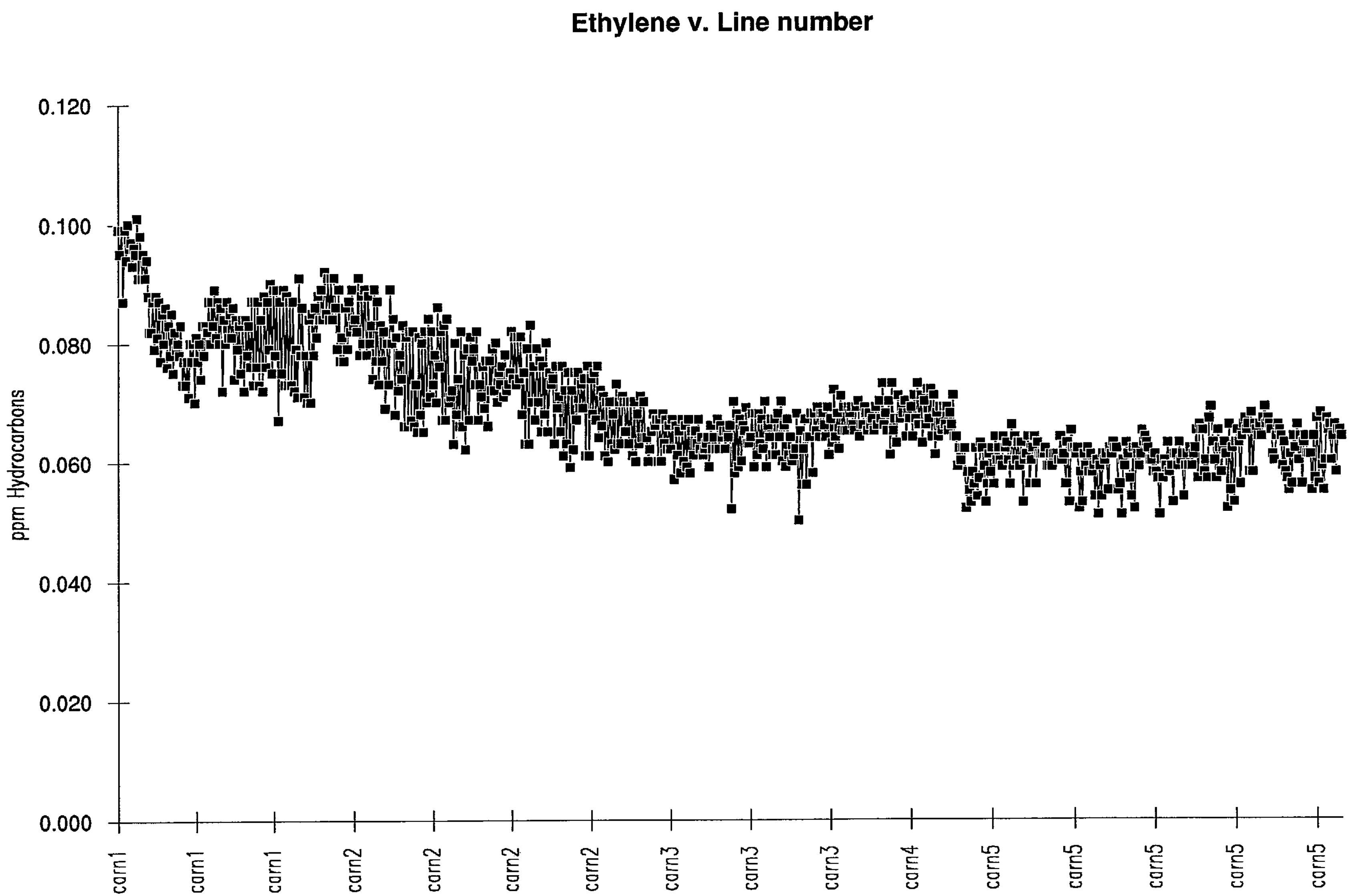


Figure 7. Ethylene versus survey line number.

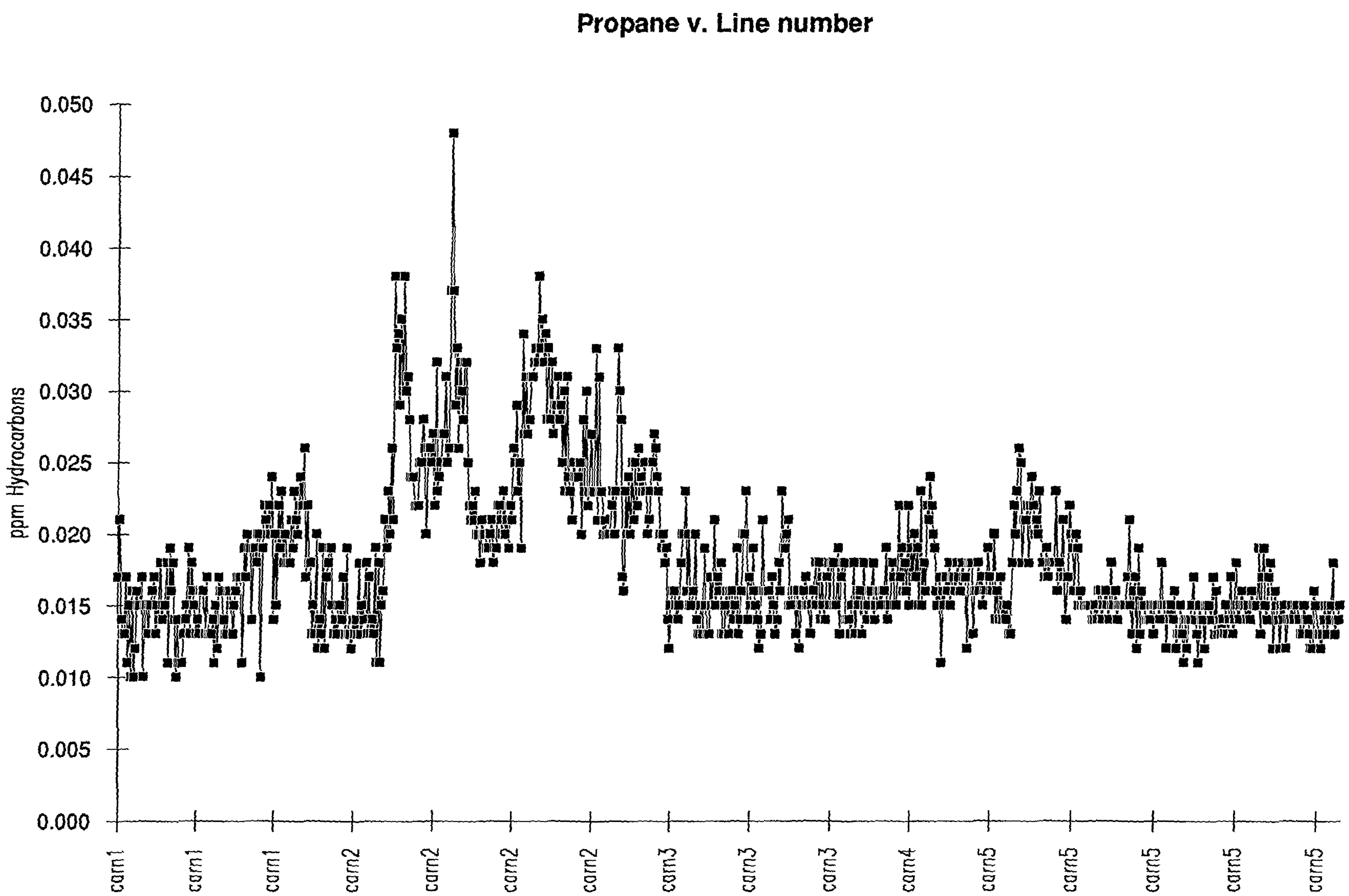


Figure 8. Propane versus survey line number.

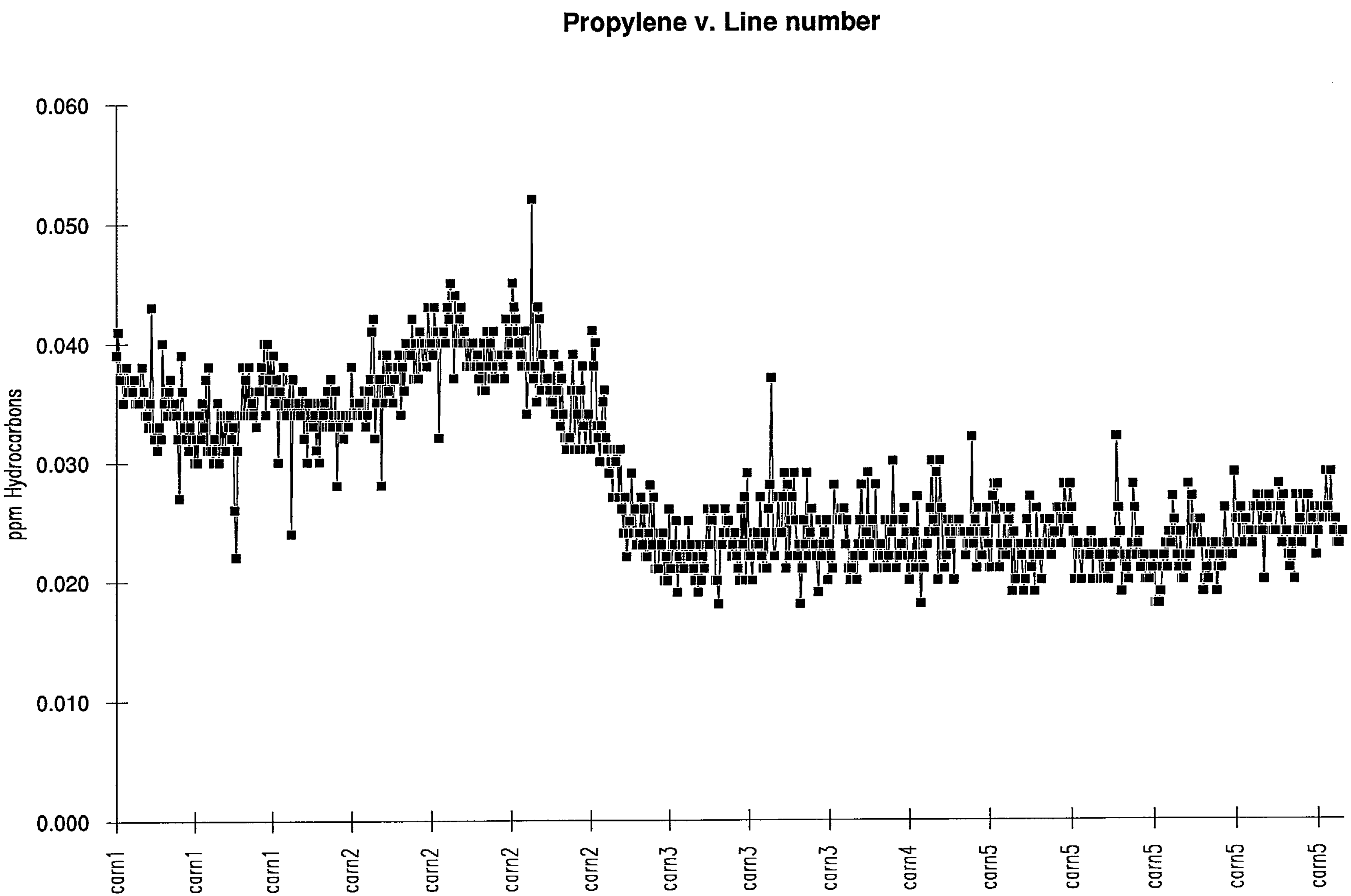


Figure 9. Propylene versus survey line number.

Bernard Parameter v. Line number

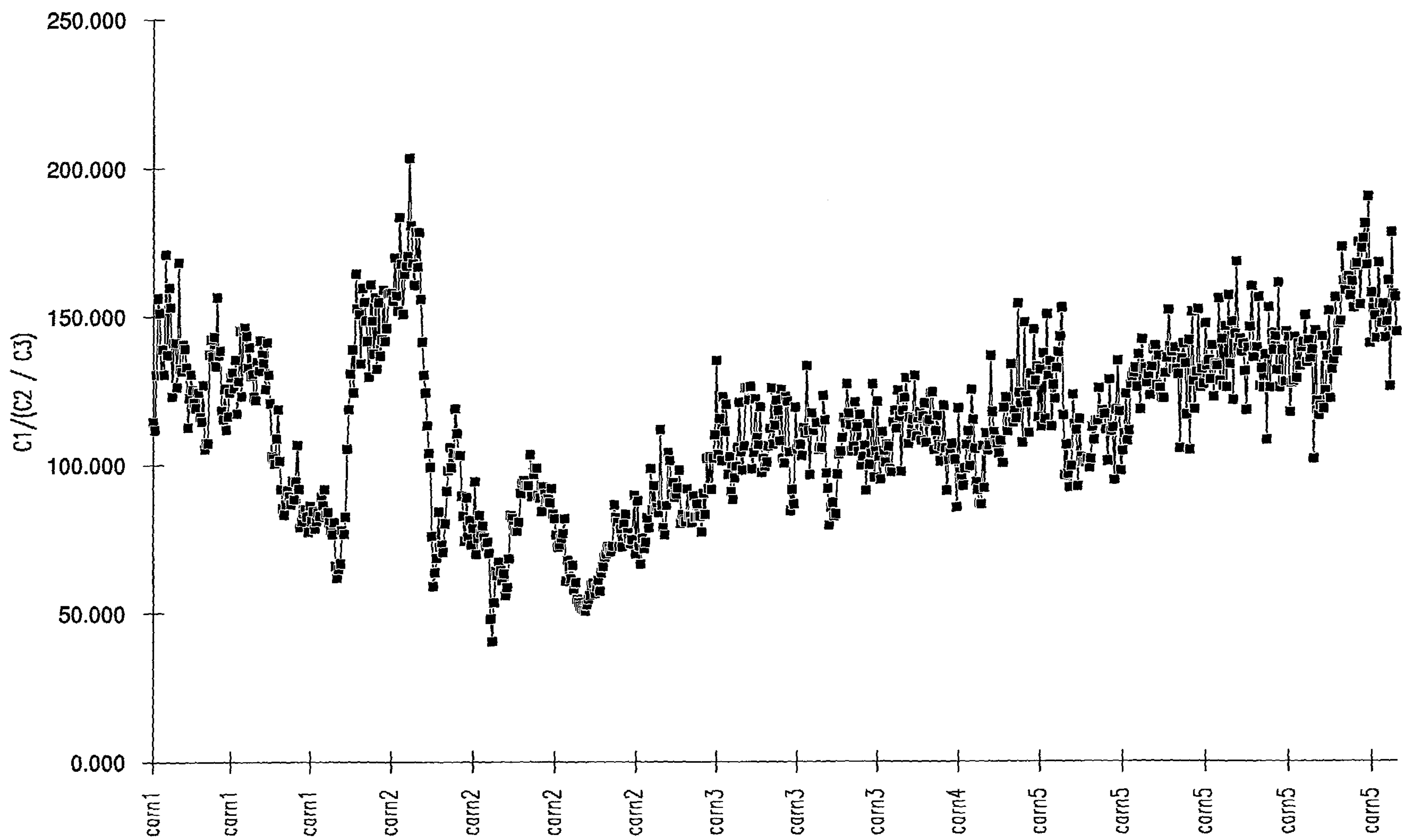


Figure 10. Bernard parameter versus survey line number.

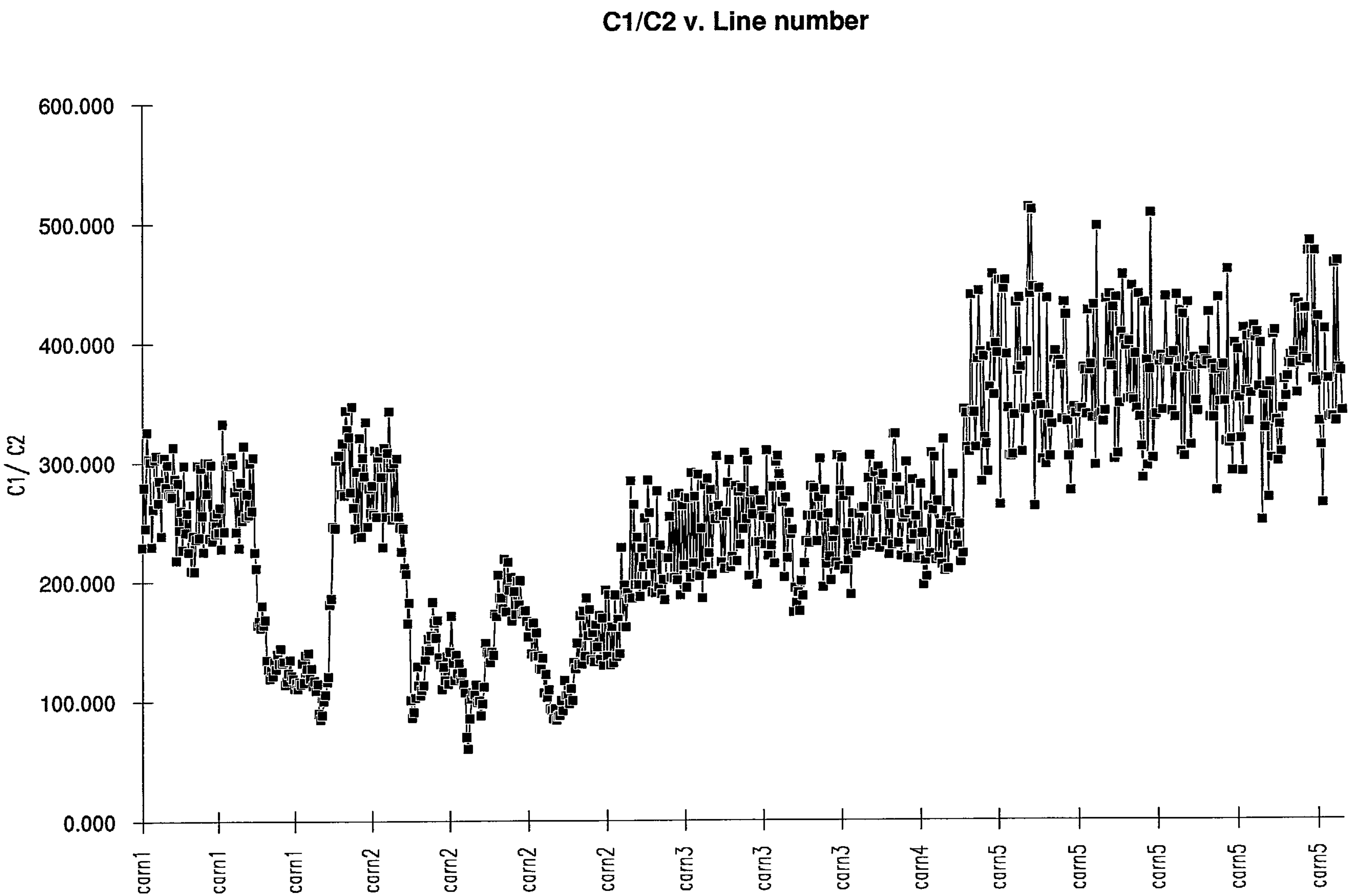


Figure 11. Methane/ethane versus survey line number.

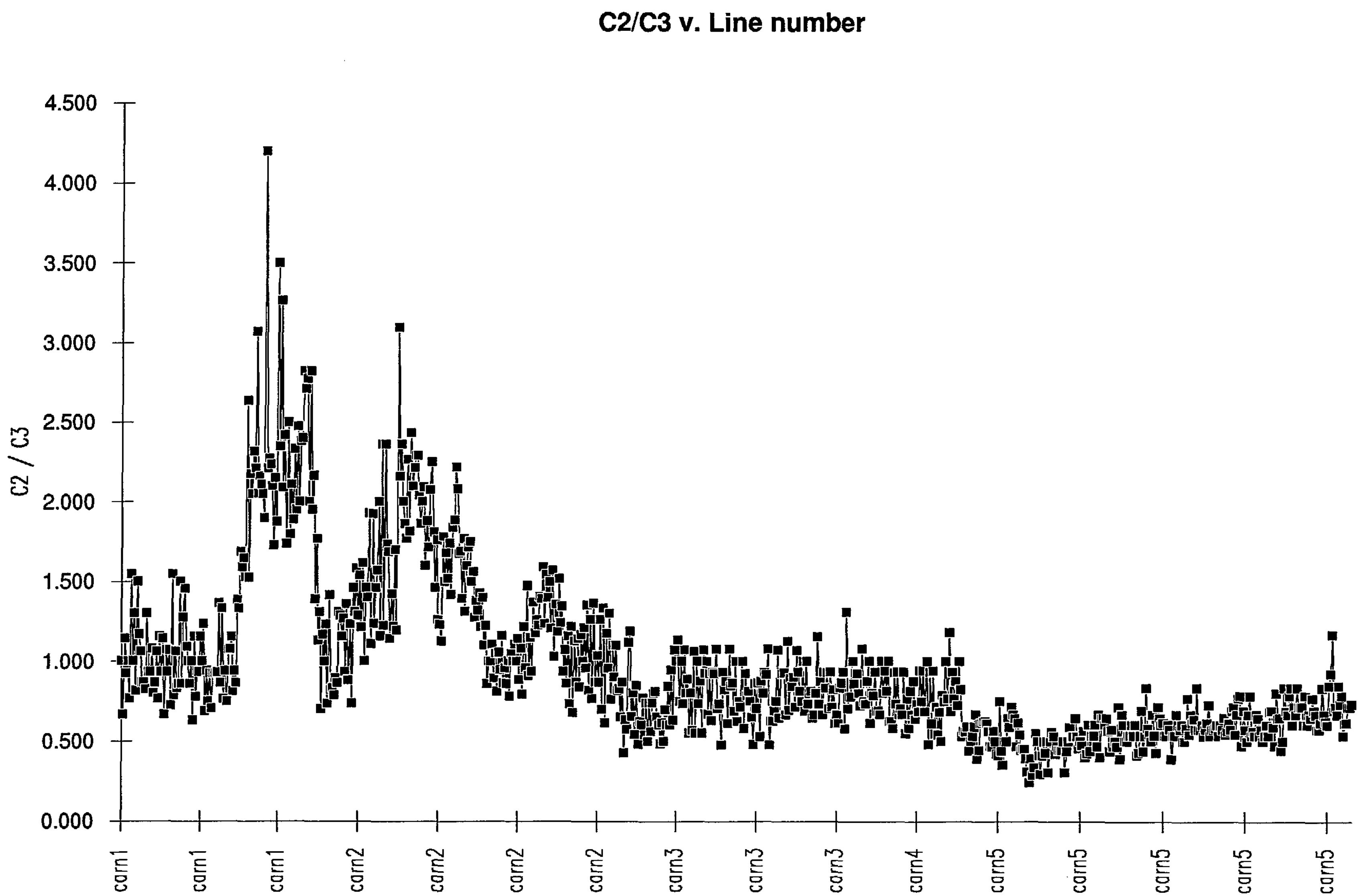


Figure 12. Ethane/propane versus survey line number.

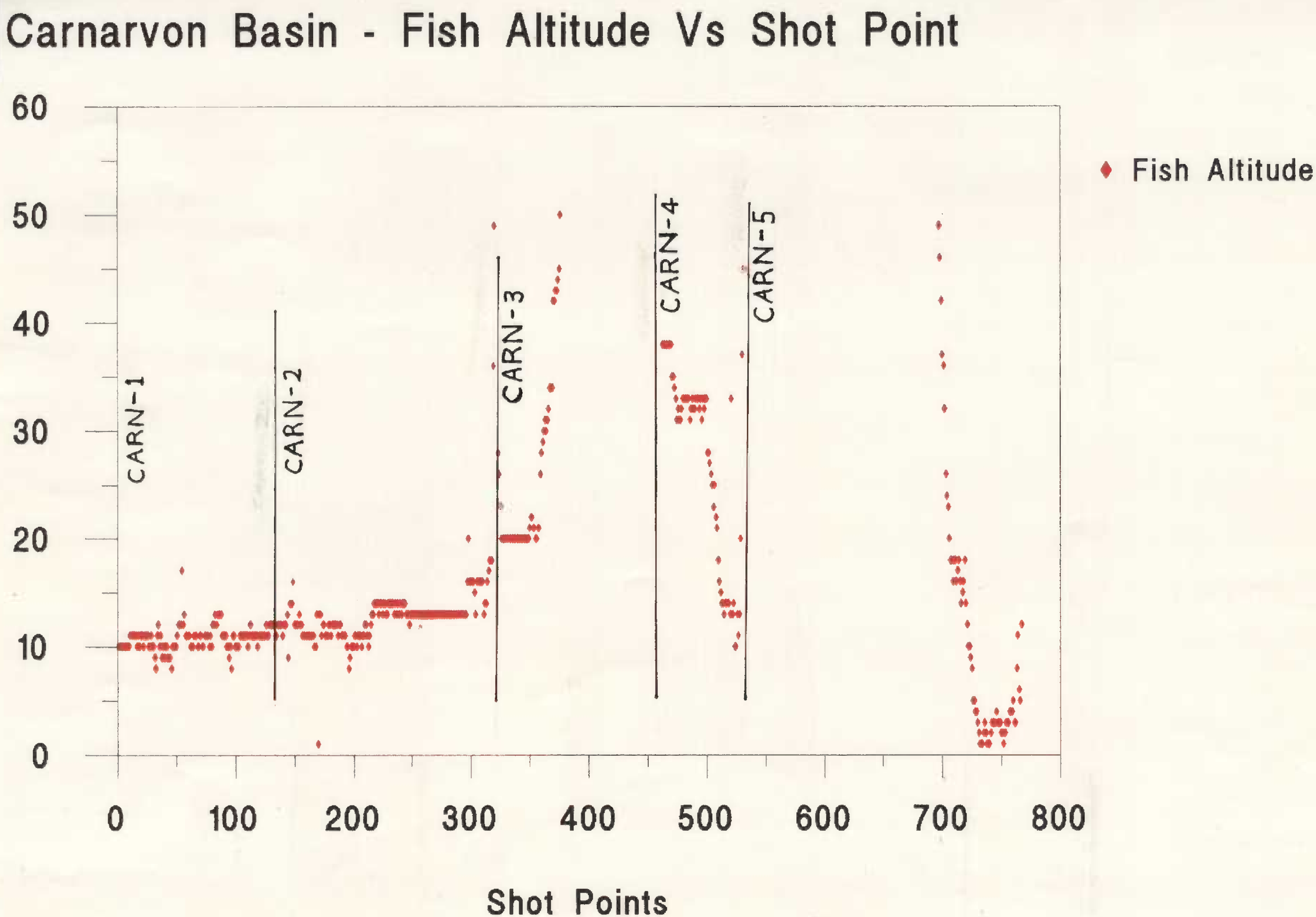


Figure 13. Fish altitude versus shot-point.

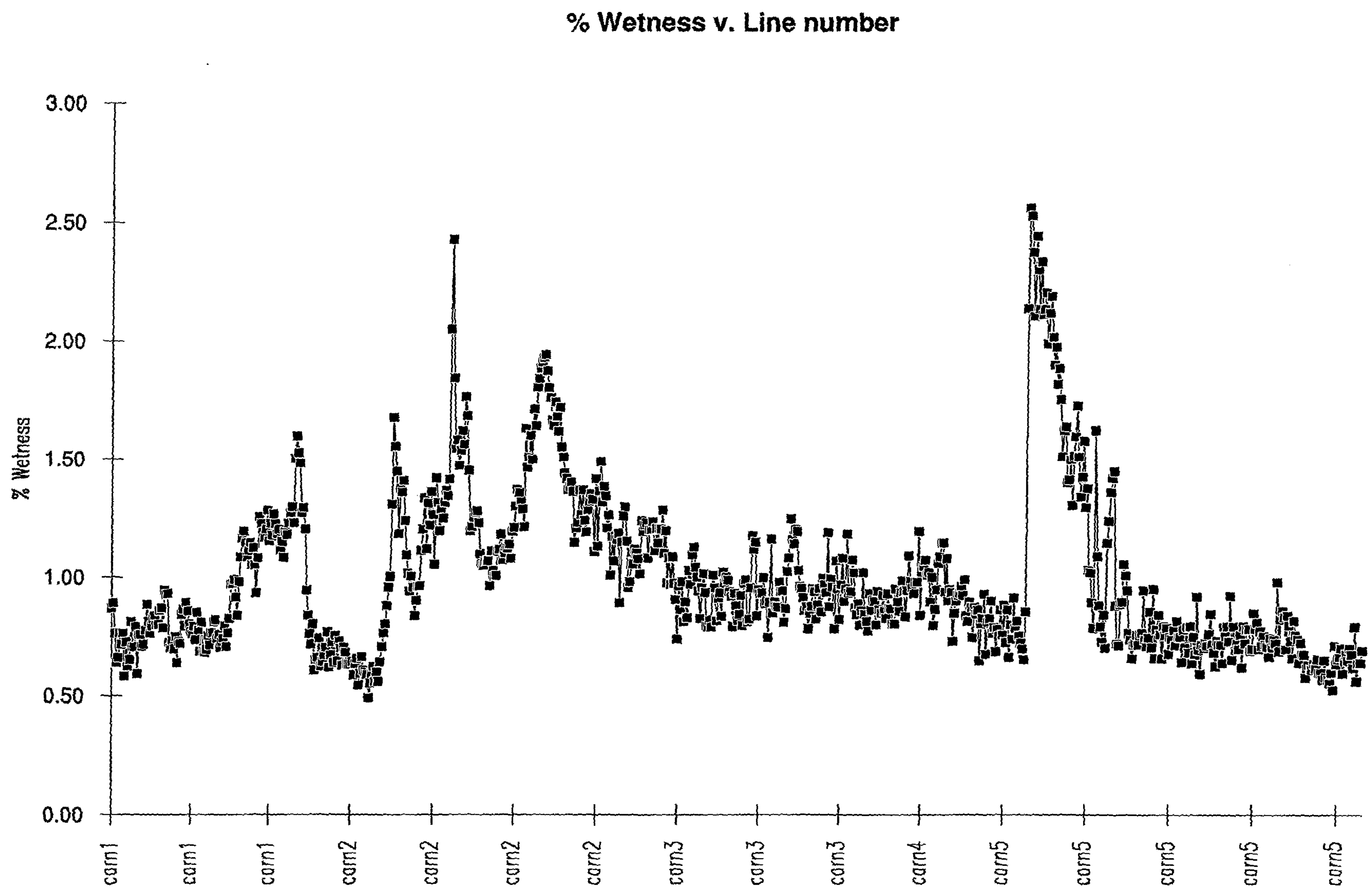


Figure 14. Percent hydrocarbon wetness versus survey line number.

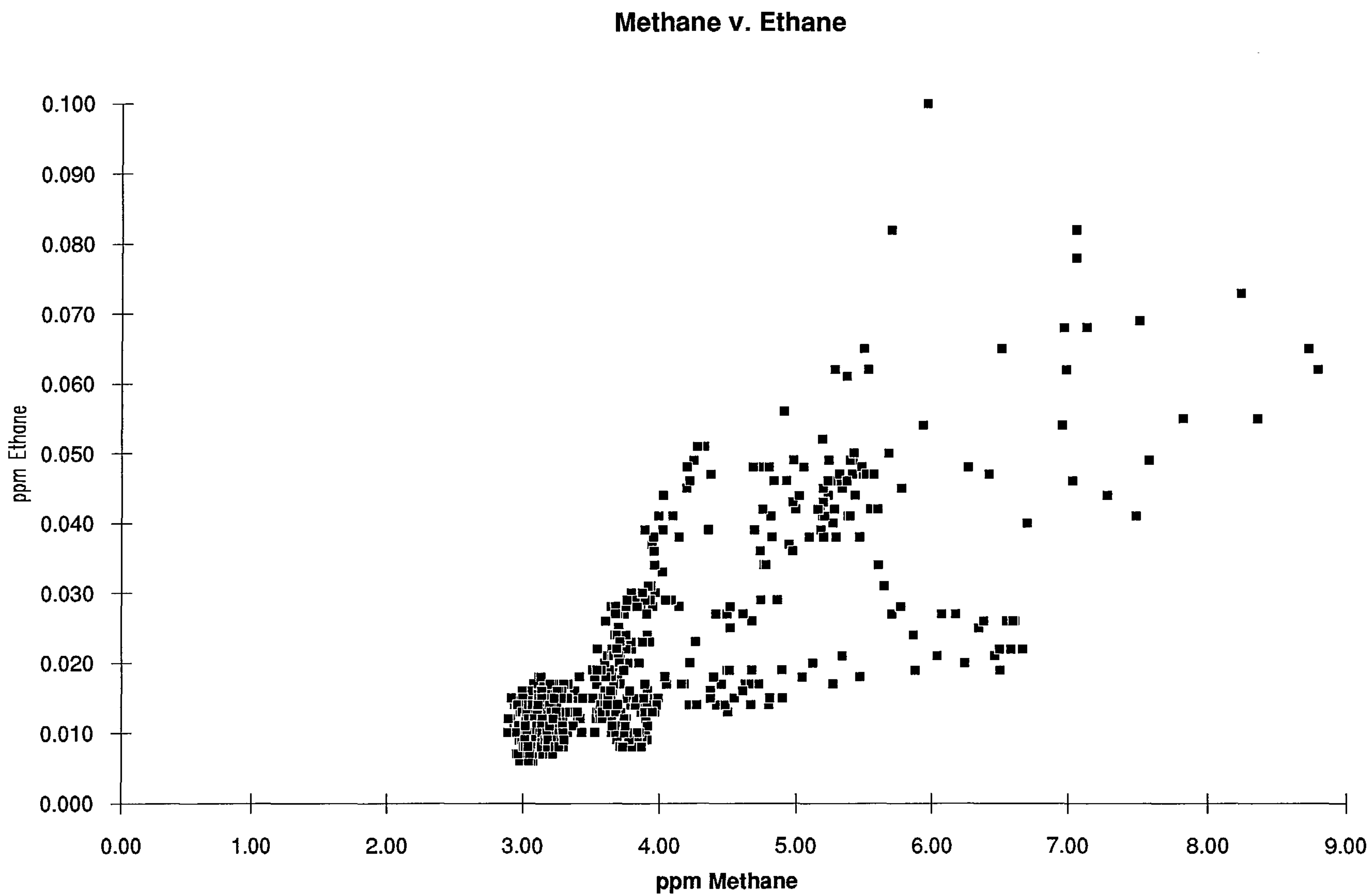


Figure 15. Methane versus ethane, all survey lines.

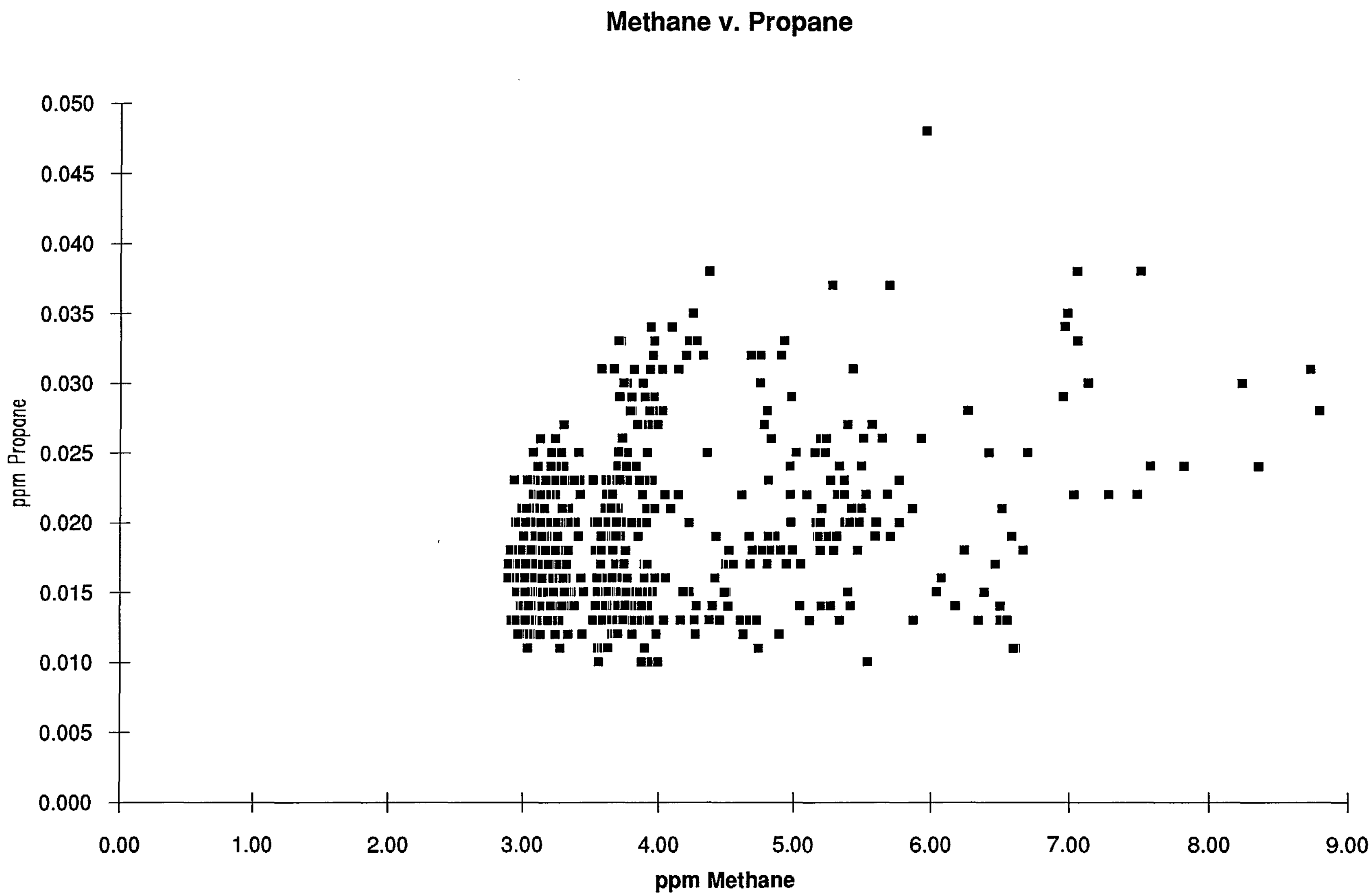


Figure 16. Methane versus propane all survey lines.

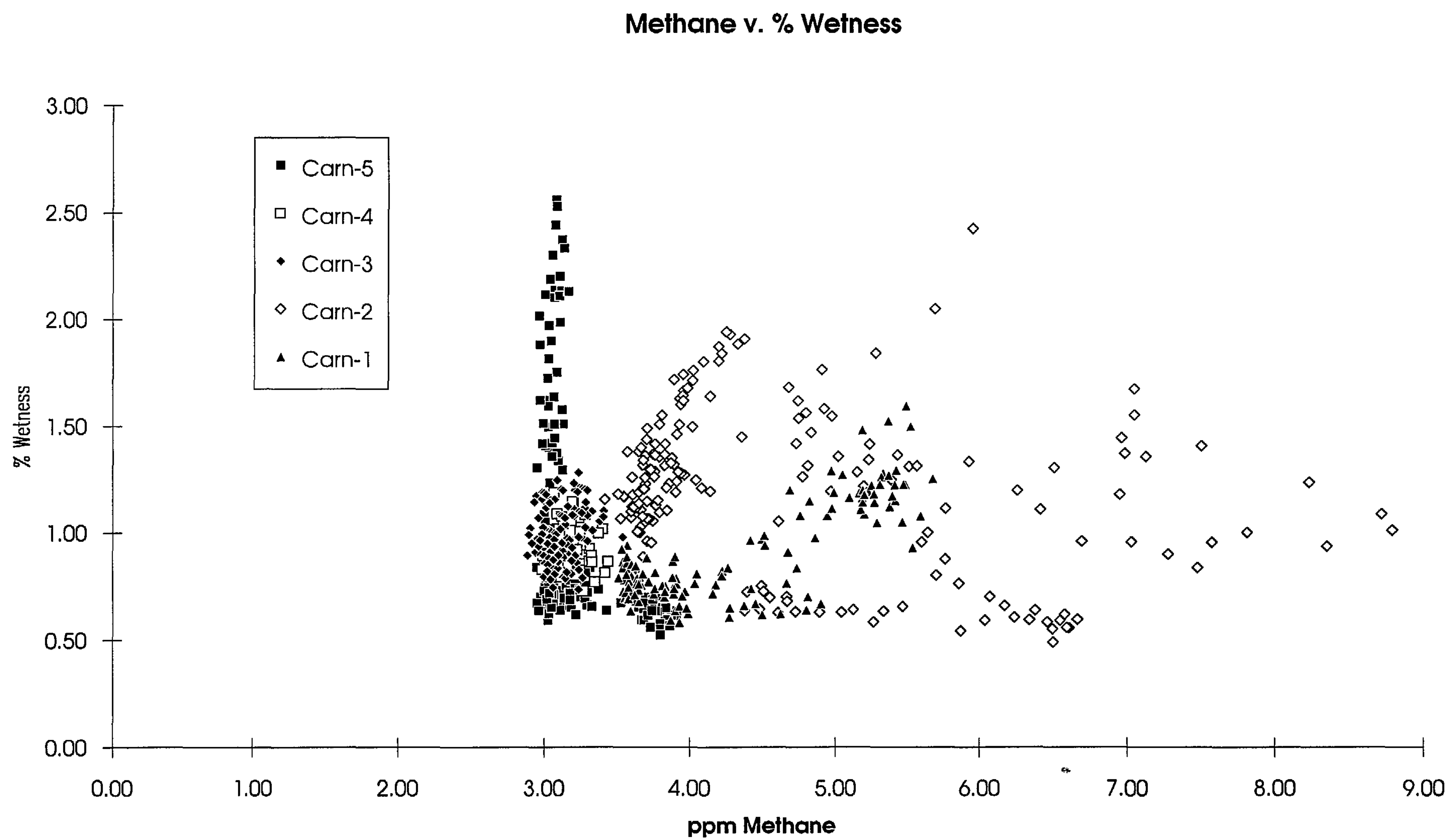


Figure 17. Methane versus percent hydrocarbon wetness for all survey lines.

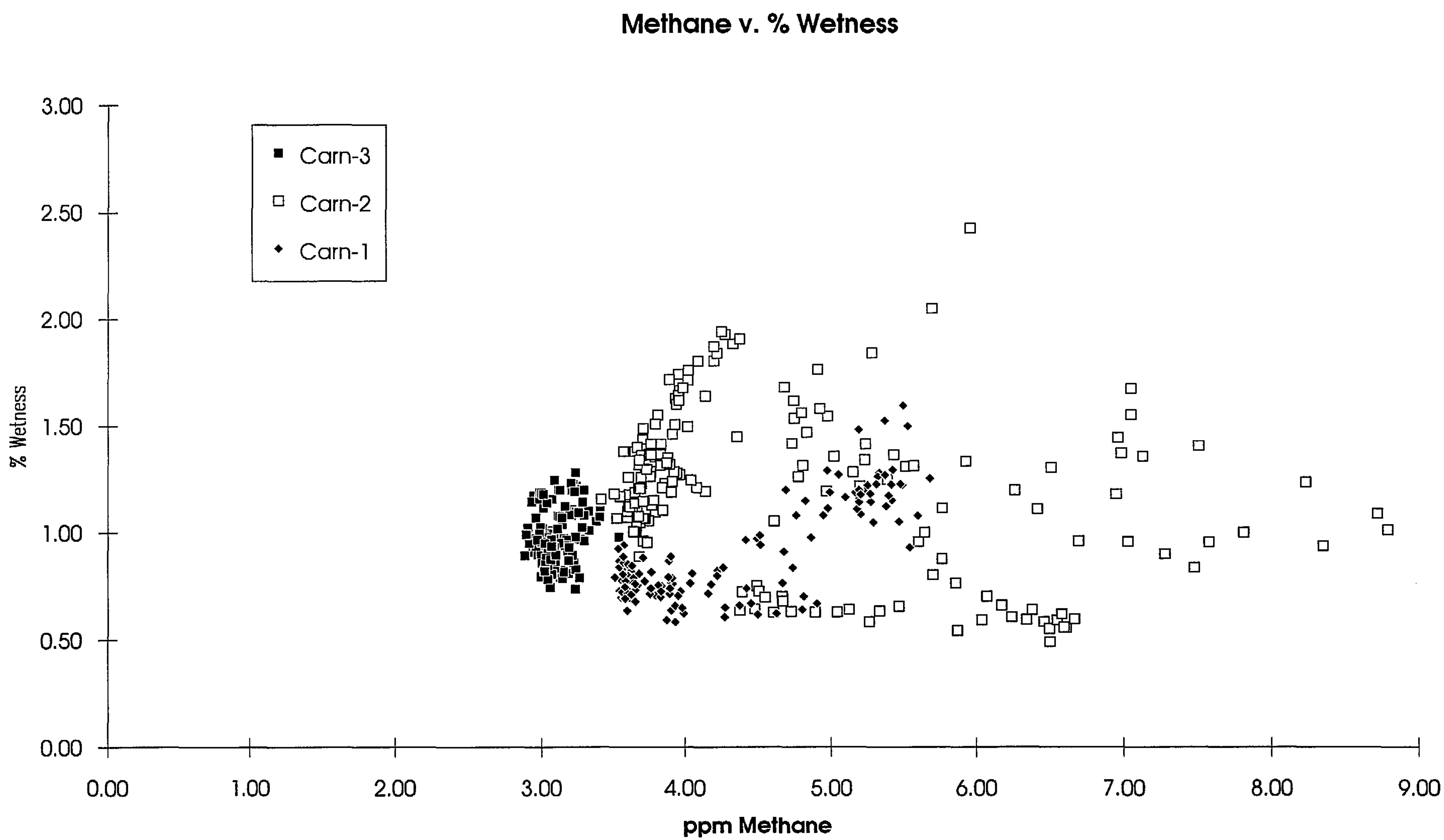


Figure 18. Methane versus percent hydrocarbon wetness for survey lines Carn-1, 2,3.

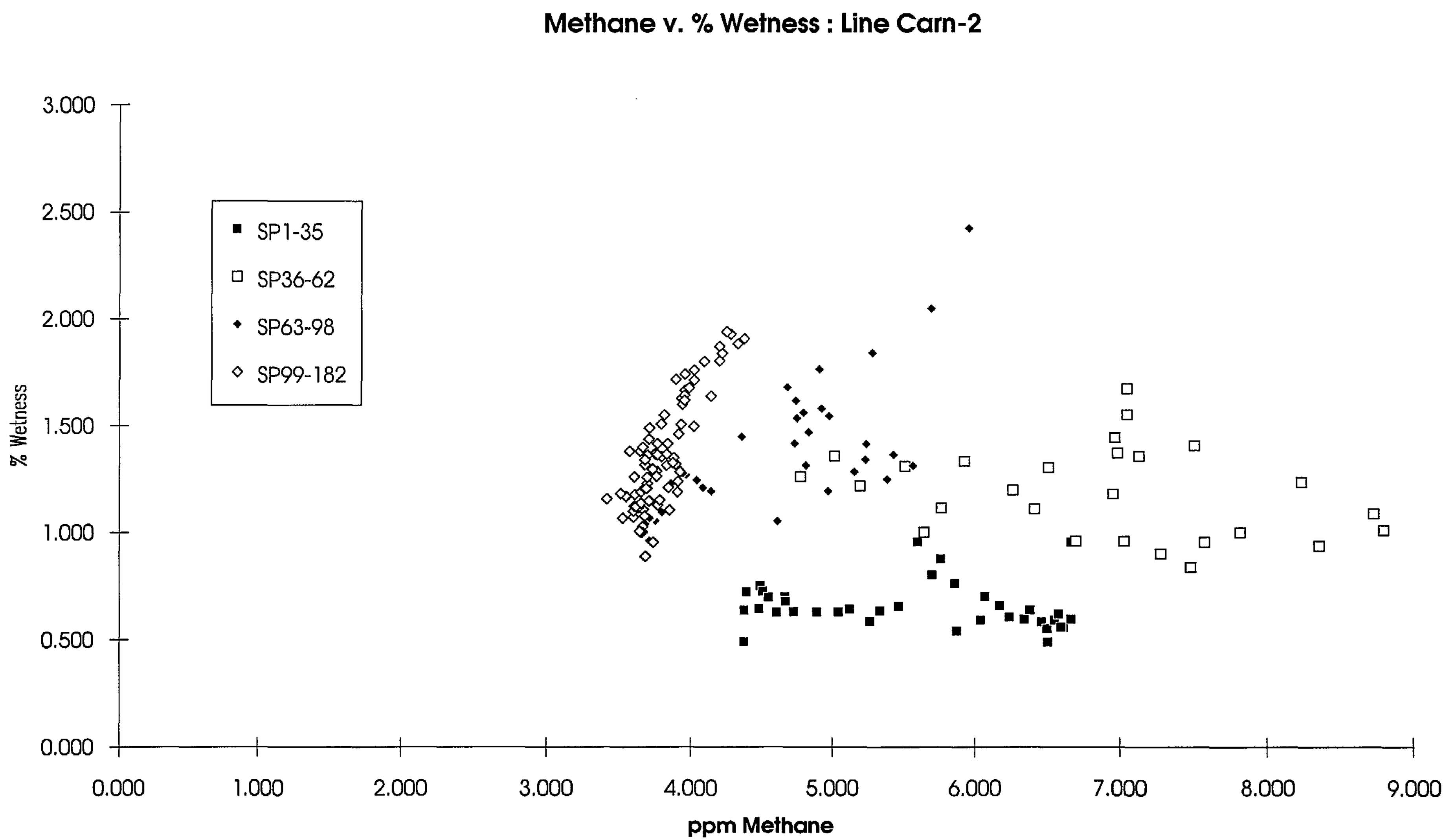


Figure 19. Methane versus percent hydrocarbon wetness for survey line Carn-2.

<u>APPENDIX I</u>

Individual line plots and line summary sheets,

Carnarvon survey lines 1 through 5.

Line Summary

Line Number	carn1
No. of Shotpoints	139

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	29-Jul-89	16:23:34	21	33.061	114	59.853
End	139	29-Jul-89	20:59:29	21	26.760	115	05.159

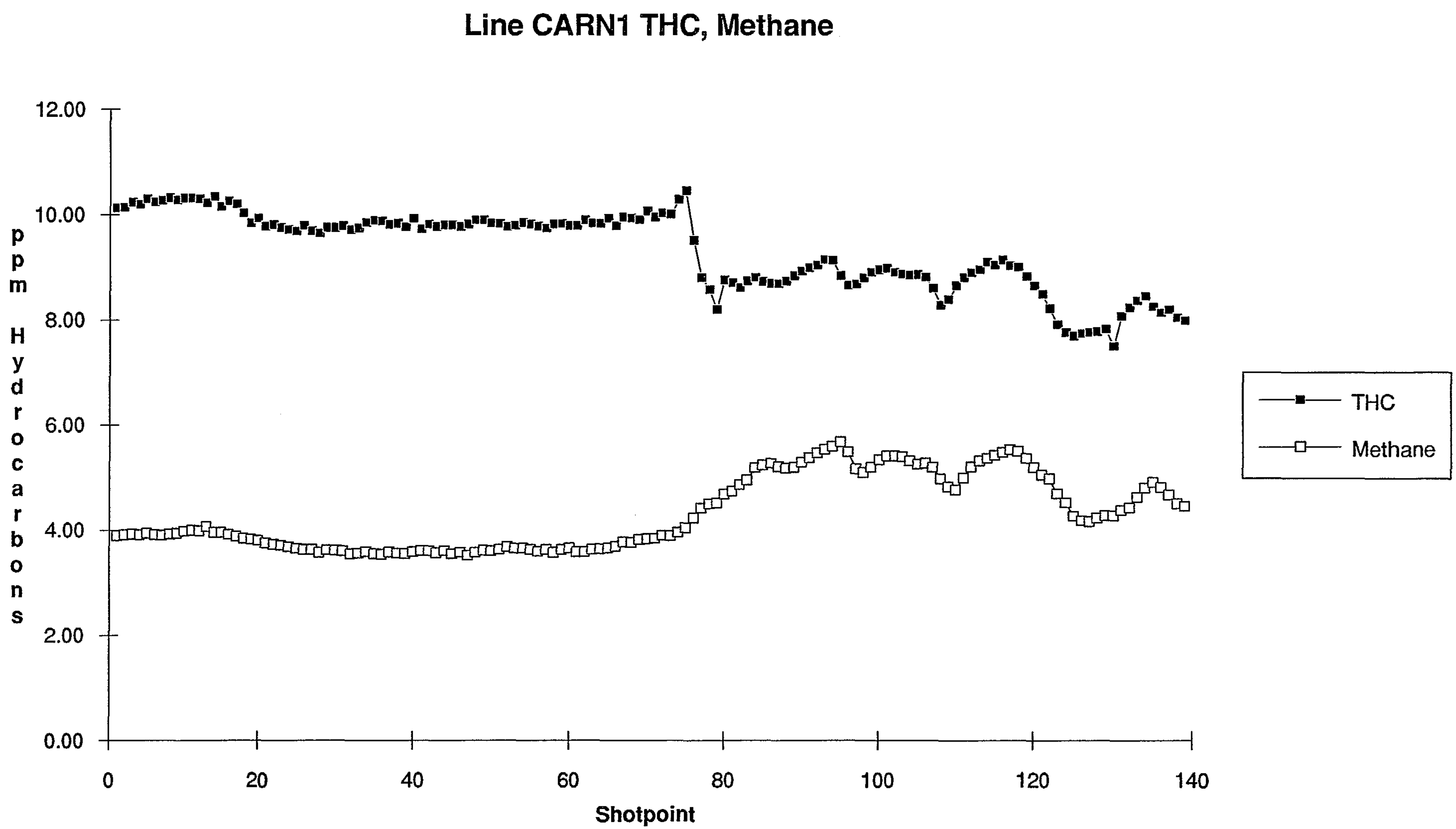
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.316	4.299	0.024	0.083	0.016	0.034	0.000	0.000					0.895
Std. Dev.	0.753	0.702	0.014	0.007	0.003	0.003	0.000	0.000					0.227
Minimum	7.504	3.514	0.011	0.067	0.010	0.022	0.000	0.000					0.582
Maximum	10.452	5.678	0.065	0.101	0.026	0.043	0.000	0.001					1.594

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean		23.265	10.000	20.763	10.763
Std. Dev.		0.430	0.000	1.107	1.107
Minimum		22.540	10.000	18.000	8.000
Maximum		23.810	10.000	27.000	17.000

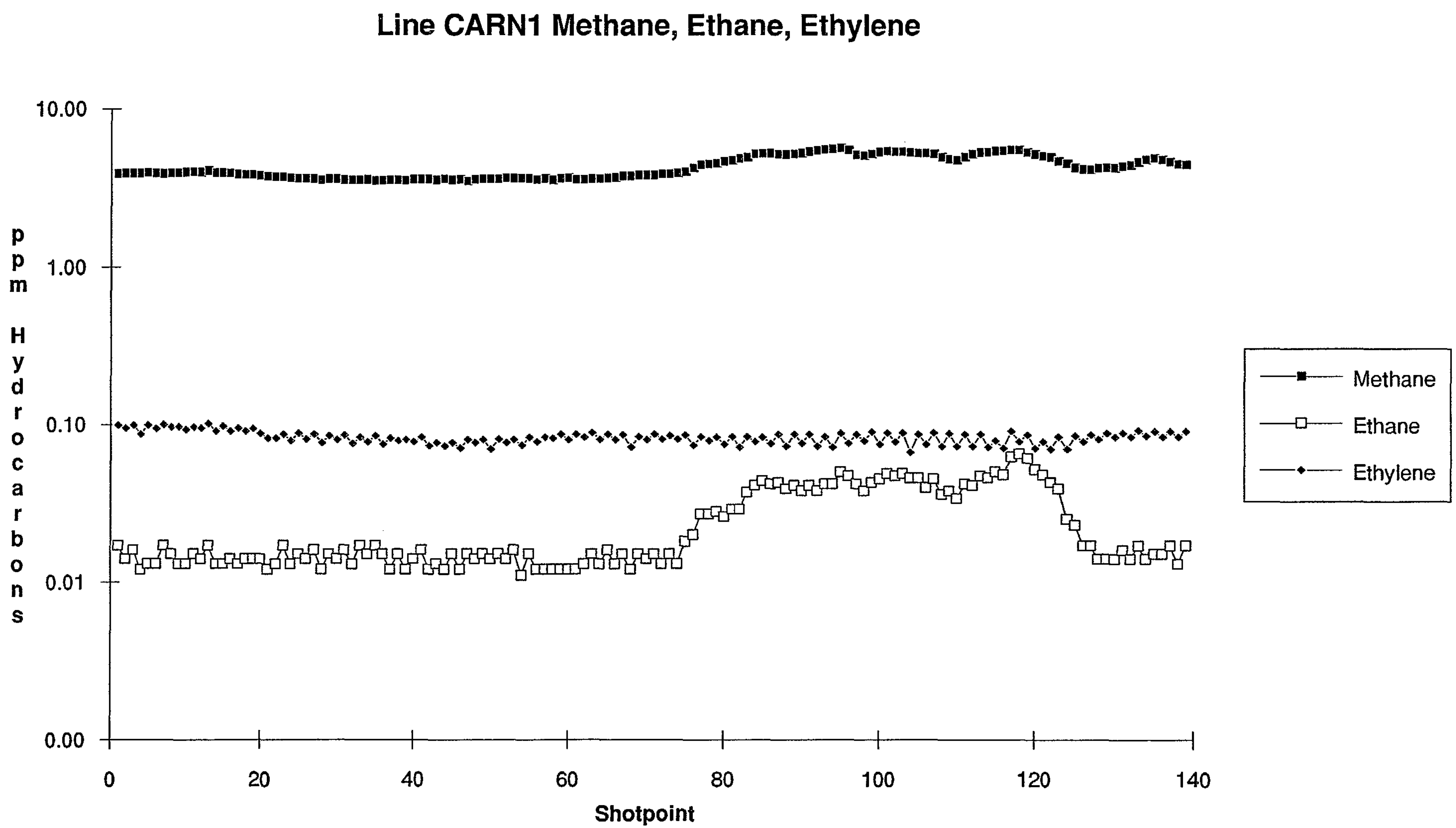
Notes

Methane and ethane anomaly towards end of line

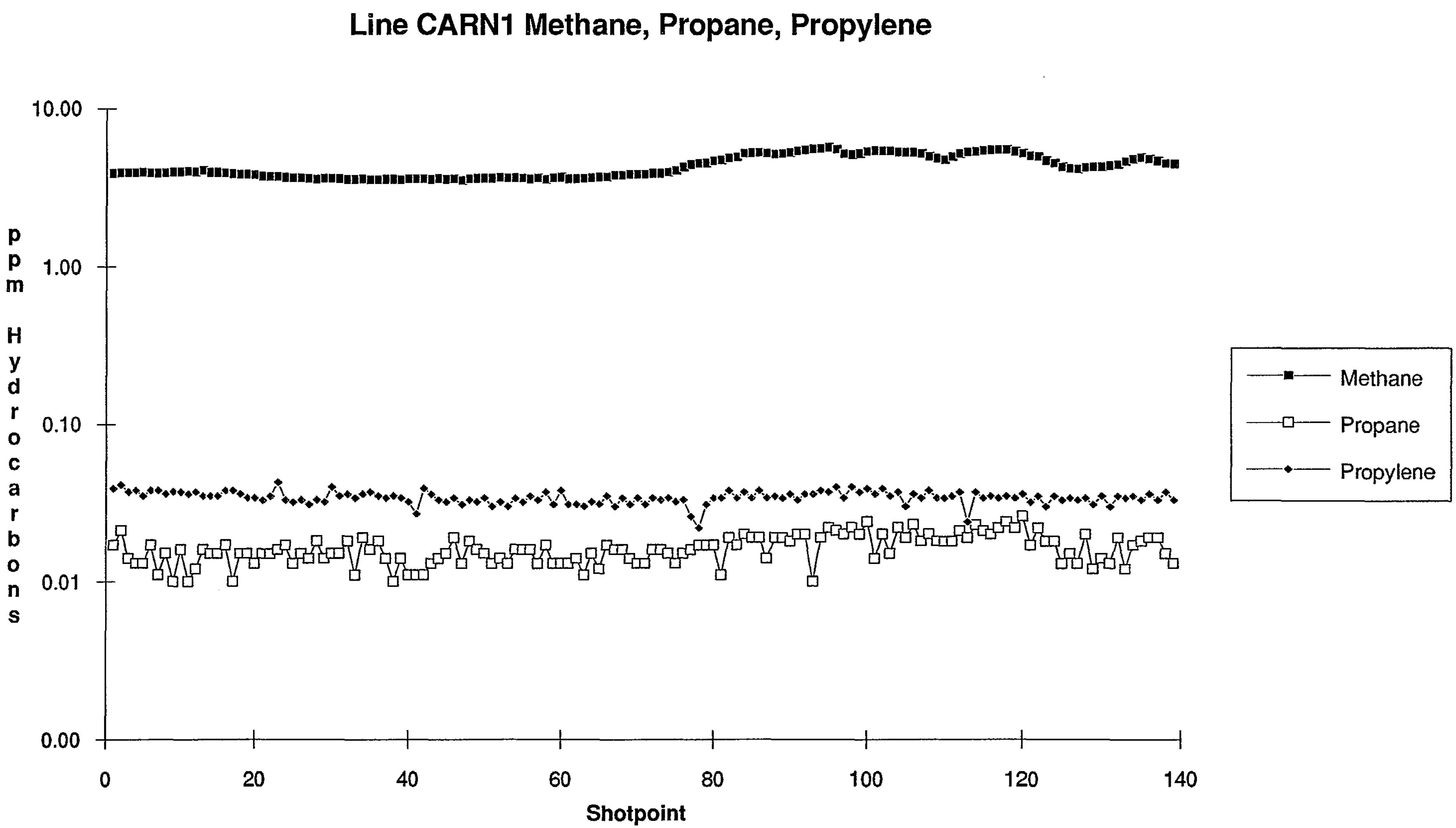
No conductivity data were collected



Line CARN1 THC, Methane
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
Shotpoint
THC
Methane

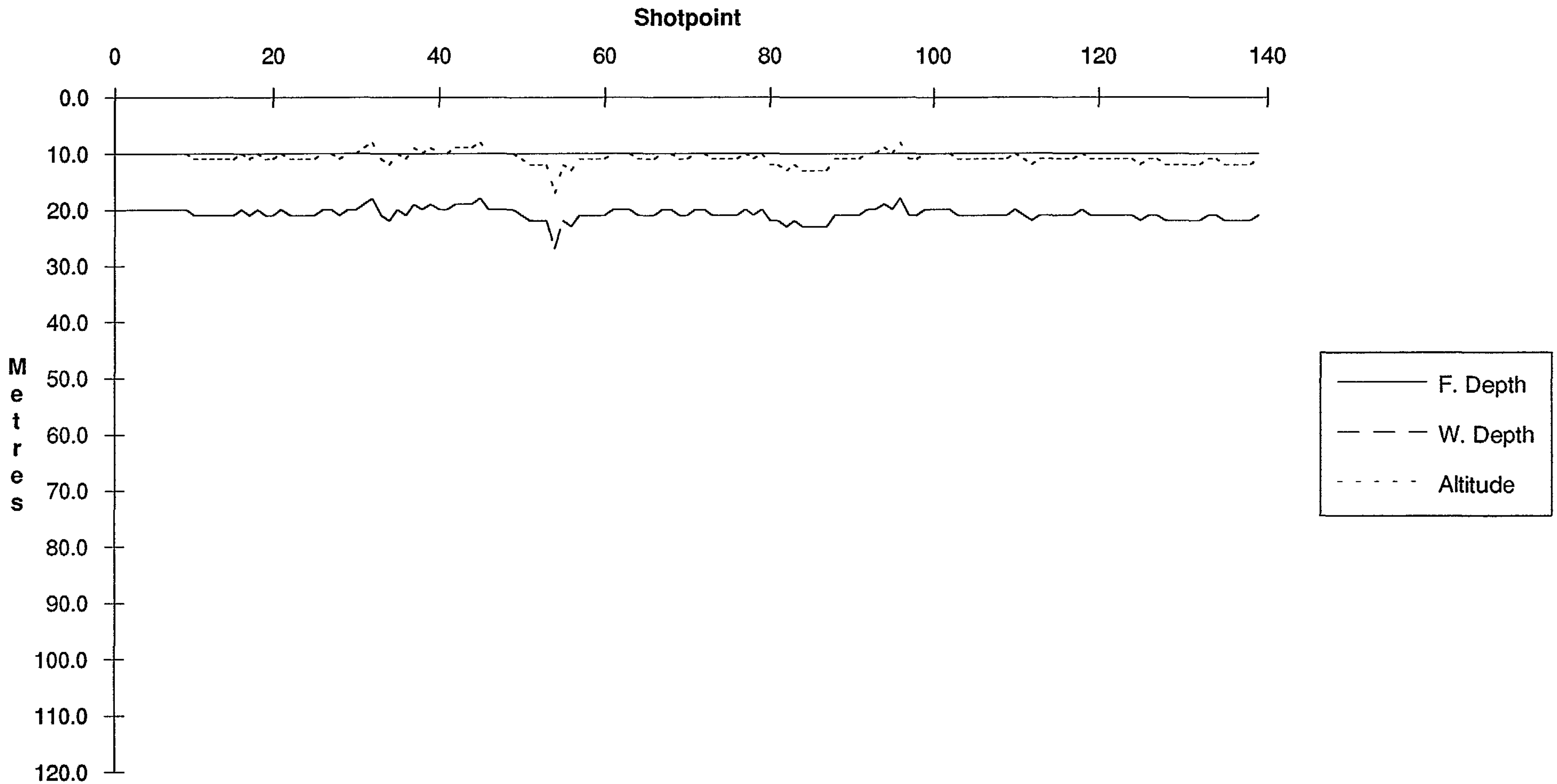


Line CARN1 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
Shotpoint
Methane
Ethane
Ethylene



Line CARN1 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
Shotpoint
Methane
Propane
Propylene

Line CARN1 Depths, Altitude



Line Summary

Line Number	carn2
No. of Shotpoints	182

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	29-Jul-89	21:11:06	21	26.289	115	04.642
End	182	30-Jul-89	03:19:22	20	57.253	115	10.015

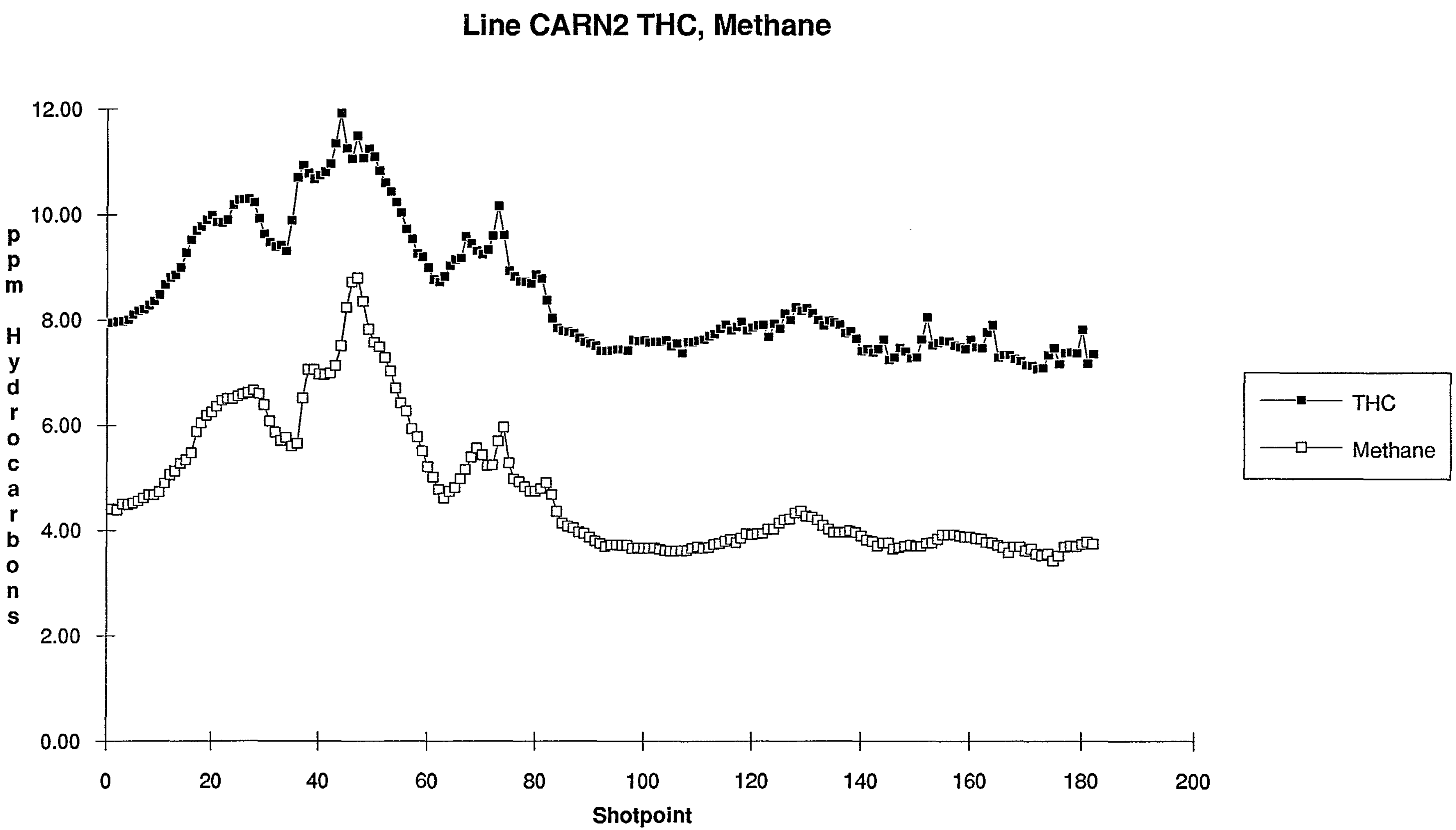
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.508	4.748	0.032	0.074	0.024	0.037	0.000	0.000					1.200
Std. Dev.	1.202	1.265	0.016	0.007	0.007	0.004	0.000	0.000					0.364
Minimum	7.072	3.417	0.013	0.059	0.011	0.026	0.000	0.000					0.490
Maximum	11.914	8.792	0.100	0.091	0.048	0.052	0.000	0.000					2.425

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean		22.442	6.637	19.493	12.855
Std. Dev.		0.470	8.483	10.138	2.612
Minimum		21.890	0.000	4.000	1.000
Maximum		23.560	30.000	65.800	35.800

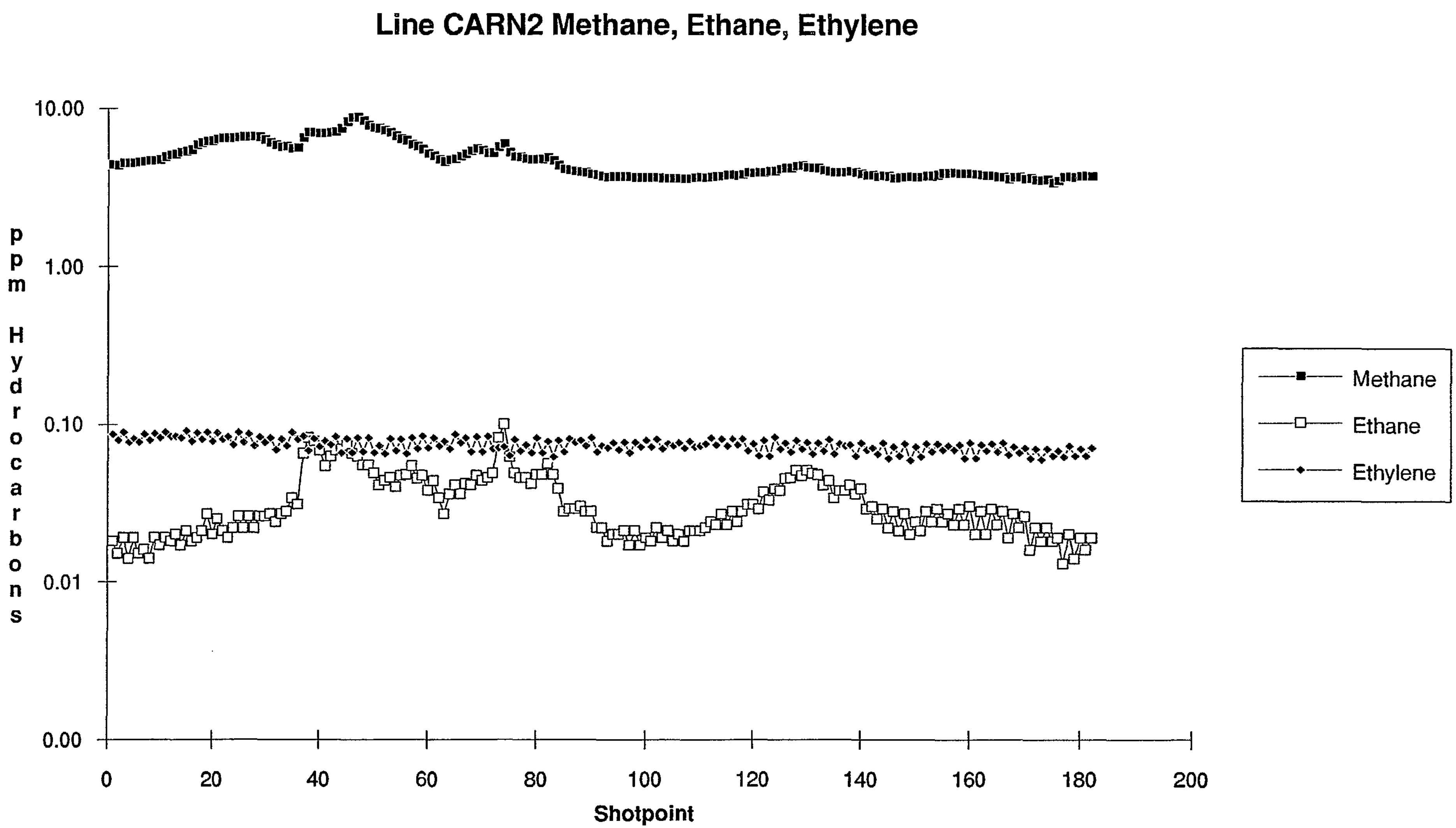
Notes

THC, methane, ethane and slight propane anomalies at SP 20 to 80, corresponding with South Chervil and Chervil fields

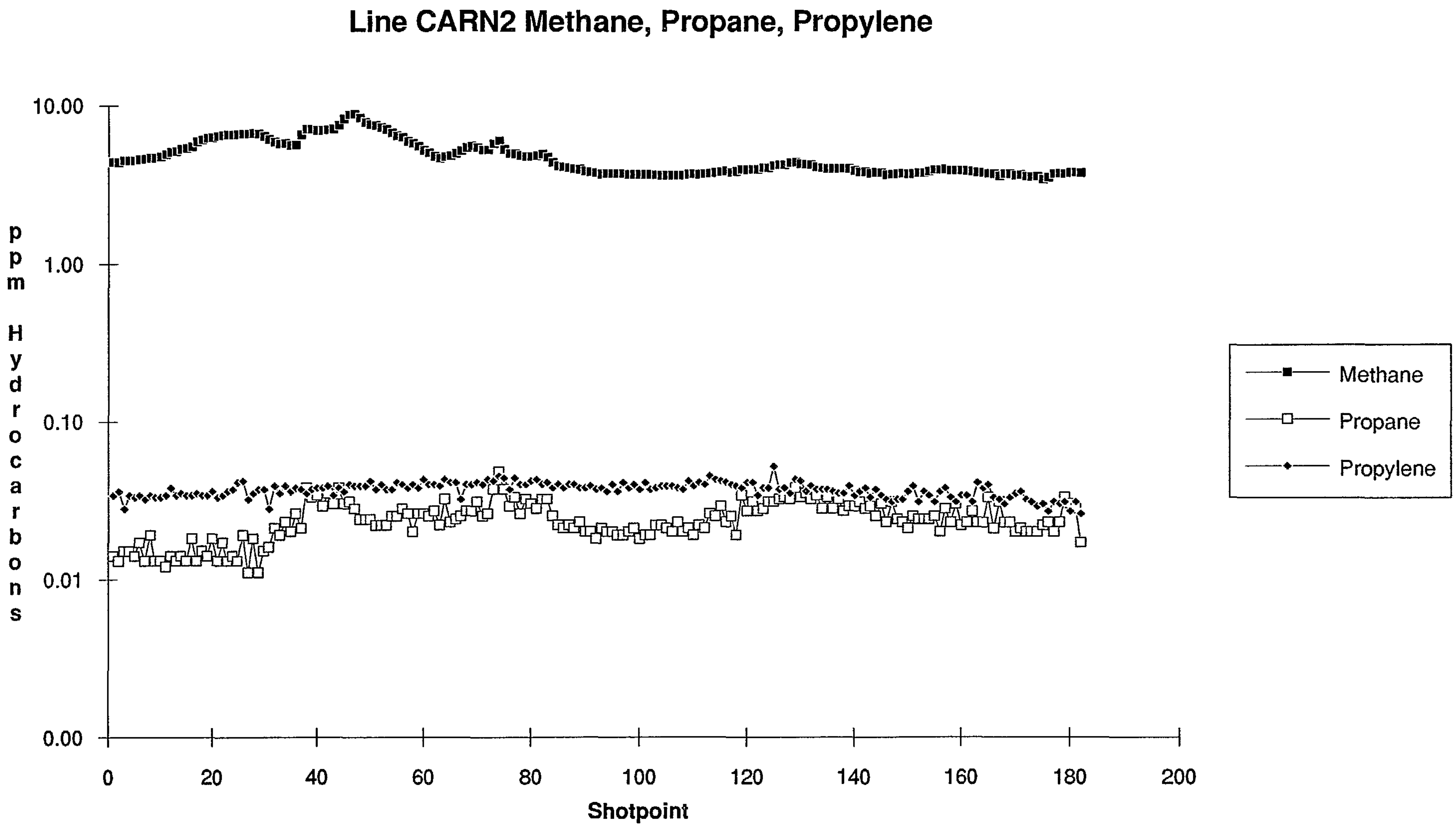
Weak anomaly at SP129 near North Herald and South Pepper accumulations



Line CARN2 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
20
40
60
80
100
120
140
160
180
200
Shotpoint
THC
Methane

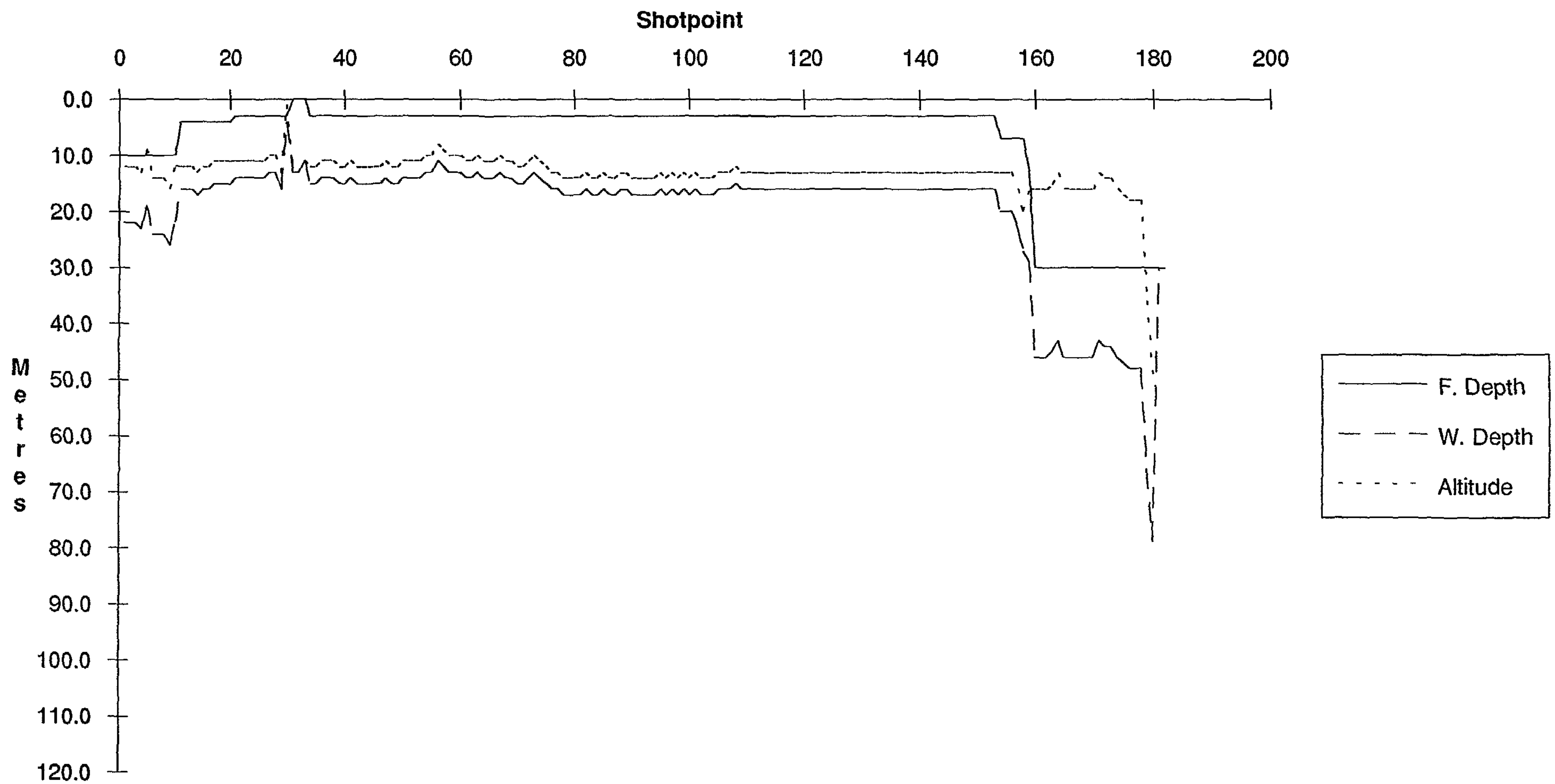


Line CARN2 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
160
180
200
Shotpoint
Methane
Ethane
Ethylene



Line CARN2 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
160
180
200
Shotpoint
Methane
Propane
Propylene

Line CARN2 Depths, Altitude



Line Summary

Line Number	carn3
No. of Shotpoints	140

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	30-Jul-89	03:23:42	20	57.308	115	09.784
End	140	30-Jul-89	08:03:37	21	02.625	114	41.535

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	6.769	3.107	0.013	0.064	0.017	0.024	0.000	0.000					0.978
Std. Dev.	0.202	0.119	0.002	0.004	0.004	0.003	0.000	0.001					0.130
Minimum	5.981	2.889	0.010	0.050	0.012	0.018	0.000	0.000					0.735
Maximum	7.484	3.542	0.019	0.072	0.027	0.037	0.004	0.006					1.280

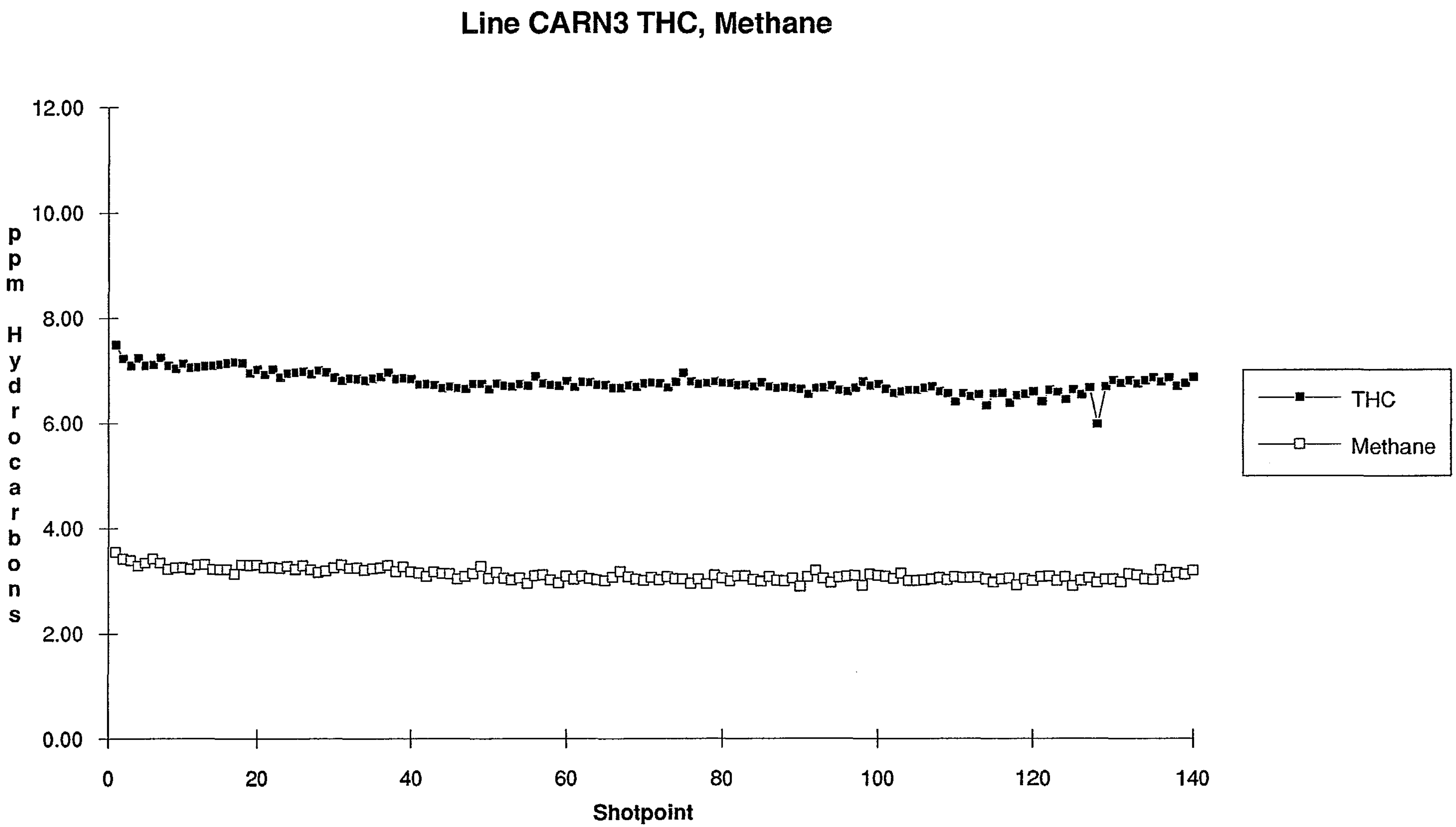
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean		23.304	14.000	39.930	25.930
Std. Dev.		0.171	0.000	8.229	8.229
Minimum		22.970	14.000	34.000	20.000
Maximum		23.610	14.000	64.000	50.000

Notes

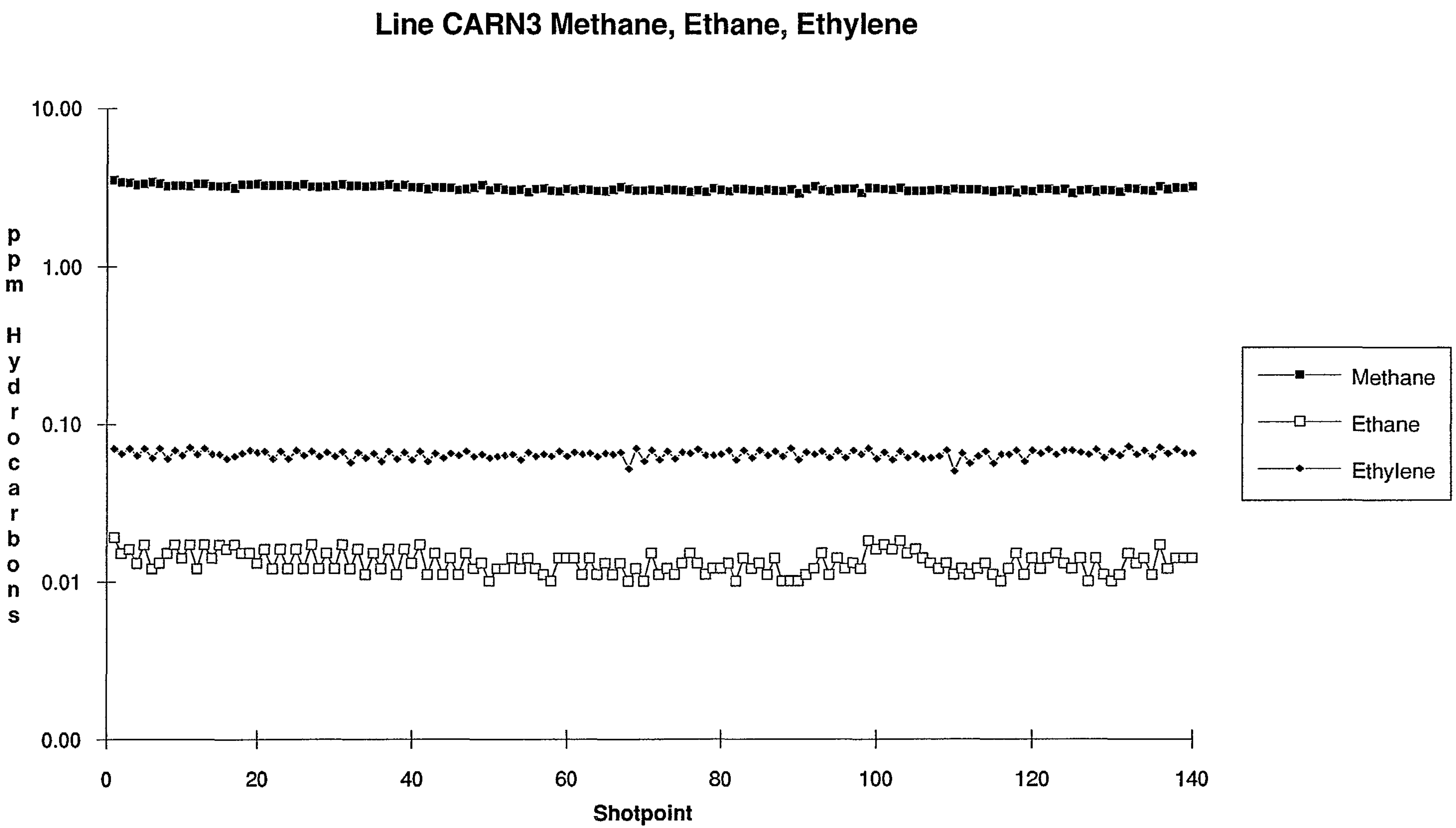
No hydrocarbon anomalies

No conductivity data

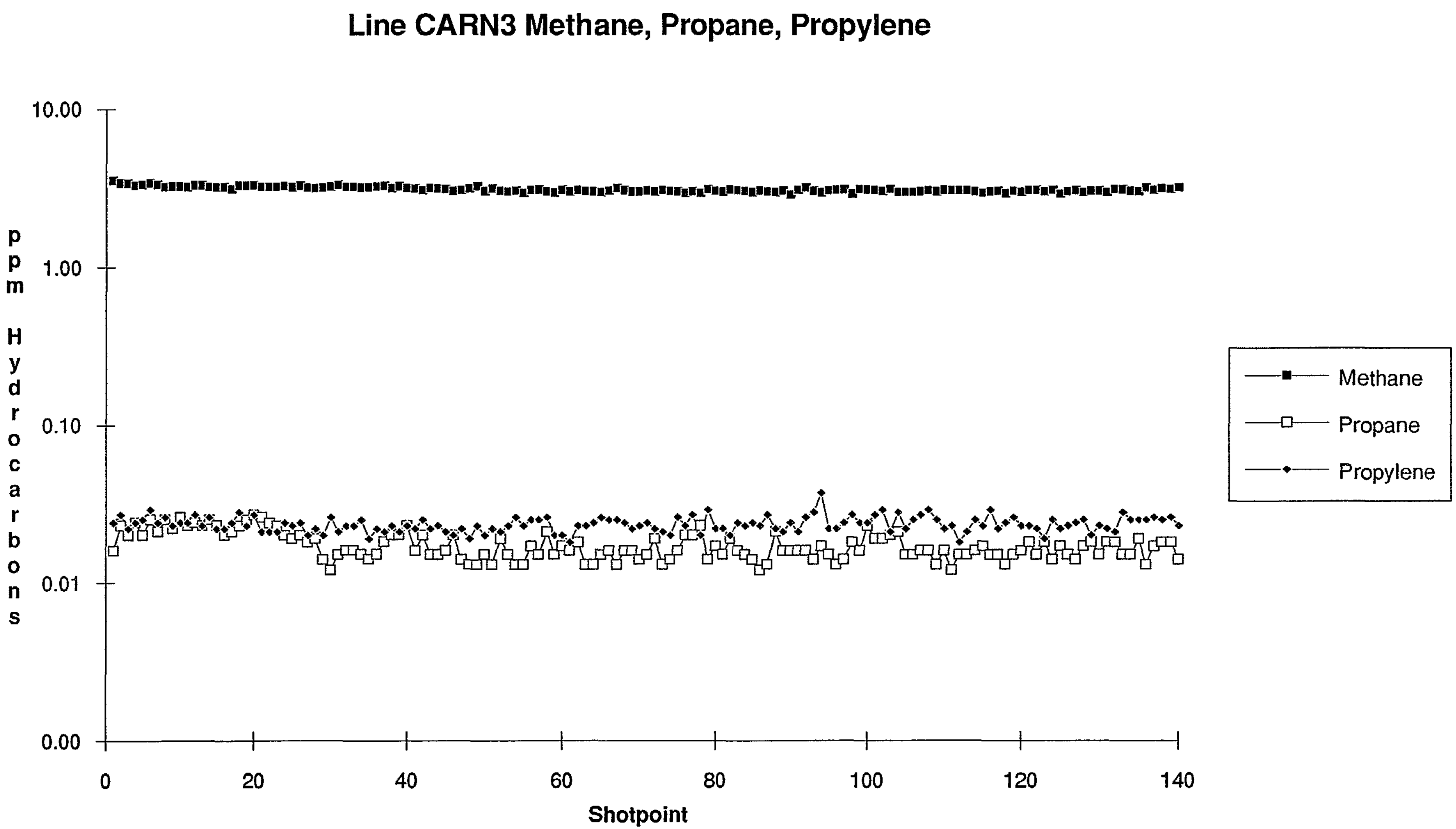
No water depth of fish altitude data after SP58



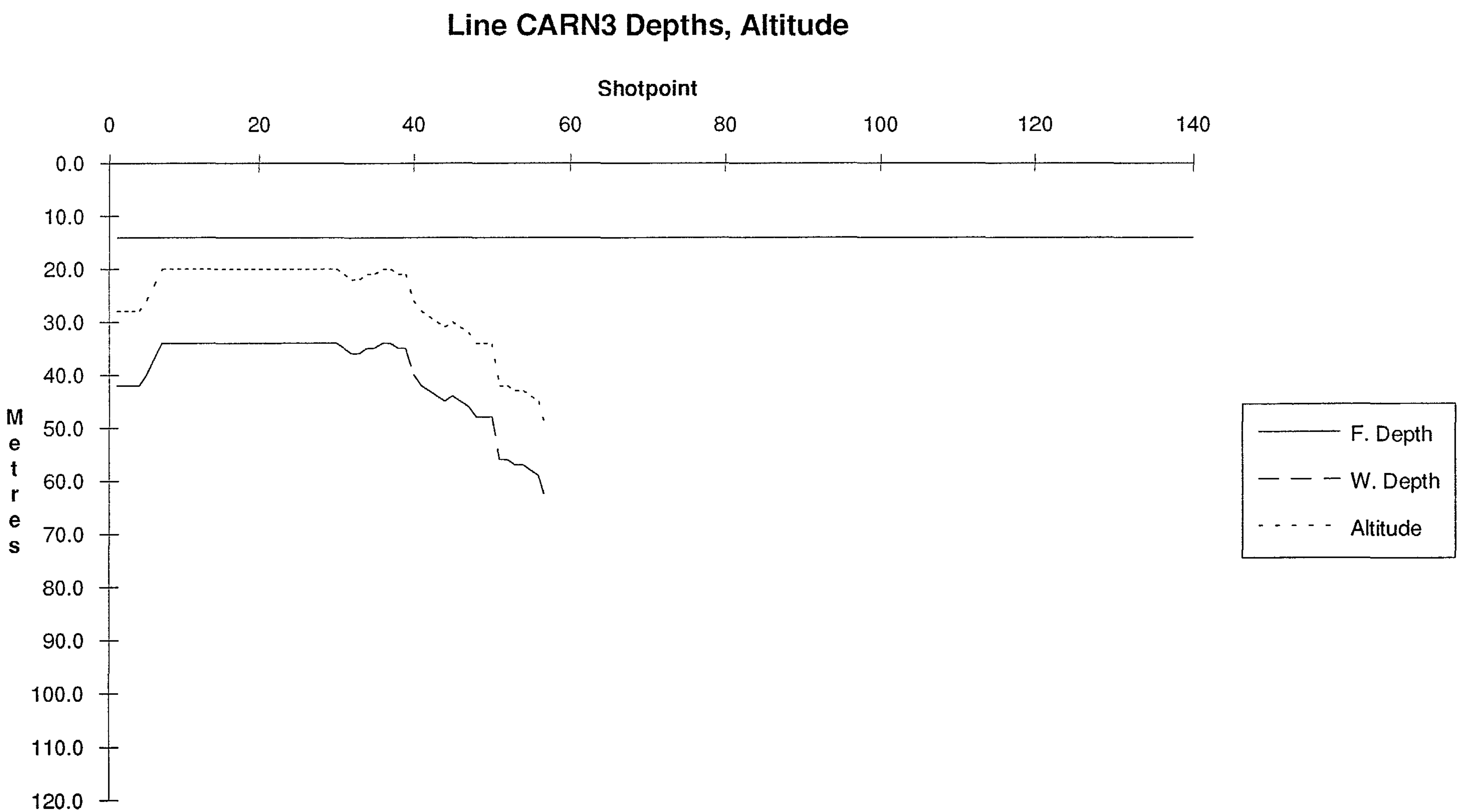
Line CARN3 THC, Methane
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
Shotpoint
THC
Methane



Line CARN3 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
Shotpoint
Methane
Ethane
Ethylene



Line CARN3 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Propane
Propylene



Line CARN3 Depths, Altitude
Shotpoint
0
20
40
60
80
100
120
140
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	carn4
No. of Shotpoints	67

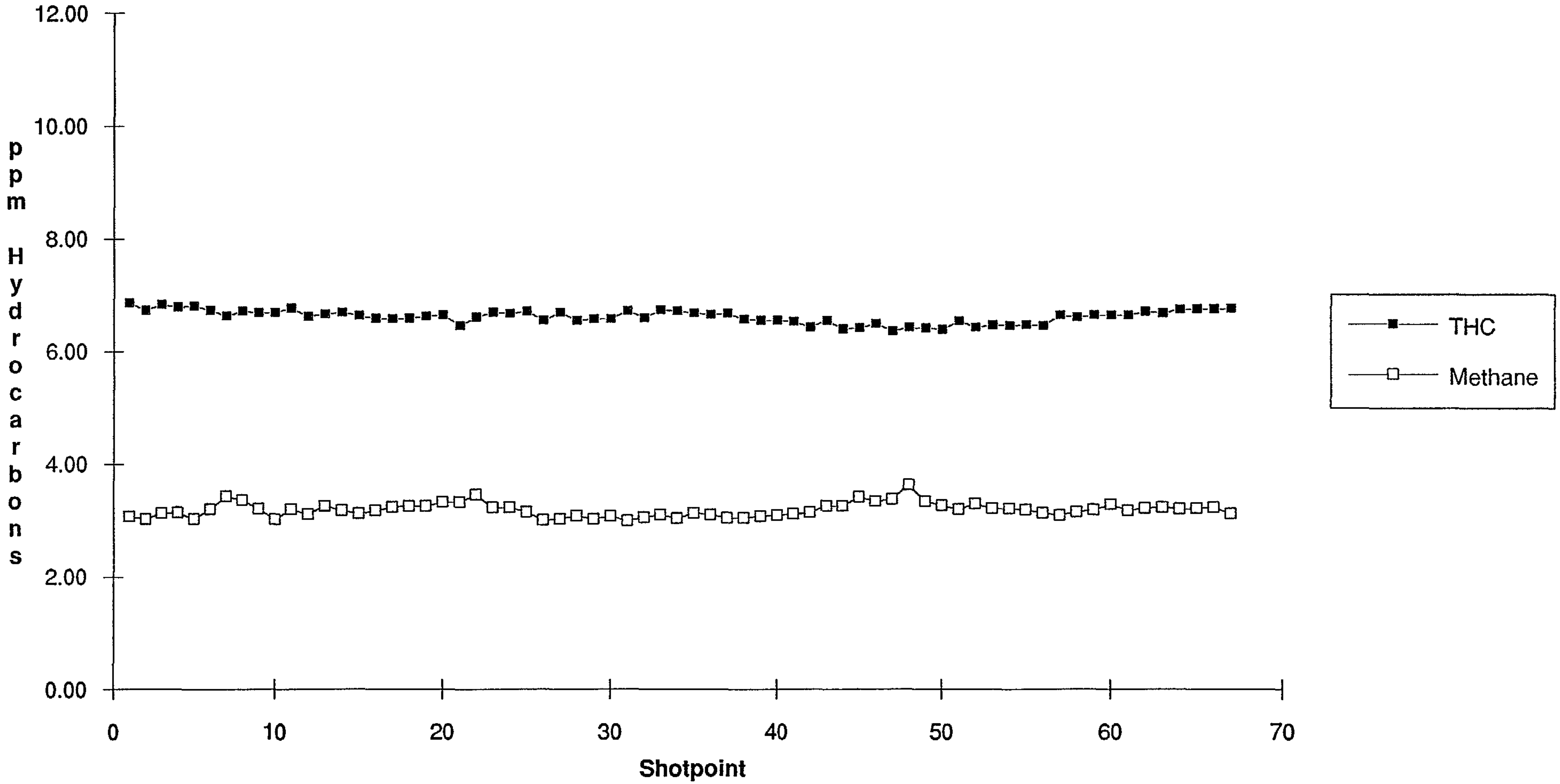
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	30-Jul-89	08:05:36	21	02.607	114	41.135
End	67	30-Jul-89	10:17:39	21	12.510	114	38.052

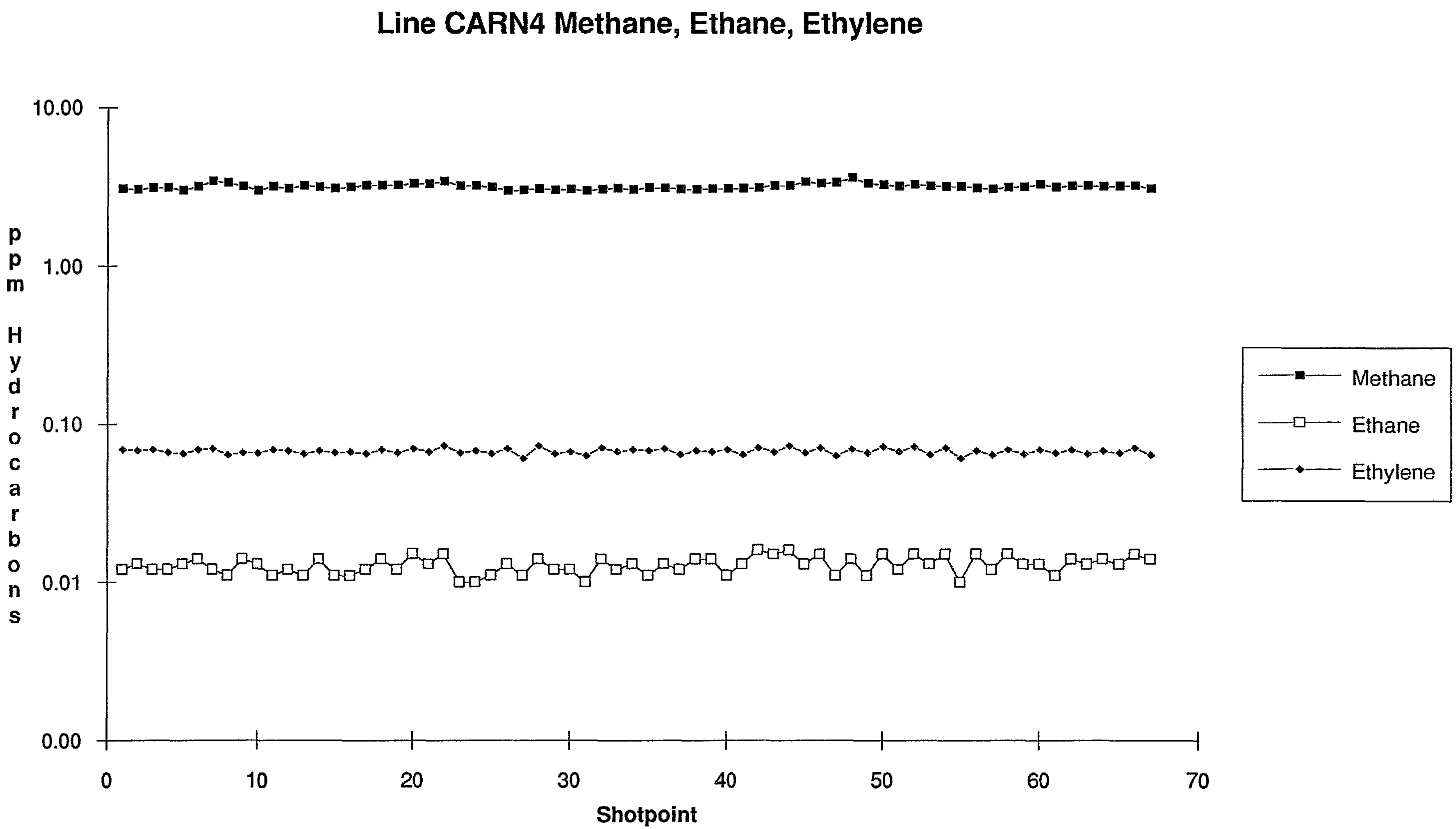
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	6.614	3.179	0.013	0.067	0.017	0.023	0.000	0.000					0.925
Std. Dev.	0.120	0.122	0.002	0.003	0.003	0.003	0.000	0.000					0.095
Minimum	6.361	2.990	0.010	0.061	0.011	0.018	0.000	0.000					0.728
Maximum	6.856	3.624	0.016	0.073	0.024	0.030	0.003	0.001					1.190

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean		24.030	130.000	157.955	27.955
Std. Dev.		0.244	0.000	8.925	8.925
Minimum		23.560	130.000	140.000	10.000
Maximum		24.310	130.000	168.000	38.000

Notes
No hydrocarbon anomalies
No conductivity data

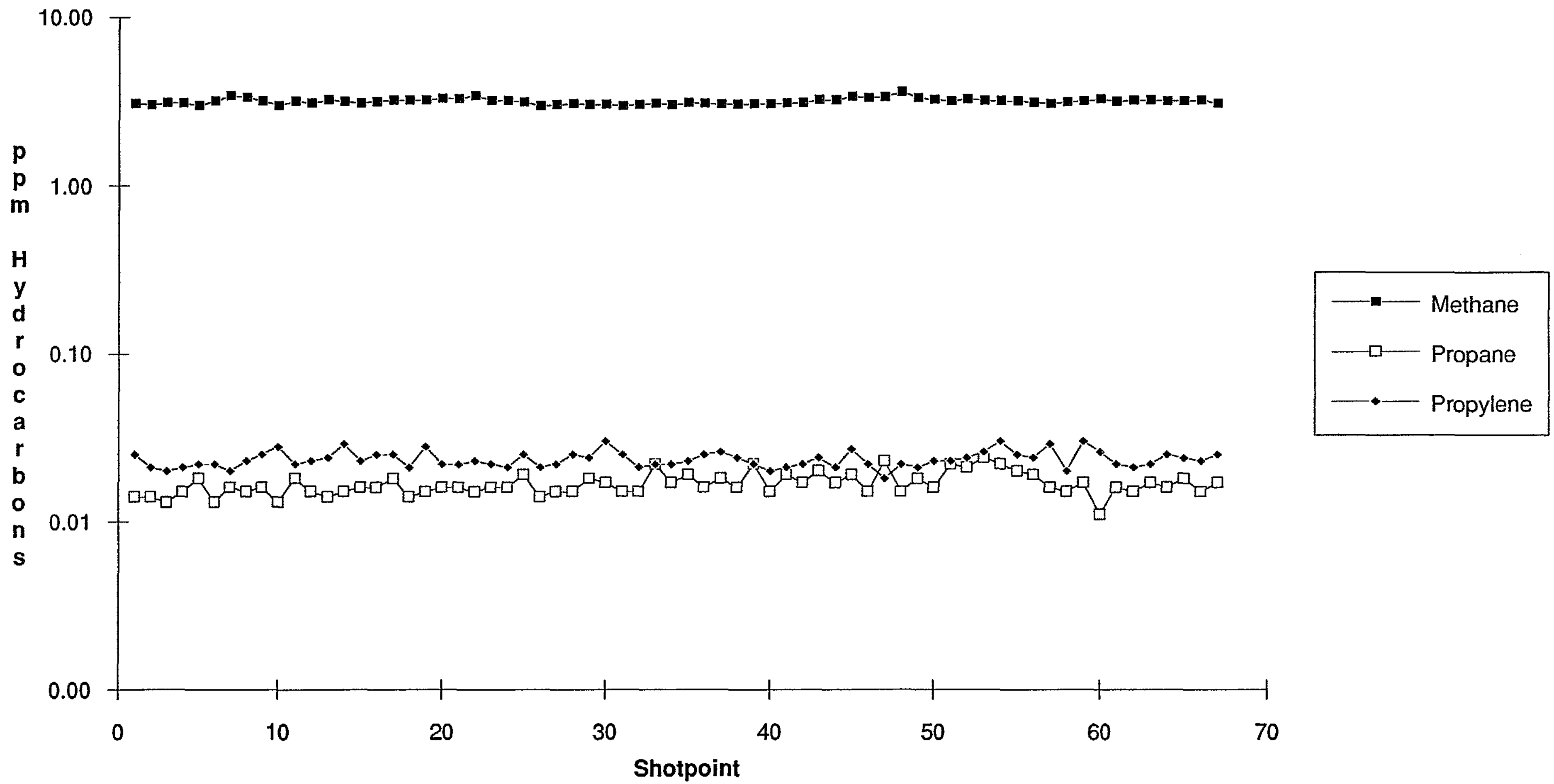
Line CARN4 THC, Methane



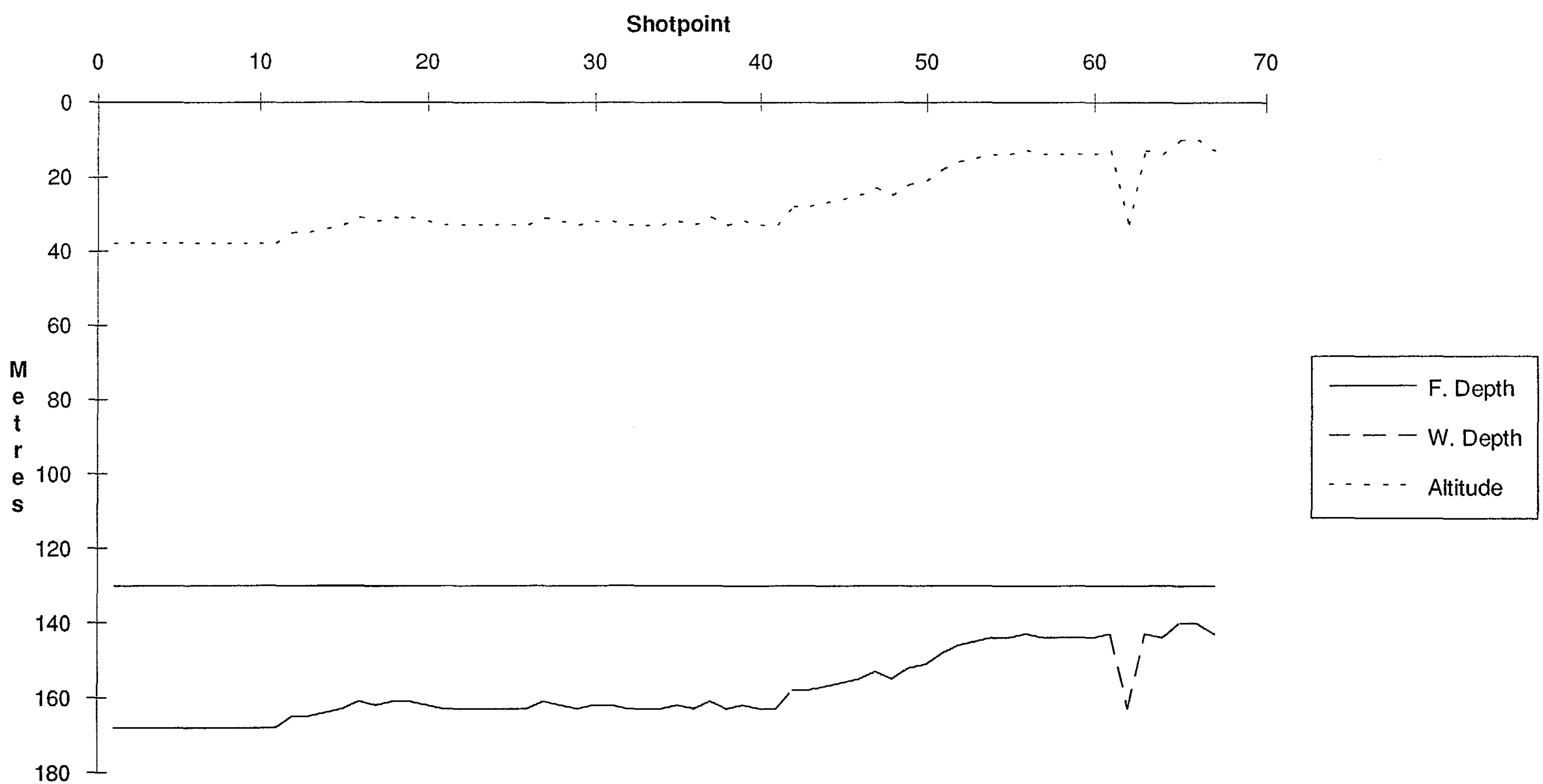


Line CARN4 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
10
20
30
40
50
60
70
Shotpoint
Methane
Ethane
Ethylene

Line CARN4 Methane, Propane, Propylene



Line CARN4 Depths, Altitude



Line Summary

Line Number	carn5
No. of Shotpoints	238

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	30-Jul-89	18:50:57	20	36.732	114	50.379
End	238	31-Jul-89	02:44:47	20	09.914	115	23.726

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	6.855	3.204	0.009	0.061	0.016	0.023	0.005	0.000					0.932
Std. Dev.	0.372	0.253	0.001	0.004	0.003	0.002	0.012	0.000					0.445
Minimum	6.294	2.954	0.006	0.051	0.011	0.018	0.000	0.000					0.524
Maximum	7.782	3.916	0.014	0.069	0.026	0.032	0.051	0.002					2.558

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean		24.522	66.218	75.752	18.082
Std. Dev.		0.274	7.490	17.317	9.827
Minimum		23.780	50.000	61.000	10.000
Maximum		24.830	70.000	119.000	49.000

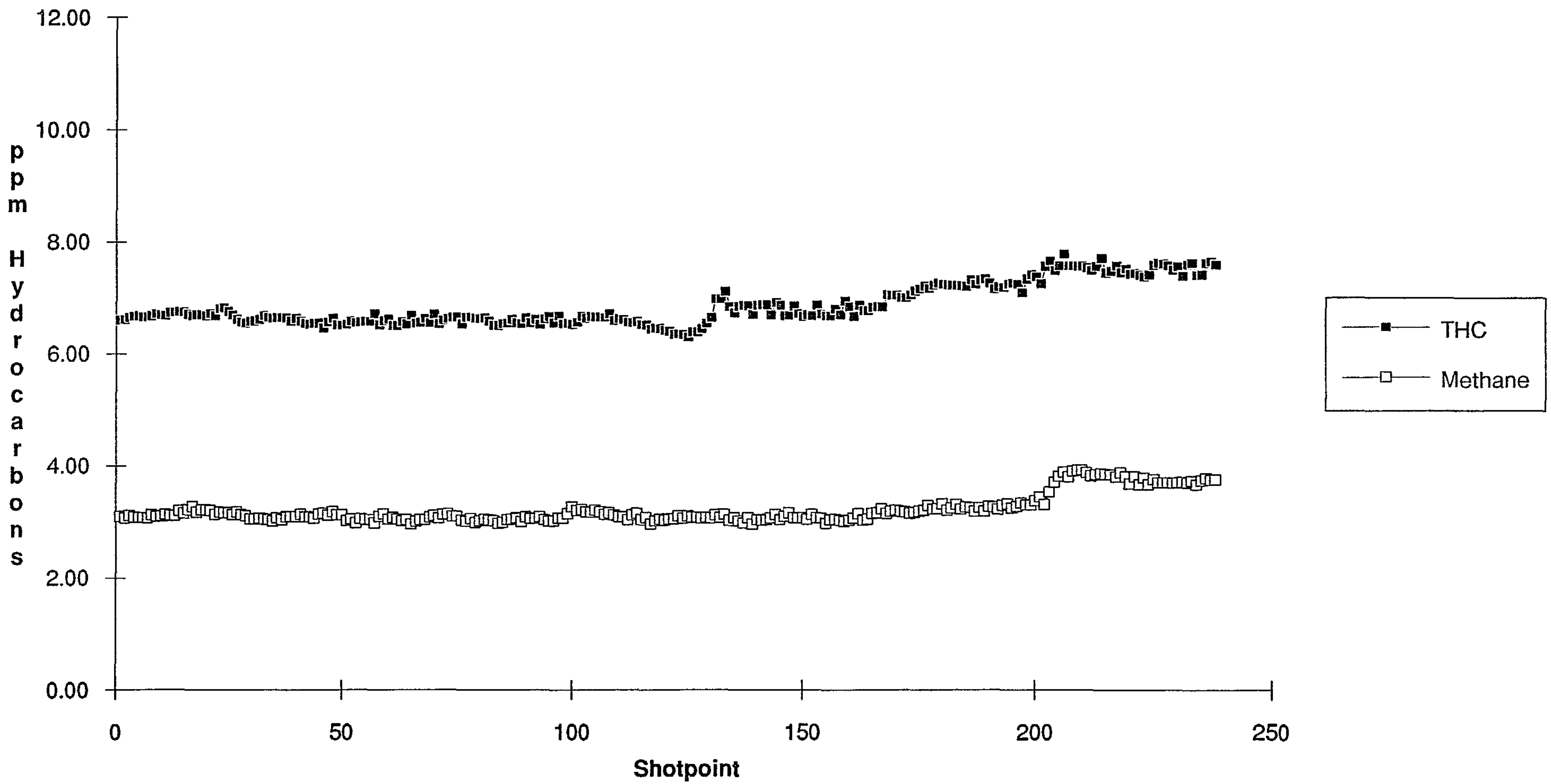
Notes

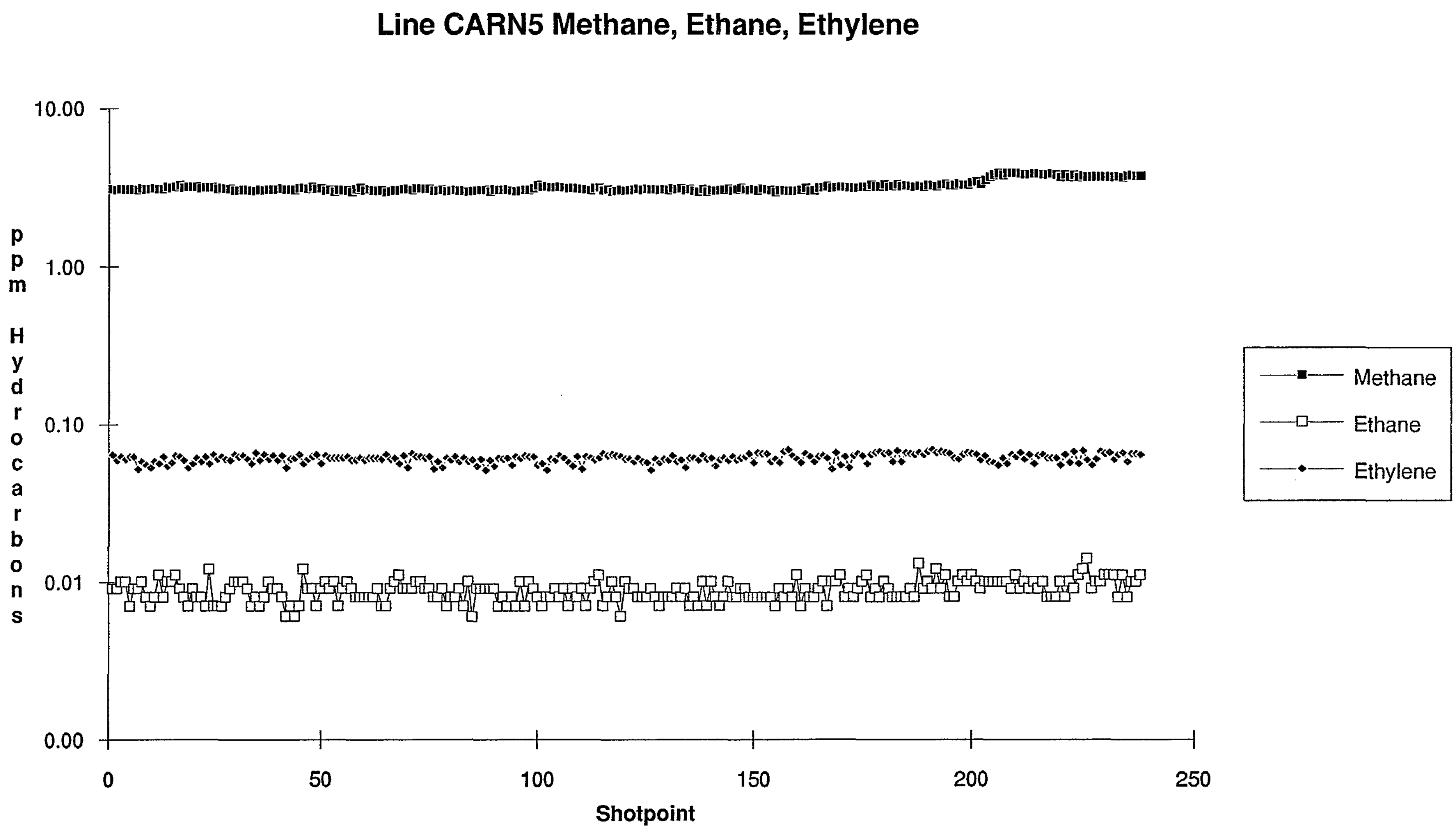
I-butane anomaly SPs 39-90, in the vicinity of Central Gorgon and North Gorgon

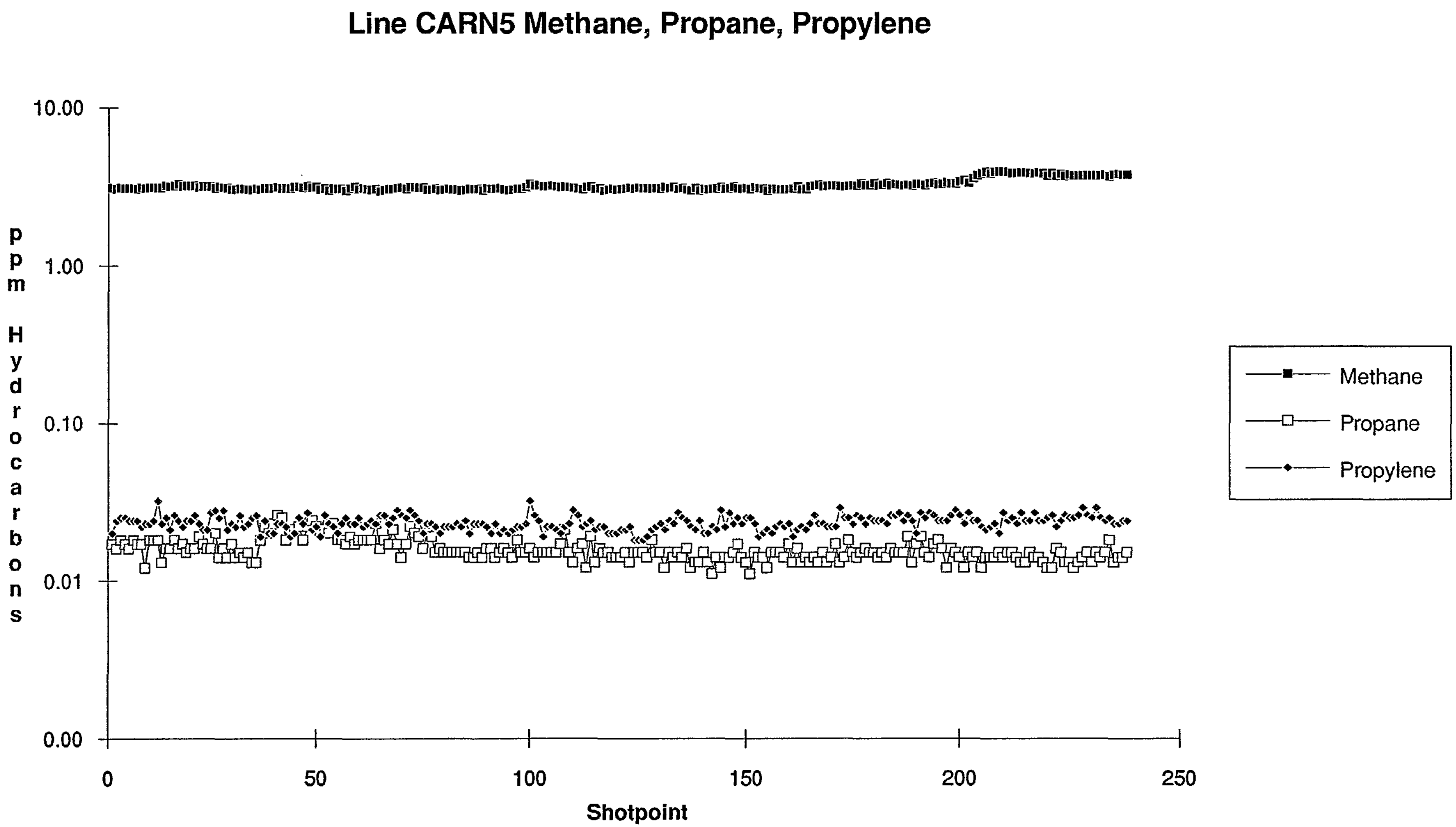
No conductivity data

No water depth and altitude data between SP6 and SP170

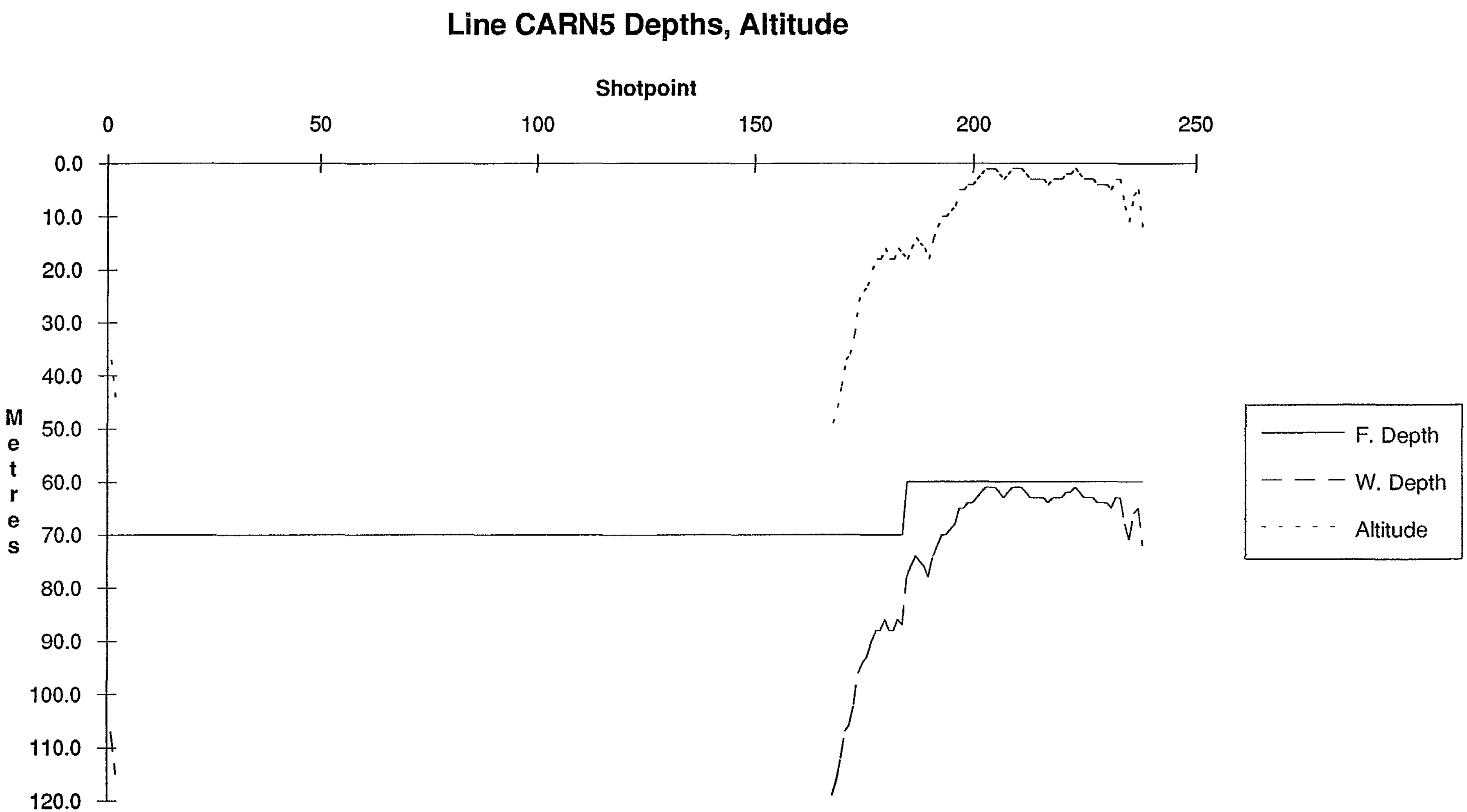
Line CARN5 THC, Methane




Line CARN5 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
Shotpoint
Methane
Ethane
Ethylene



Line CARN5 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
Shotpoint
Methane
Propane
Propylene


Line CARN5 Depths, Altitude
Shotpoint
0
50
100
150
200
250
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
Metres
F. Depth
W. Depth
Altitude

APPENDIX II

DHD METHODOLOGY

Direct hydrocarbon detection in bottom-water (DHD) is accomplished with the equipment schematically shown in Figure II-1. The equipment comprises four major components.

(1) The over-the-side gear includes a towed 'fish' fitted with a submersible pump which delivers seawater to the geochemical laboratory on the ship via a hollow cable. A conductivity/temperature/depth sensor (CTD) in the 'fish' measures the depth of the 'fish' as well as the temperature and salinity of the seawater (to relate the depth of sampling to the depth of the thermocline, to detect hydrographic 'fronts', and to detect sub-seafloor freshwater aquifers that may drain through sedimentary layers from the continent). A sonar measures and continuously displays the altitude of the 'fish' above the seafloor allowing the operator to maintain the 'fish' at an altitude of about 10 m.

(2) A hollow cable (consisting of medical grade nylon tubing wrapped with insulated conductors which both transmit power to the fish and relay CTD and sonar data from the 'fish') delivers bottom-water to the geochemical laboratory. The tubing and conductors are wrapped in a stainless steel braid. Plastic fairings, which are attached to the cable to reduce frictional drag, allow the 'fish' to be towed almost directly beneath the ship.

(3) The analytical equipment includes a gas extraction unit and gas chromatographs connected in parallel to measure the concentrations of a variety of (C_1-C_8) hydrocarbons extracted from the seawater. The total hydrocarbon concentrations are measured every 30 seconds or at a ship speed of 5 knots, a distance of about 75 m on

the seafloor. The light hydrocarbons (C_1-C_4) are measured at 2 minute intervals (approximately 300 m on the seafloor), whereas the C_5-C_8 hydrocarbons are measured every 8 minutes (approximately 1200 m). Sub-samples of extracted gas may be taken and stored for subsequent shore-based isotopic analyses.

(4) The data acquisition system is PC based: all data is displayed, edited and stored in a database for plotting at sea.

The towed 'fish' is deployed over the stern from the M.V. Mermaid Searcher. Echo sounder data and GPS navigation are displayed in the laboratory and these provide clues to the locations of surface expressions of gas seeps on the seafloor. All data are recorded continuously so that any hydrocarbon anomalies in the water column can be quickly recognised and additional measurements (or samples can be collected) if appropriate.

Detector sensitivity is < 10 parts per billion in the stripped headspace sample. Calibrations were conducted on a daily basis and were within 10% for the entire program and system blanks were less than 2 ppm for methane and 5 ppb for C_{2+} compounds.

The following parameters are measured:

Parameter	Units	Equipment Used
Total Hydrocarbon (THC)	ppm	Shimadzu GC with FID Detector using 6" Glass bead column
Methane	ppm	Shimadzu GC with FID Detector using 42" Activated alumina column
Ethane	ppm	"
Ethylene	ppm	"
Propane	ppm	"
Propylene	ppm	"
i-Butane	ppm	"
n-Butane	ppm	"
i-Pentane	ppm	Shimadzu GC with FID Detector using 30 Megabore DB1 column
n-Pentane	ppm	"
i-Hexane	ppm	Shimadzu GC with FID Detector using 30 Megabore DB1 column
n-Hexane	ppm	"
Water Depth	Metres	On-board Echo sounders
Fish Altitude	metres	Water Depth minus Fish Depth
Conductivity	mmhos/cm	Conductivity Meter
Water Temperature	°Celsius	Temperature thermistor
Fish Depth	d-bar	Pressure transducer

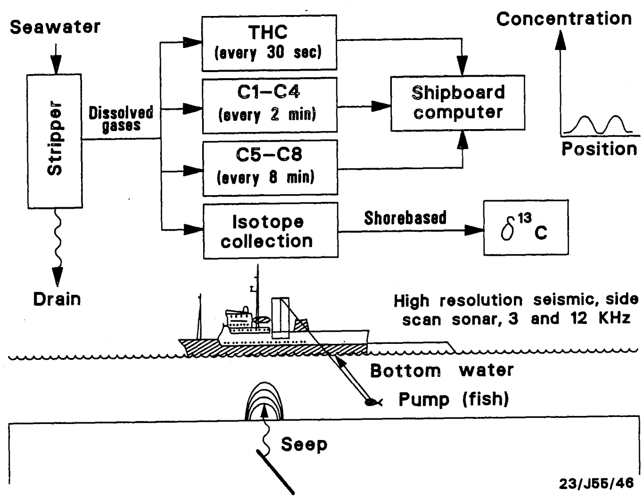


Figure II -1. Schematic of the geochemical equipment aboard Rig Seismic for the continuous profiling of hydrocarbons in seawater: the bottom-water DHD technique.

APPENDIX III

INTERPRETATIVE METHODOLOGY

The DHD equipment installed on Rig Seismic can be used for measuring hydrographic, environmental or petroliferous parameters. The light hydrocarbon data (C_1 to C_6) contained in this report can be produced by a variety of sources. These sources include biological activity associated with the degradation of organic matter in seawater and near-surface sediments and reservoired petroleum products (oil, gas and condensate). The aim of the data interpretation is to determine the origin (biogenic or thermogenic) of the light hydrocarbon gases measured, and via a variety of cross-plots of molecular and isotopic compositions of gases, to infer the 'source' (dry gas, gas-condensate or liquids) of detected seepage.

Light Hydrocarbons In Seawater

Light (C_1-C_4) and intermediate (C_5-C_8) hydrocarbons are present in seawater and sediments principally as a result of the following three processes.

(1)Thermogenic processes. The effect of heat on organic matter (catagenesis and metagenesis) buried to depths of several kilometres in sedimentary basins produces thermogenic hydrocarbons (Hunt 1979; Tissot and Welte 1984). The products of these reactions include methane and the saturated (C_2-C_8) hydrocarbons, which are the hydrocarbons mostly analysed in surface geochemical techniques. Some of the thermogenic hydrocarbons migrate to the surface, either directly from source rocks (primary migration) or indirectly, from gas, gas-condensate or liquid reservoirs (secondary migration). Hydrocarbons may migrate kilometres to permeate the near-surface sediments and seep into the overlying bottom-water resulting in thermogenic anomalies.

(2)Biological processes. Hydrocarbons are produced microbially and photochemically in seawater. In addition, during early diagenesis, a variety of hydrocarbons are produced by the activities of microbial organisms during aerobic and anaerobic destruction of organic matter which occurs primarily in the top few tens of metres of sediments. The products of these reactions include methane and minor quantities of both saturated and unsaturated hydrocarbons (Hunt 1979; Claypool & Kvenvolden 1983 and references cited therein). The presence of the unsaturated hydrocarbons, which are only produced biochemically (Primrose & Dilworth 1976; Claypool & Kvenvolden 1983), provides one criteria to distinguish between biogenic and thermogenic hydrocarbons.

These compounds produced in-situ generally occur in low concentrations as background hydrocarbons in seawater (Claypool & Kvenvolden 1983). However, high concentrations of biogenically-produced hydrocarbons may accumulate in relatively shallow-buried sediments and seep into the overlying water, resulting in biogenic anomalies (Brooks et al. 1974; Bernard et al. 1976).

(3)Anthropogenic processes. Man's activities can introduce anthropogenically-sourced hydrocarbons into the marine environment. Anthropogenic hydrocarbons may be of a thermogenic origin (e.g., ship spills, refined petroleum products used in industrial processes) or a biogenic origin (such as those produced from urban sewage when excessive loads of organic matter are dumped into the sea and degraded microbially).

The concentrations of in situ biogenic (i.e., background) light hydrocarbons in seawater are generally an order of magnitude lower than those in the underlying seafloor sediments (Claypool & Kvenvolden 1983). Consequently, it is relatively easier to detect migrated thermogenic hydrocarbons in seawater (low background concentration) than in seafloor sediments (high and variable background concentrations). Herein, lies one perceived advantage in the use of bottom-water DHD compared with sediment geochemistry in offshore petroleum exploration.

The bottom-water DHD technique is dependent upon hydrocarbons migrating from hydrocarbon reservoirs or petroleum source rocks to the seafloor. Although the exact mechanism(s) of migration may be variable or even unknown, some form of vertical migration, as evidenced by the many observations of seepage (e.g., Brooks et al. 1974; Bernard et al. 1976; Reed & Kaplan 1977; Cline & Holmes 1977; Nelson et al. 1978; Reitsma et al. 1978; Brooks et al. 1979; Kvenvolden et al. 1979; Kvenvolden & Field 1981; Hovland & Judd 1988) does occur (via porous sediments, fault planes and microfissures etc). It is generally accepted that migration by diffusion is not important (Leythaeuser etal., 1982; Reitsma et al. 1981; Whelan et al. 1984) although bubble ebullition from saturated solution, oil and gas transport in solution in carbon dioxide and advective processes involving basinal fluids are all likely mechanisms (e.g., Kvenvolden & Claypool 1980; Hunt 1984; Sweeney 1988; Hovland & Judd 1988).

Data interpretation: the mixing model

The detection of seepage requires that anomalous concentrations of hydrocarbons be distinguished from the background inventory of hydrocarbons. Thermogenic hydrocarbons that seep into the bottom-waters mix with the background concentration of hydrocarbons. One approach to defining anomalies and distinguishing seep hydrocarbons from background hydrocarbons requires that a mean background concentration be defined (either statistically or graphically), and this mean concentration is then subtracted from the measured concentrations. Because of variability in the background concentrations, this approach may be problematic, particularly where seepage is weak and the anomalies are very subtle.

Our initial approach is to review the data on a line-by-line basis and compare measured concentrations with the regional background. Then, a variety of hydrocarbon cross-plots are constructed, particularly where methane is plotted versus percent hydrocarbon wetness (wetness % = [SUM(C_2-C_4)/SUM(C_1-C_4)] x100) to delineate seepage. The rationale behind this plot (Figure III-1) is that different hydrocarbon 'sources' e.g., biogenic versus thermogenic gas, condensate and liquids, can be distinguished on the basis of differences in their light hydrocarbon molecular compositions (Hunt 1979; Tissot & Welte 1984; Claypool & Kvenvolden 1983). In this model background hydrocarbons plot in a narrow range towards the left origin (low concentrations), while end-member 'source' hydrocarbons i.e., hydrocarbons from either oil-prone, condensate-prone or gas-prone source rocks or reservoirs, plot to the right (high concentrations).

As the hydrocarbons in bottom-waters represent mixtures of the end-member background (low) and 'source' (high) concentrations, the trends between the end-members in these plots are indicative of the 'source' of the hydrocarbons comprising the anomalies. For example, when the % hydrocarbon wetness increases with increasing methane concentration, the trend indicates that the anomaly was probably derived from a gas-condensate or oil-prone 'source'. In contrast, increasing methane concentrations, coupled with decreasing % hydrocarbon wetness, suggest that the anomaly was derived from a gas-prone thermogenic 'source' or is of a biogenic origin. This model cannot distinguish between biogenic and gas-prone thermogenic anomalies. Carbon isotope (e.g., Fuex 1977; Bernard et al. 1977) and molecular compositional data are required to discriminate between biogenic gas and 'dry' thermogenic anomalies.

Classification of anomalies.

'Strong' (arbitrarily defined here as when some of the measured C_1-C_4 concentrations increase more than an order of magnitude above the background concentration) and 'moderate' thermogenic anomalies (some C_1-C_4 increase 5-10 fold above background) are obvious and are accompanied by large increases in individual C_1-C_4 hydrocarbons with no increase in the biogenic components (ethylene and propylene). 'Weak' anomalies (individual C_1-C_4 is less than five-fold the background concentration) are more difficult to discern. In some cases, what appear to be weak anomalies may result from variations in the depth of the fish above the seafloor, a shoaling of the water depth, penetration of the fish above the local thermocline or combinations of these factors. In these cases, plotting the saturated hydrocarbon (methane, ethane, propane) concentrations against the 'fish' depth, seawater temperature and salinity, or against the biogenic hydrocarbons (ethylene, propylene), generally resolves apparent anomalies from those anomalies related to seepage.

A cross plot of two compounds (e.g., ethane vs. methane) indicates whether the compounds are being added to the natural hydrocarbons in an area. Positive trends on plots of one compound versus another indicate that both compounds are being added concurrently and thus, the source of the anomaly contains both compounds. Because a mixing trend is created by one hydrocarbon source supplying hydrocarbons to the background, all data on the same trend reflect the same source regardless of the absolute concentrations or absolute ratios. For example, an anomaly with ethane at 0.1 ppm would reflect the same hydrocarbon source as a second anomaly with ethane values at 1.0 ppm if the data from the two anomalies lie on the same mixing trend. Similarly, an anomaly with a wetness of 2% (oil-like) may actually represent a dry gas source if it falls on a mixing trend that has low wetness values at higher concentrations.

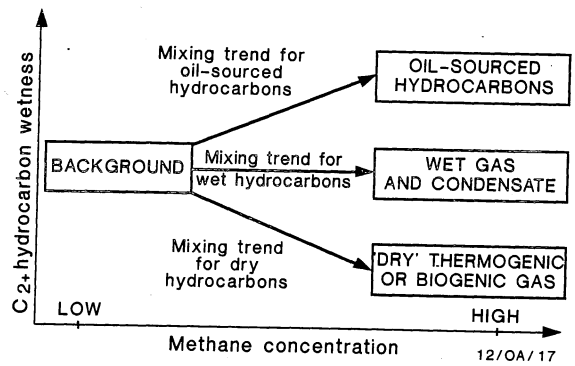


Figure III-1. Cross-plot of methane versus hydrocarbon wetness, showing the general decrease in wetness with increasing methane for gas-prone or biogenic sources. Conversely, oil-prone sources are indicated by increasing wetness with increasing wetness with increasing methane. Gas-condensate sources fall between the dry gas and oil-prone trends.

APPENDIX III REFERENCES

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APPENDIX IV

SYSTEM OPERATIONS REPORT

Relatively few problems were encountered with the geochemical laboratory acquisition system during the survey. Water depth data was determined with a portable over-the-side echo sounder. The intermittently faulty digital altimeter meant that fish altitude was calculated from water depth and fish depth for much of the survey. Problems with the tow cable and winch on survey line Carn 4 and Carn 5 resulted in the tow fish not being able to be towed close to the seafloor.

DHD

Conductivity data is not included in the line summary sheets for this report, however, salinity data is included in the ASCII files in Enclosure 1.

NON GEOCHEMICAL SYSTEMS

Navigation was provided by a combination of Global Positioning Satellite (GPS) and transit satellite navigation by Racal Survey Ltd (Perth WA). Accuracy of recorded positions are +/- 20 metres when GPS was operational and +/- 100 metres when transit satellite was on-line.

Enclosure 1

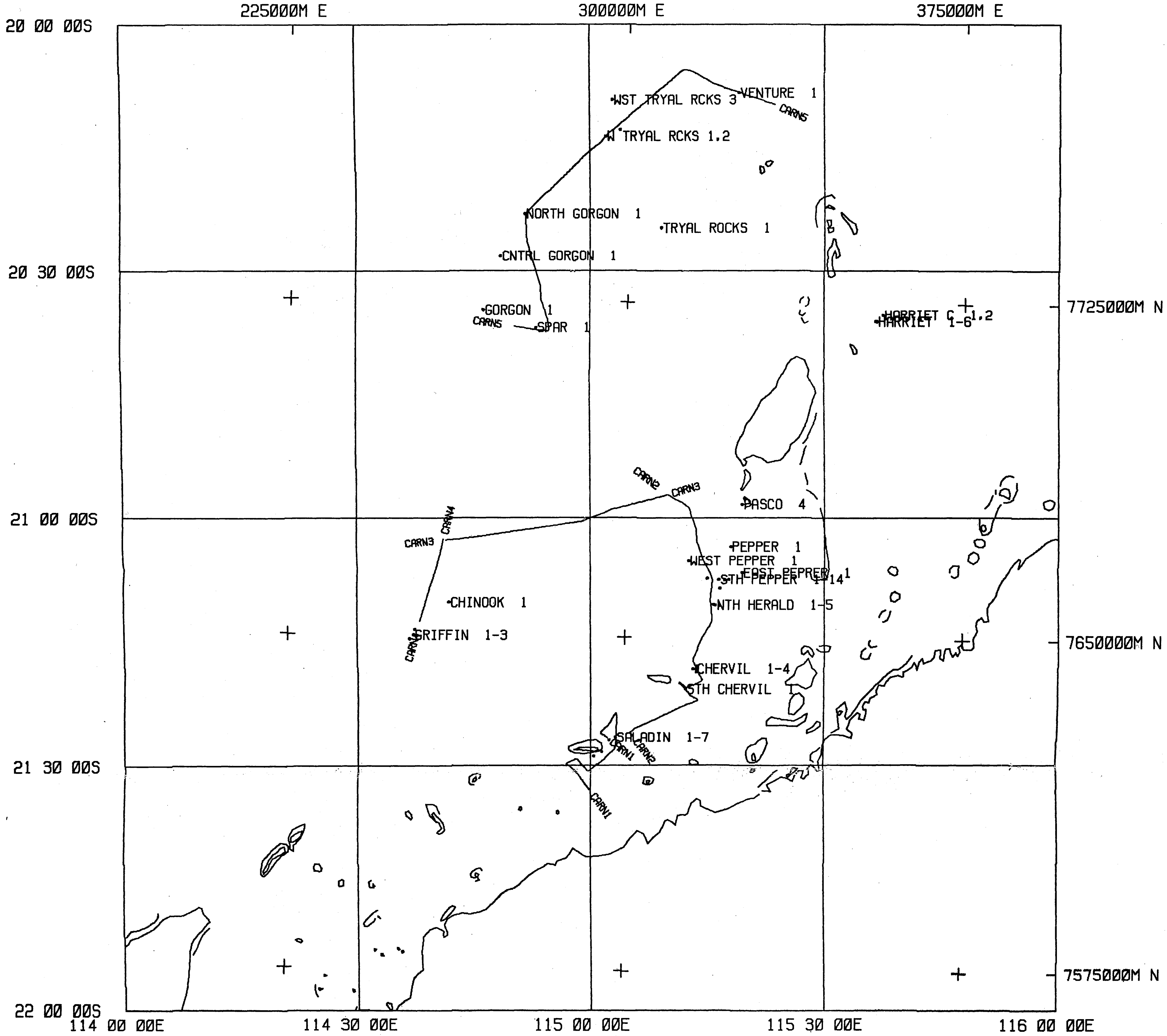
Floppy disk with ASCII file of geochemical data.

Enclosure 1 data has been made available as a separate download file.

Enclosure 2

Map showing DHD survey lines

CARNARVON BASIN



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KILOMETRES

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MILES

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TEG/BMR CALIBRATION SURVEY		
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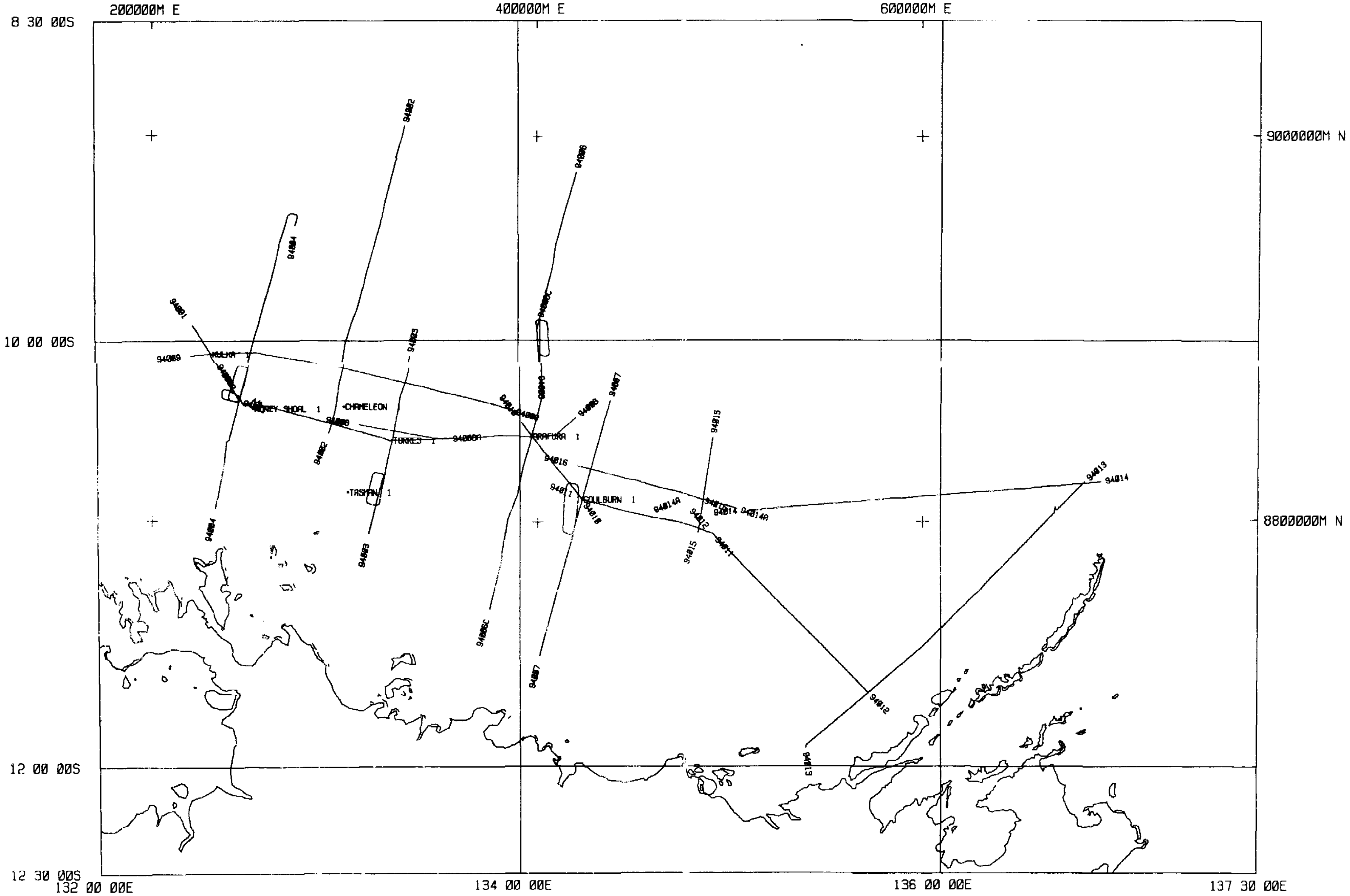
ARAFURA SEA



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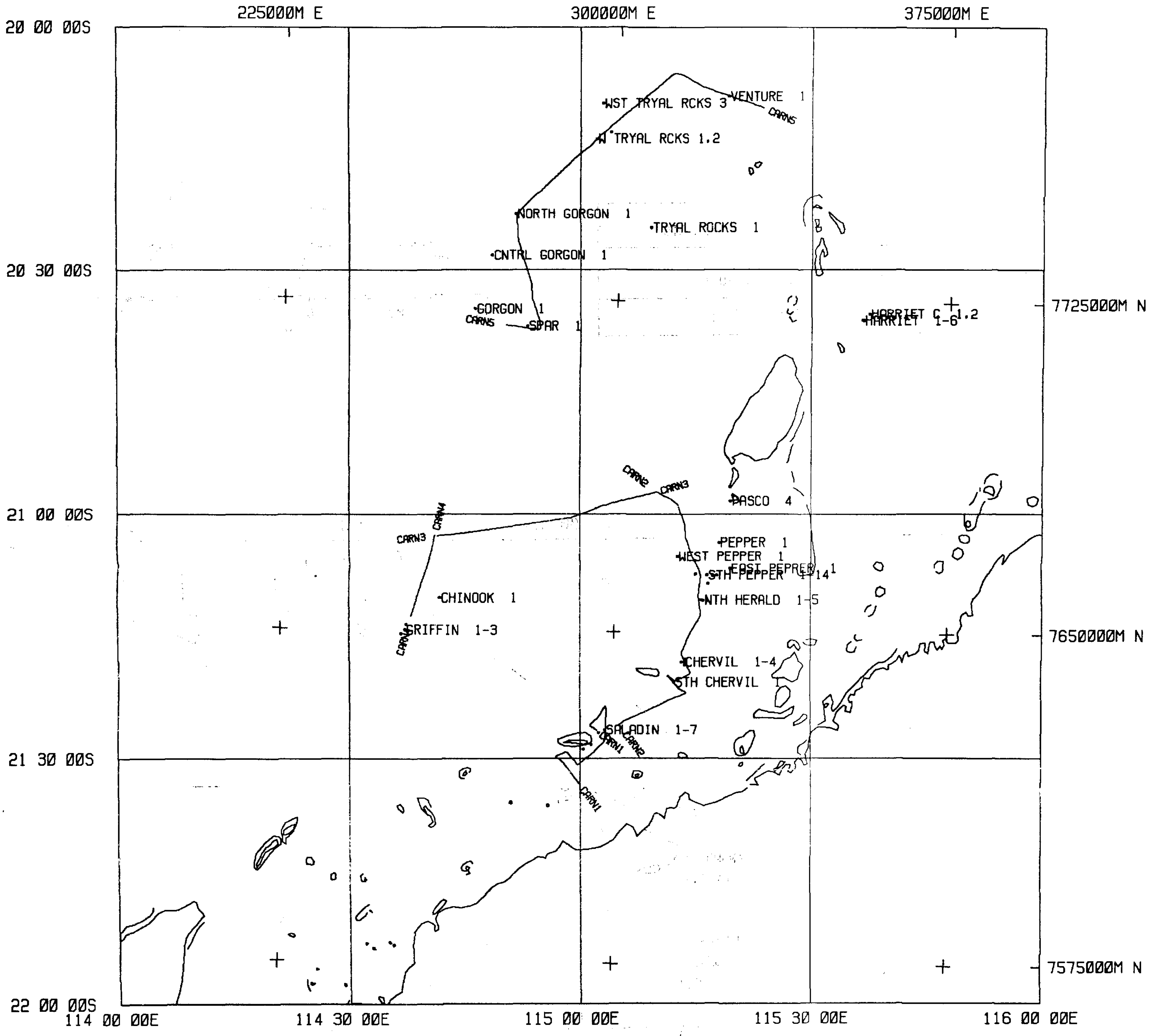

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