BMR RECORD 1992/50
LIGHT HYDROCARBON GEOCHEMISTRY OF THE BONAPARTE BASIN; INCLUDING THE SAHUL SYNCLINE, MALITA GRABEN AND NORTHERN PETREL SUB-BASIN: RIG SEISMIC SURVEY 99

PROJECT 121.24

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EXECUTIVE SUMMARY

During February-March 1991 the BMR conducted a combined Direct Hydrocarbon Detection (DHD) and high resolution seismic survey (Rig Seismic Survey 99; Fig. 1) in the Bonaparte Basin. This survey is one of three combined seismic and DHD surveys which were conducted in the Timor Sea (Fig. 2). Survey 99 collected approximately 3466 km of DHD, high resolution seismic, gravity, magnetics and side-scan sonar data. The data from this survey complement those obtained from Survey 100 (Bishop et al. 1992), which was conducted in the same general area. Three vibracores were taken in the northwestern corner of WA-217-P, while two grab sample sites were occupied in the vicinity of the Petrel gas field.

Several bottom-water light hydrocarbon anomalies were detected during the survey, with most of these being located within the Petrel Sub-basin. A single, strong bottom-water anomaly, and several weaker hydrocarbon anomalies, were found in the vicinity of the Petrel gas field, while weak, but aerally extensive anomalies were associated with the Tern gas field. No significant hydrocarbon anomalies were found in the Sahul Syncline. There were no strong C_1 - C_4 anomalies in the Malita Graben, however, one strong butane anomaly was found in the western end of the Malita Graben (principally composed of n-butane). Slightly elevated concentrations of light hydrocarbons were detected over an area of about 30 km in the eastern end of the Malita Graben (in the vicinity of the Heron 1 well).

Cross-plots of percent hydrocarbon wetness versus methane indicate that the water column anomalies detected in the vicinity of the Tern and Petrel gas fields were sourced from a gas/condensate source, which is consistent with the known composition of the reservoired hydrocarbons at Petrel and Tern. The anomalies detected over the Tern and Petrel fields probably represent seepage directly from those accumulations. The general lack of hydrocarbon anomalies in both the Sahul Syncline

and the Malita Graben may indicate that these source rock "kitchens" are no longer actively expelling hydrocarbons.

A vertical profile conducted over one of the bottom-water anomalies near the Petrel gas field showed that the anomaly could be detected 40 metres above the seafloor. This highlights the fact that the DHD fish should be towed as close to the seafloor as possible if weak bottom-water anomalies are to be detected.

INTRODUCTION

Surface geochemistry and offshore exploration for hydrocarbons

The aims of surface geochemical techniques in offshore petroleum exploration are: (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. The 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 remain proprietary and the opinions expressed publicly, about surface 'sniffer' geochemical techniques, by the petroleum exploration community remain divided. Scheiner et al. (1985) have reviewed 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 south-eastern 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, under 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, ie. 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 C_1-C_8 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 provides both the basic data and a preliminary interpretation of the bottom-water hydrocarbon data which were collected in the Bonaparte Basin during

Survey 99. This report focuses on the DHD aspects of the survey; other aspects, such as sediment sampling, side-scan sonar and the high resolution seismic program are not dealt with.

PREVIOUS WORK AND OBJECTIVES: Bonaparte Basin including the Sahul Syncline, Petrel Sub-basin and Malita Graben

Objectives

As part of the Bureau of Mineral Resources Continental Margin Program, the Marine Geosciences and Petroleum Geology Program conducted a high resolution seismic, side-scan sonar and bottom-water geochemistry survey within the Timor Sea in February-March 1991 using R.V. Rig Seismic. The survey had several objectives, which fall into broad, often inter-related categories. The objectives were:

- To investigate the processes of structural reactivation associated with collision and foreland basin development along the northern margin of the Australian craton using high resolution seismic reflection profiling.
- To better understand how these processes have controlled the entrapment of hydrocarbons and, in some cases, how reactivation has resulted in the breaching of hydrocarbon reservoirs (as occurred at Avocet 1A for example [Whibley & Jacobsen, 1990]). Side-scan sonar data were acquired in conjunction with the high resolution seismic data, allowing the seafloor expression of pockmarks and the orientation of reactivated faults to be mapped.
- To investigate processes of hydrocarbon generation and migration, and seepage of hydrocarbons to the seafloor in the Sahul Syncline, Malita Graben and Petrel Sub-basin of the Bonaparte Basin.
- To conduct 'calibration' surveys over known hydrocarbon accumulations.

- To test a model which predicts the hydrocarbon 'source' (dry gas, gas/condensate and liquids-prone) of bottom-water anomalies

During the survey, DHD data were acquired over a complete range of structural styles within the region. Detailed DHD surveys were carried out over the Tern and Petrel gas fields, allowing the method to be 'ground-truthed', and the composition of any detected hydrocarbon anomalies to be compared with that found in the reservoir.

Work Program

To achieve these objectives approximately 3446 line-km of high resolution seismic, gravity, magnetics and DHD data were collected within the three major structural elements of the area, namely the Sahul Syncline, the Malita Graben and the Petrel Sub-basin..

Sahul Syncline

The work program within the Sahul Syncline had two principal focuses. The first focus was to extend the BMR high resolution seismic coverage from the Avocet/Gargeny area (collected during BMR Survey 97) to the boundary of Area A of the Zone of cooperation [ZOC]). The second focus was to traverse as many of the structural leads and prospects in the area as possible while carrying out the DHD program. Hence the potential of DHD data as a direct indicator of hydrocarbon accumulations in this area could be assessed.

Malita Graben

Objectives within the Malita Graben were basically similar to those for the Sahul Syncline, though it was hoped that the DHD program might help to confirm the source potential of the Malita Graben, which has been inferred but not demonstrated.

Petrel Sub-Basin

The program within the Petrel Sub-basin consisted largely of a number of long, regional tie-lines which were oriented to include a number of hydrocarbon discoveries, as well as yet undrilled prospects. These lines included ties from the Palaeozoic gas discoveries at Petrel and Tern to the Mesozoic Malita Graben.

A DHD program over the Petrel gas field allowed the geochemical composition of the light hydrocarbon gases detected within the water column to be compared to the known composition of the gases within the reservoir. In addition, the vertical distributions of hydrocarbons within a seep were investigated.

DHD RESULTS: Bonaparte Basin including the Sahul Syncline, Petrel Sub-basin and Malita Graben

The program in the Bonaparte Basin consisted of 30 lines with a total survey length of approximately 3446 kilometres. A map showing the DHD survey lines is shown in Figure 1 (and Enclosure 2), and a map showing the locations of bottom-water anomalies is shown in Figure 1a. This survey and other DHD surveys conducted in this area are shown in Figure 2 (and Enclosure 3). Composite summary plots of the DHD data are presented in Figures 3-50.

The survey data, by individual line number, are presented in the line summary sheets (Appendix I), which show the light hydrocarbon characteristics and the beginning and end positions of each survey line. The distributions of the C_1 to C_4 hydrocarbons (and tow-fish depth) along each line are also shown graphically in Appendix I. DHD data were collected on all survey lines except parts of line 99/019 and all of line 99/020 due to mechanical problems (see Appendix IV). No DHD data were collected on survey line 99/027. A vertical profile was conducted in the vicinity of the Petrel gas field.

A summary of the anomalies is presented in Table 1.

Sahul Syncline (Survey lines 99/001-010 and line 99/026)

No significant hydrocarbon anomalies (Figures 3-14) were detected in the Sahul Syncline (survey lines 99/001-010 and 99/026; Fig 1), though weak, total hydrocarbon (THC) anomalies were detected on survey lines 99/002, 003, 007, 009 and 99/010 (Fig. 3). These increases in THC (to about 2.5 times typical background concentrations), were mostly not accompanied by increases in the concentrations of the other hydrocarbons. The weak variations in hydrocarbon values observed on survey lines 99/001, 99/007 and 99/010 are associated with variations in tow-fish depth, and as such are artefacts and are not related to hydrocarbon seepage from the seafloor. However on survey line 99/002, anomalous ethane and ethylene concentrations (ethane to 0.081 ppm; Fig. 6 and ethylene to 0.132 ppm; Fig. 7) were observed over a distance of approximately 1 km to the south-east of Kite 1.

The absence of ethane and propane data on survey line 99/001 was due to poor quality carrier gas (see Appendix IV). Propane (Fig. 8), propylene (Fig. 9), and butane (Fig. 10) hydrocarbon values are very noisy, and resulted from a temporary deterioration in integrator performance (see Appendix IV). This affected data acquisition quality for the C3 and C4 hydrocarbons on survey lines 99/0001 to 99/017. While these data are very noisy, the general trends in the data do not indicate any significant anomalies.

As an indication of the relative abundances of various hydrocarbons, the ratio of methane/ethane; (Fig 11), ethane/propane; (Fig. 12) and the Bernard parameter (methane/ethane + propane; Fig 14) are included. Background hydrocarbon wetness (Fig. 13) values (despite the noise resulting from the C3 and C4 integrations) are typical and are mostly <1%.

Malita Graben

The Malita Graben is considered to be a potential source of hydrocarbons for the northern Petrel Sub-basin and also the Zone of Cooperation (Botten & Wulff, 1990). The principal lines in the graben included 99/015, 99/016,. 99/021 and the north-western ends of lines 99/017, 99/019, 99/025 and parts of 99/010, 99/011, 99/012, 99/013, 99/014 on the south-west edge of the graben, and the northern portion of line 99/022.

There were no strong C1-C4 bottom-water anomalies detected in the Malita Graben.

Weak increases detected in THC (Fig. 15) on survey lines 99/014 and 99/015 were not accompanied by increases in other hydrocarbons (Figs. 16-22). An increase in butane (Fig. 22) on survey line 99/015 was detected towards the eastern edge of the Malita Graben.

A strong butane anomaly was detected, comprised only of n-butane (butane increased from background levels of < 10 ppb to concentrations > 0.2 ppm). This anomaly was found on the north-western end of survey line 99/017 (Fig. 22), in the south-western corner of the Malita Graben, and was not near an exploration well.

Another anomaly, which was characterised by weak increases in THC (from background levels of 9 ppm to 13 ppm; Fig. 27), sum C1-C4 (Fig. 28), methane (from 3 ppm to 6 ppm; Fig. 29), and a small increase in ethane (Fig. 30) was detected on survey line 99/022, south of Heron 1. These increases in the saturated hydrocarbons were not accompanied by corresponding increases in the unsaturated hydrocarbons (eg., ethylene; Fig. 31). This anomaly extended for 30 km.

The weak variations in hydrocarbon values observed on survey lines 99/019 and 99/021 (Appendix I) are associated with variations in tow-fish depth, and as such are artefacts and are not related to hydrocarbon seepage from the seafloor.

Petrel Sub-basin

Survey lines in the Petrel Sub-basin included long strike lines (99/017, 99/019, 99/024, and 99/025) and dip lines (99/023, 99/018, 99/028, 99/029 and 99/030) in the vicinity of the Tern and Petrel gas/condensate accumulations.

The majority of anomalies detected during the survey were located in the Petrel Sub-basin.

Elevated hydrocarbon values were detected on survey line 99/017 in the vicinity of the Tern accumulation. This anomaly was weak, with levels of THC (Fig. 15), sum C1-C4

(Fig.16) and methane (Fig. 17) increasing about two-fold above background. Distinct increases in ethane (Fig. 18) were found over Tern, and these were accompanied by a regional increase in the unsaturated hydrocarbon ethylene (Fig. 19). The increase in ethylene is probably related to the decreasing water depth rather than the increase in the saturated hydrocarbons. These elevated levels of hydrocarbons observed around Tern were reproduced during a subsequent resurvey of the area, survey line 99/024 (Figs. 27-30).

Four distinct anomalies were detected on survey line 99/018, which commences south-east of Tern and continues to beyond Petrel.

- The first detected anomaly in the vicinity of Tern showed increases in THC (Fig. 15), sum C1-C4 (Fig. 16), methane (Fig. 17), ethane (Fig. 18) and a slight increase in ethylene (Fig. 19).
- A second anomaly on this line was detected about midway along the line and comprised small amounts of butanes (n-butane and i-butane; Fig. 22) and trace increases in propane. However, no increase in concentrations of the other hydrocarbons were detected. This anomaly was also detected on a subsequent resurvey of the area (line 99/025); trace increases in propane (Fig. 33) and butane (Fig. 34) were observed, and several analyses were obtained that suggest this weak anomaly (detected several days apart) was long-lived, and detectable over a distance of about 3 km.
- A third anomaly on line 18 showed small increases in THC (Fig. 15), sum C1-C4 (Fig. 16), methane (Fig. 17), ethane (Fig. 18), together with trace increases in propane (Fig. 20) and butane (Fig. 22). This anomaly was detected 17 km to the south-west of Petrel 1.
- A fourth anomaly, was located 12 km to the north-east of Petrel 1, and comprised increases in THC concentrations. No anomalies were detected directly over the Petrel 1 well-head. This observation contrasts with that observed during Rig Seismic Survey 100, where strong increases in all C1-C4 hydrocarbons were

observed during a transit of the DHD tow-fish over the Petrel 1 well location. This contrast may indicate that the strong anomalies observed on Survey 100 may not be related to a leaky well-head, as originally proposed by Heggie et al (1991). The contrasting observations also indicate the ephemeral nature of light hydrocarbon plumes in the water column.

A detailed survey was conducted over the Petrel gas field (survey lines 99/028, 99/029 and 99/030). Survey line 99/028 traversed Petrel 3, survey line 99/029 did not cross any well-head, but crossed the field, and survey line 99/030 passed over Petrel 2. Several anomalies were detected on this mini-survey. The strongest anomaly was found on survey line 99/030, in the vicinity of Petrel 2. THC, methane and the C2+ hydrocarbons increased more than five times above background values (THC to 75 ppm; Fig 39, sum C1-C4; Fig; 40, methane 50 ppm; Fig. 41, ethane 1 ppm; Fig. 42, propane 0.2 ppm; Fig. 44, and butane to 0.05 ppm; Fig 46). Other bottom-water anomalies were detected during this mini-survey on survey lines 99/028, 029 and 99/030 (Figs. 39-46). These anomalies around the Petrel gas field were distinct and quite areally restricted (of the order of 8-40 km). Even considering the fact that the Petrel 1 well blew-out during drilling in 1969 (and therefore the potential exists for continued leakage from the well-head), the distribution of the anomalies around the Petrel gas field suggest that the bottom water anomalies are principally related to seepage from the geological structure itself, rather than from the well-head.

A strong anomaly, which consists solely of increases in propane (approximately three times background levels; Fig. 32) and butanes (>10 fold background; Fig. 34), was detected on survey line 99/023. This anomaly was not associated with any known accumulation. Increases in methane (Fig. 29) and ethane (Fig. 30) were observed towards the end of survey line 99/023. This regional anomaly is probably related to hydrocarbon seepage from the Tern gas field.

Vertical distribution of hydrocarbons in the water column

A vertical profile of hydrocarbon concentrations in the water column (Figs. 51, 52) was conducted east of Petrel 1 in approximately 90 metres of water. This profile was conducted where a bottom-water anomaly had been detected earlier in the survey. The bottom-water anomaly was detectable up to 40 metres above the seafloor. THC increases approximately two-fold and methane concentrations in the bottom-water are about five-fold the concentrations detected in the surface water. The distributions indicate that the DHD tow-fish should be towed as close as possible to the seafloor to detect relatively weak hydrocarbon anomalies.

The cross-plot of methane versus percent hydrocarbon wetness (Fig. 53) suggests that the bottom-water anomaly, in the vertical profile, is from a gas/condensate source (see Appendix III).

Hydrocarbon 'source'

To investigate the possible hydrocarbon 'source' of the observed bottom-water anomalies, cross-plots of percent hydrocarbon wetness versus methane concentration in the anomalies were generated. The rationale for these plots is discussed in Appendix III, and Figure III-I (Appendix III). The following cross-plots were chosen from selected lines because they reflect the differences in the types of anomalies found during the survey.

Two anomalies were detected on survey line 99/017 (Fig. 1a): one was associated with Tern, the other was not associated with any known hydrocarbon accumulations and was found near the southern boundary of the south-western Malita Graben. A cross-plot of methane versus percent hydrocarbon wetness from this line (Fig. 54), indicates two trends:

(i) One trend shows small increases in wetness (from 1% to 2%) with about a two-fold increase in methane values (from 3 ppm to 6 ppm) associated with Tern. This trend suggests a gas/condensate source.

(ii) A second trend shows a strong increase in wetness (from background of <1% to 8%), with no increase in methane. This trend from the anomaly in the south-western corner of the Malita Graben suggests a liquids-prone hydrocarbon source. The trend is associated with strong increases in butane and a trace increase in propane.

A cross-plot of methane versus percent hydrocarbon wetness (Fig. 55) for the weak anomaly south of Heron 1 shows a 'shallow' trend of increasing methane with little change in hydrocarbon wetness. This trend is consistent with hydrocarbons from a gas/condensate source.

A cross-plot (Fig. 56) from survey line 99/030 (part of the mini-survey over the Petrel gas field) shows an increase in wetness from <1% to approximately 2.5% with an increase in methane from background of < 5 ppm to >50 ppm. Methane and ethane (Fig. 57), and methane and propane (Fig. 58) are correlated, suggesting that these hydrocarbons are being produced from the same source. The shallow (wetness values <3%) trends shown in this plot are consistent with hydrocarbons from a gas/condensate source. The accumulations at Tern and Petrel are from such a source (Lavering and Ozimic, 1989).

Implications for Petroleum Exploration

No significant anomalies were identified within the Sahul Syncline, even though this area has been subject to structural reactivation associated with continental collision during the Late Tertiary, is characterised by significant shallow faulting, and is considered to be the major source 'kitchen' for the region (Botten & Wulff, 1990). Similarly, the Malita Graben, another potential Mesozoic source rock depocentre, was almost devoid of water bottom anomalies. Two weak anomalies were found in the western part of the Malita Graben, while the hydrocarbon values in its eastern end (near Heron 1) were slightly higher than background values. Consequently, these DHD data shed little light on either the present-day charge emerging from the Sahul Syncline or Malita Graben, or the prospectivity of the Sahul Platform. However, the general lack of anomalies, when taken in conjunction with the highly faulted nature of parts of the Sahul Syncline (in particular) and Malita Graben, may indicate that neither of these depocentres are presently expelling a large hydrocarbon charge.

These observations may be relevant to the exploration strategy in the Eider Horst area, where a number of residual oil columns have been intersected in wells (Whibley & Jacobsen, 1990). The lack of present-day charge would indicate that only traps which had been charged *prior* to the Late Tertiary collision, and which were *not breached during the associated reactivation*, would be attractive targets. A similar rationale would apply to prospects around the margin of the Malita Graben and Sahul Syncline within the Zone of cooperation.

The majority of the anomalies detected during the survey were located in the Petrel Sub-basin. A strong hydrocarbon anomaly was found in the vicinity of the Petrel gas accumulation, while a weaker, but areally extensive, anomaly was associated with the Tern gas field. This may indicate that the DHD technique is (at least partially) successful at directly detecting large gas accumulations within the Timor Sea. Moreover, the cross-plot results for the Petrel data correctly predicted that the anomaly was sourced from a gas-condensate accumulation. Consequently, the possibility exists that DHD could be used as a direct exploration tool, or possibly as a means of assessing the "gas-risk" of specific prospects within the region. However, the results of the vertical DHD profile within the hydrocarbon anomaly located east of Petrel 1 show that the DHD tow-fish should be towed as close to the seafloor as possible (ie., at approximately 10 m altitude) if weak seeps are to be detected.

SUMMARY

During this survey several bottom-water anomalies were detected.

(1) Most anomalies were detected in the Petrel Sub-basin. Anomalies, comprising elevated concentrations of methane and C2+ hydrocarbons, were found over both the Tern and Petrel gas fields. Two other anomalies were detected in the Petrel Sub-basin that were not associated with known hydrocarbon accumulations. These anomalies comprised trace amounts of propane and elevated levels of butane. One of these anomalies was found to the northwest of the Petrel gas field and the other between the Tern and Petrel gas fields. The anomaly between Tern and Petrel was able to be reproduced on resurveying several days later. The source of these propane and butane anomalies is unknown.

(2) Another weak propane and butane anomaly was found near the south-western boundary of the Malita Graben. The propane and butane anomalies observed here and noted above, suggest a liquids-prone hydrocarbon source. However, the lighter

hydrocarbons, methane and ethane were not found in conjunction with the propane and butane anomalies.

(3) Another weak anomaly was found to the east of the Malita Graben, south of Heron 1, and consisted of increases in THC, methane, ethane. Despite being weak this anomaly was detected over about 30 km.

(4) No significant anomalous hydrocarbon concentrations were found in the Sahul Syncline.

(5) Cross-plots of percent hydrocarbon wetness versus methane content of the anomalies from near the Tern and Petrel Gas Fields are consistent with a gas/condensate source.

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LIST OF TABLES

Table 1. Summary of anomalies

Anomaly No.	Anomolous hydrocabons	Anomaly strength	Line number
1	THC	weak	99/002
2	ethane, ethylene	moderate	99/002
3	THC	weak	99/003
4	THC	weak	99/009
5	THC	weak	99/014
6	THC	weak	99/015
7	butane	strong	99/015
8	butane	strong	99/017
9	THC, methane, ethane, ethylene, n-butane	weak	99/017
10	THC, methane, ethane, ethylene	weak	99/018
11	THC, methane, ethane	weak	99/018
12	propane, butane	strong	99/018
13	THC	weak	99/018
14	THC, methane, ethane	weak	99/022
15	propane, butane	strong	99/023
16	methane, ethane	weak	99/023
17	THC, methane, ethane, ethylene, n-butane	weak	99/024
18	THC, ethane, propane, butane	weak	99/025
numerous	THC, methane, ethane, propane	strong	99/028, 99/029, 99/030

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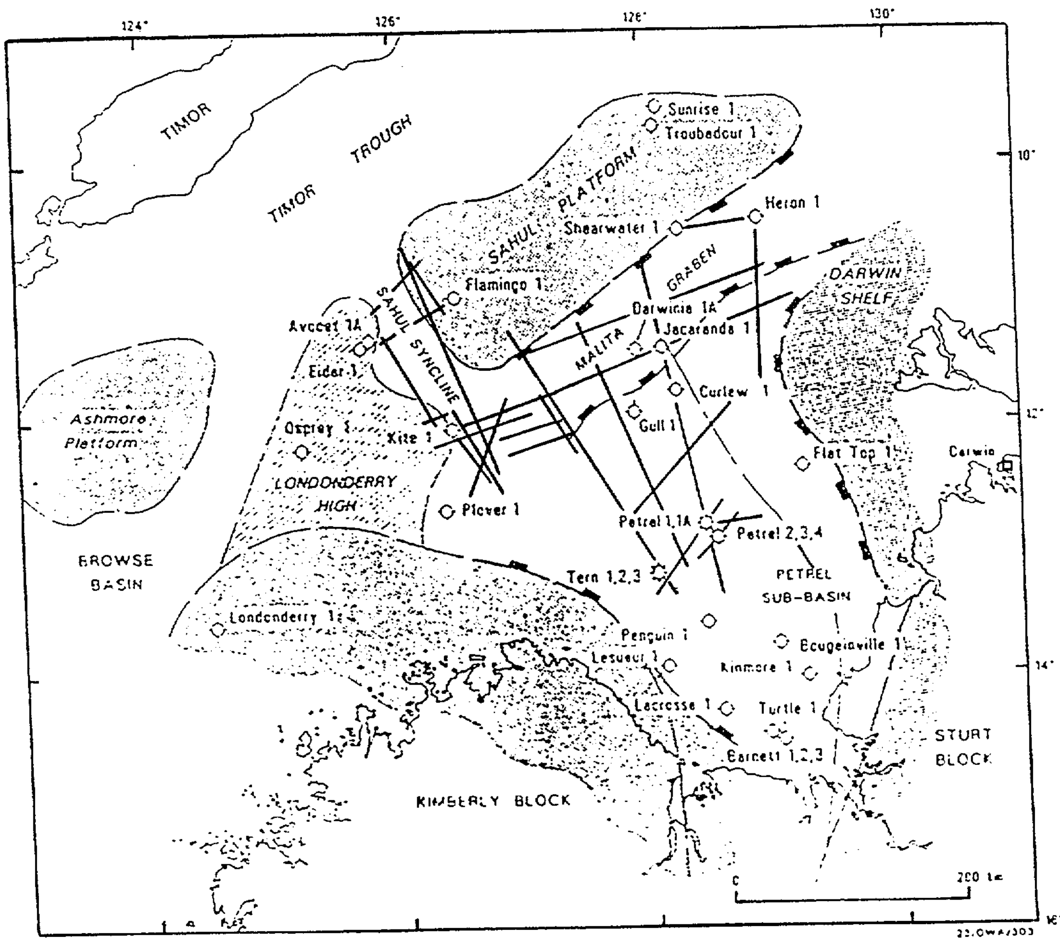

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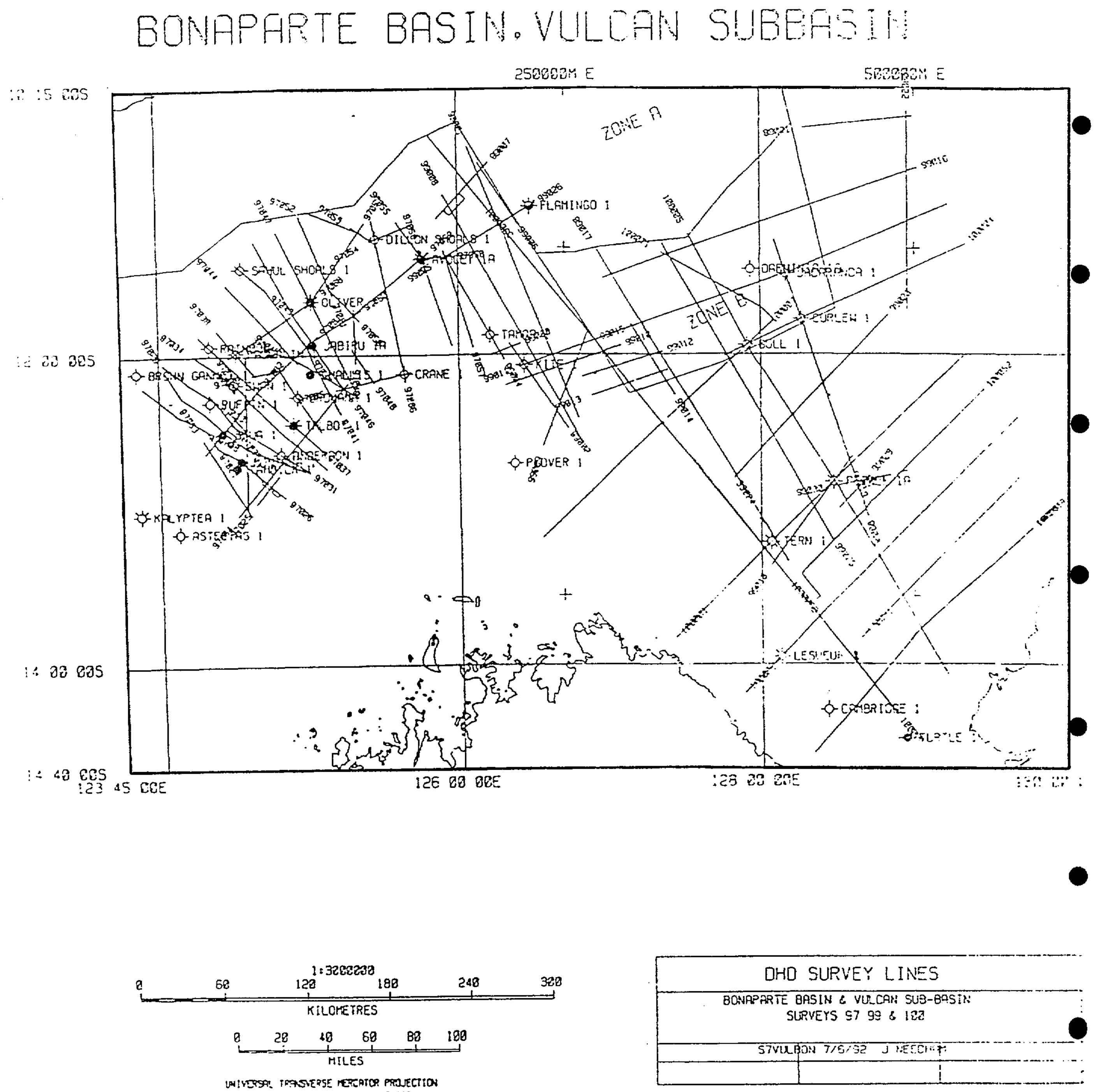

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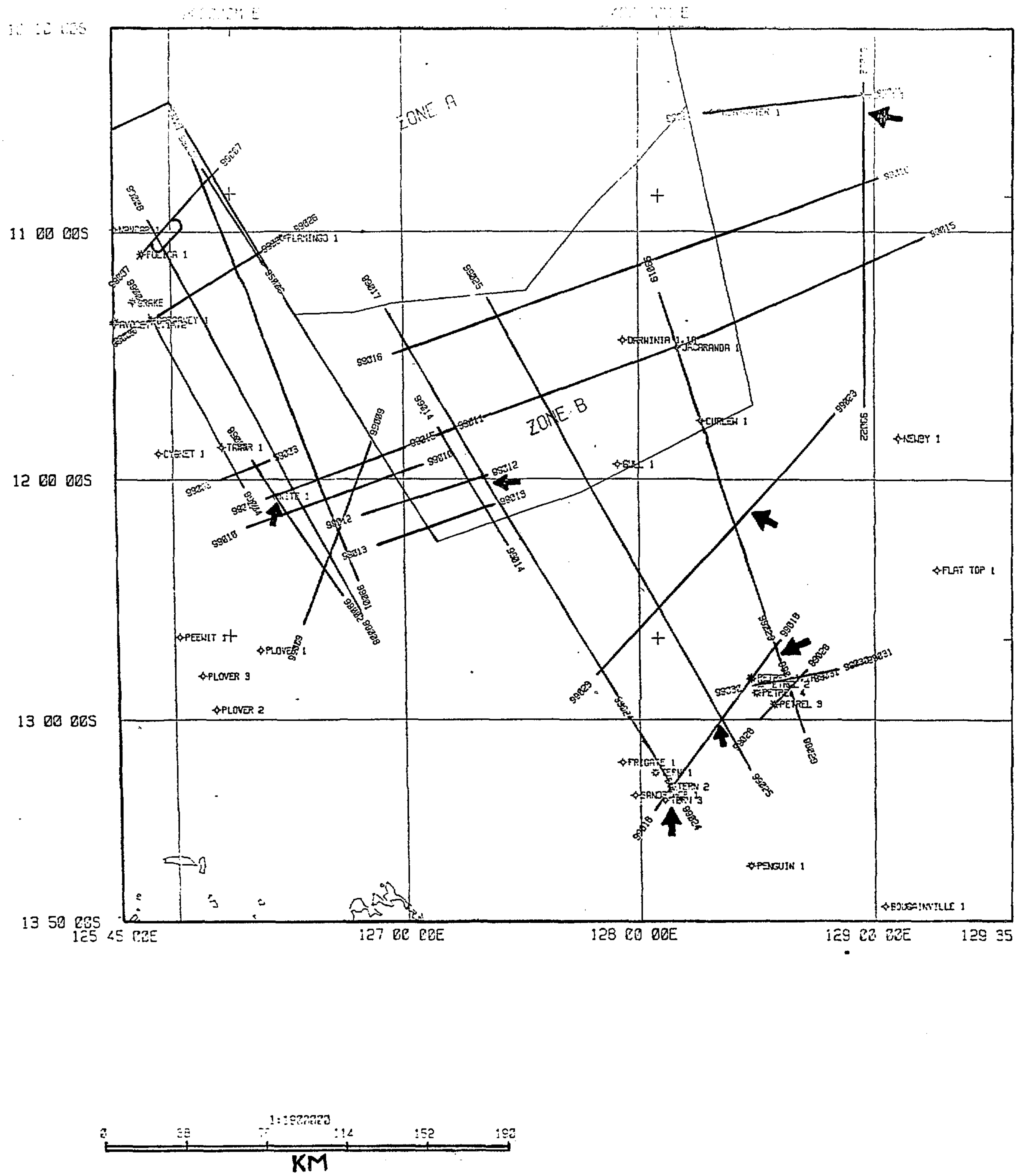

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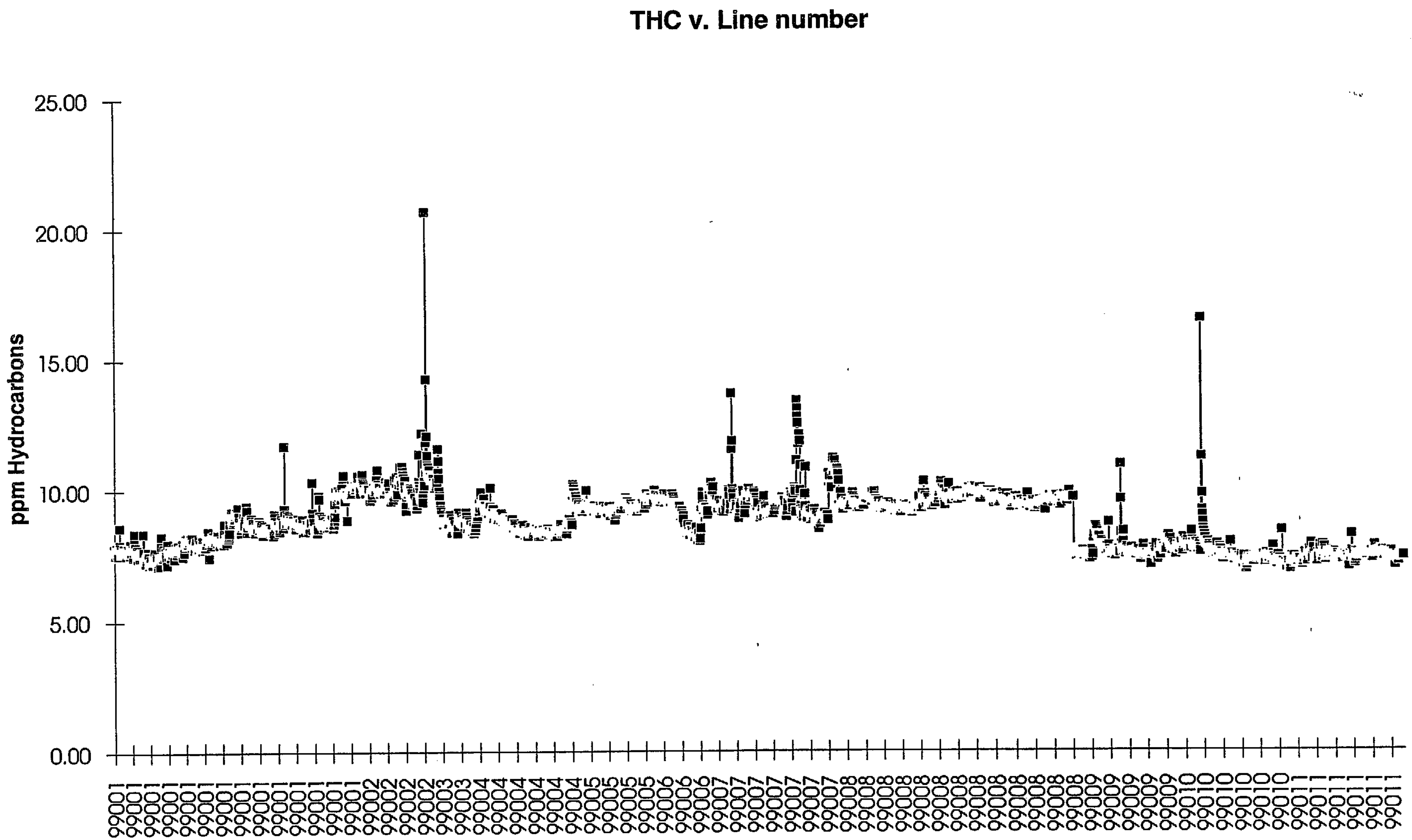

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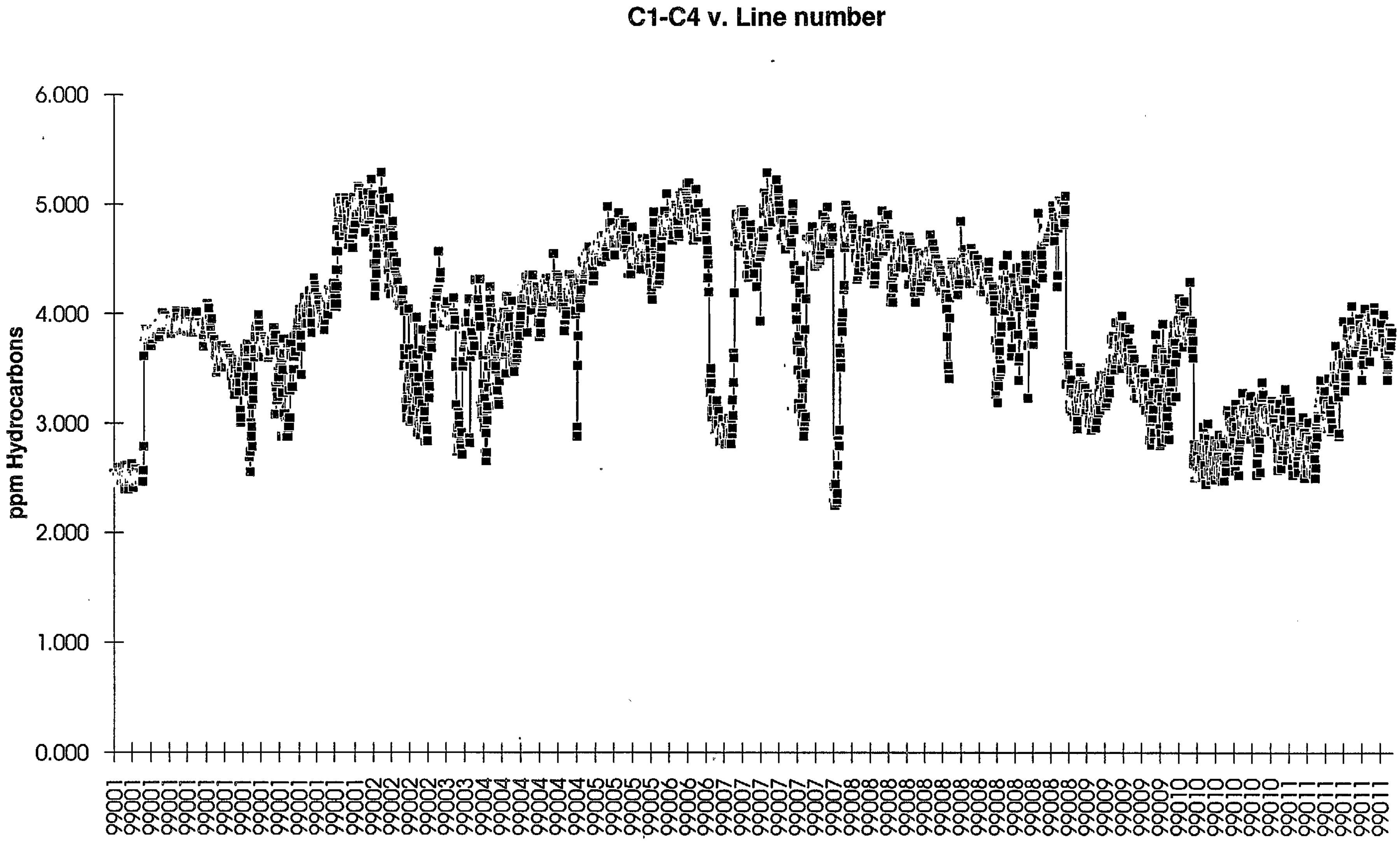

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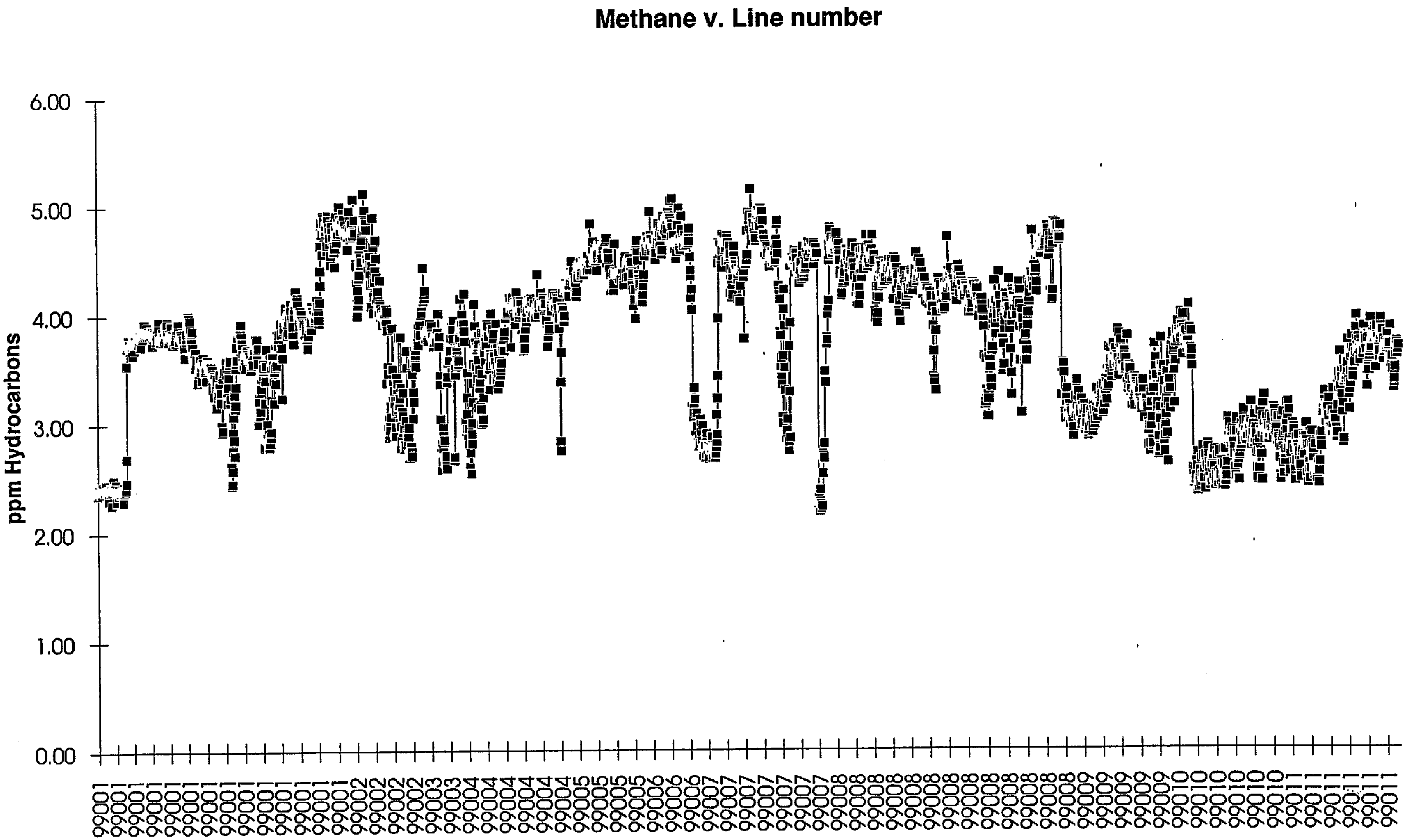

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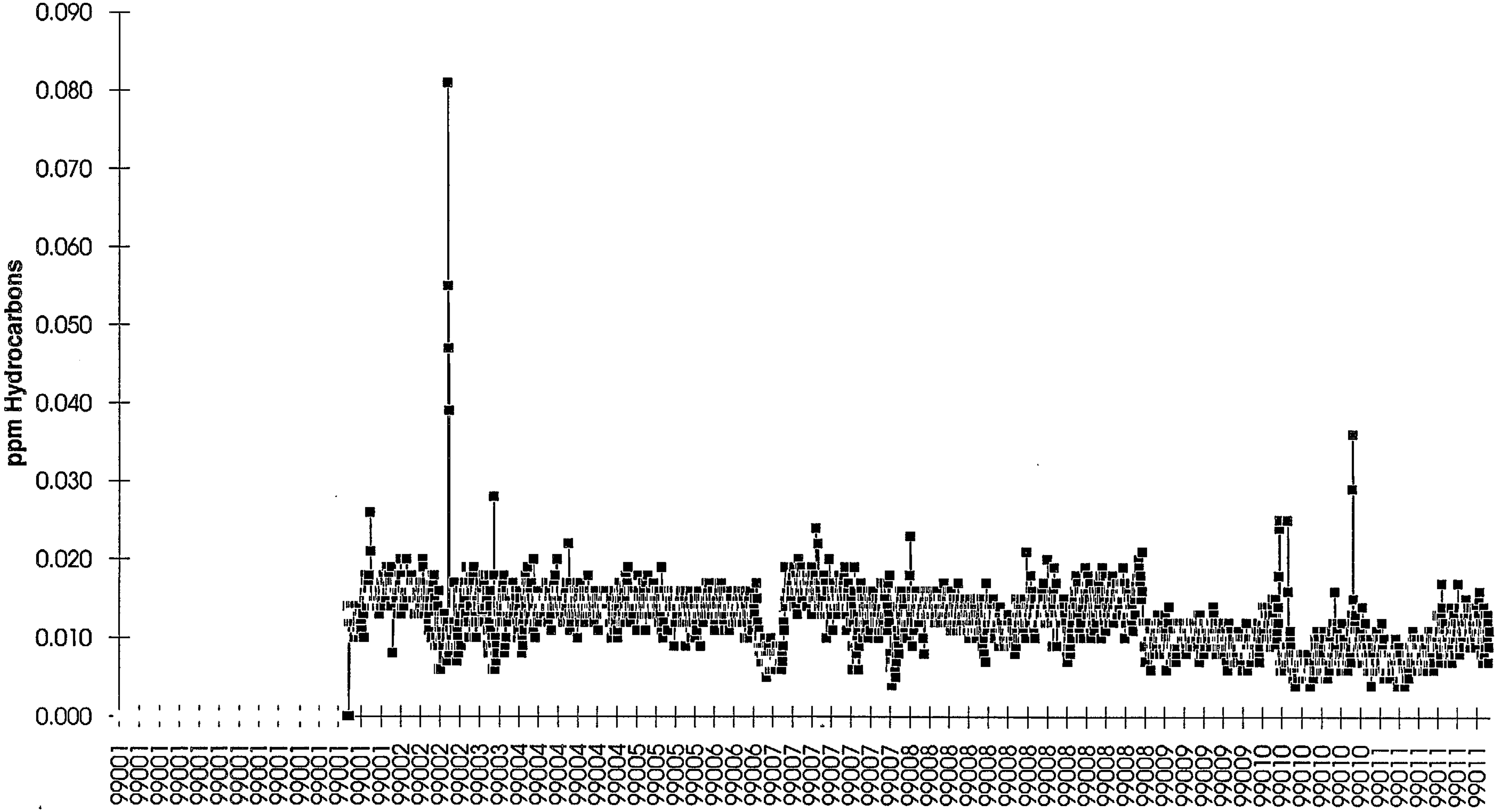
Ethane v. Line number



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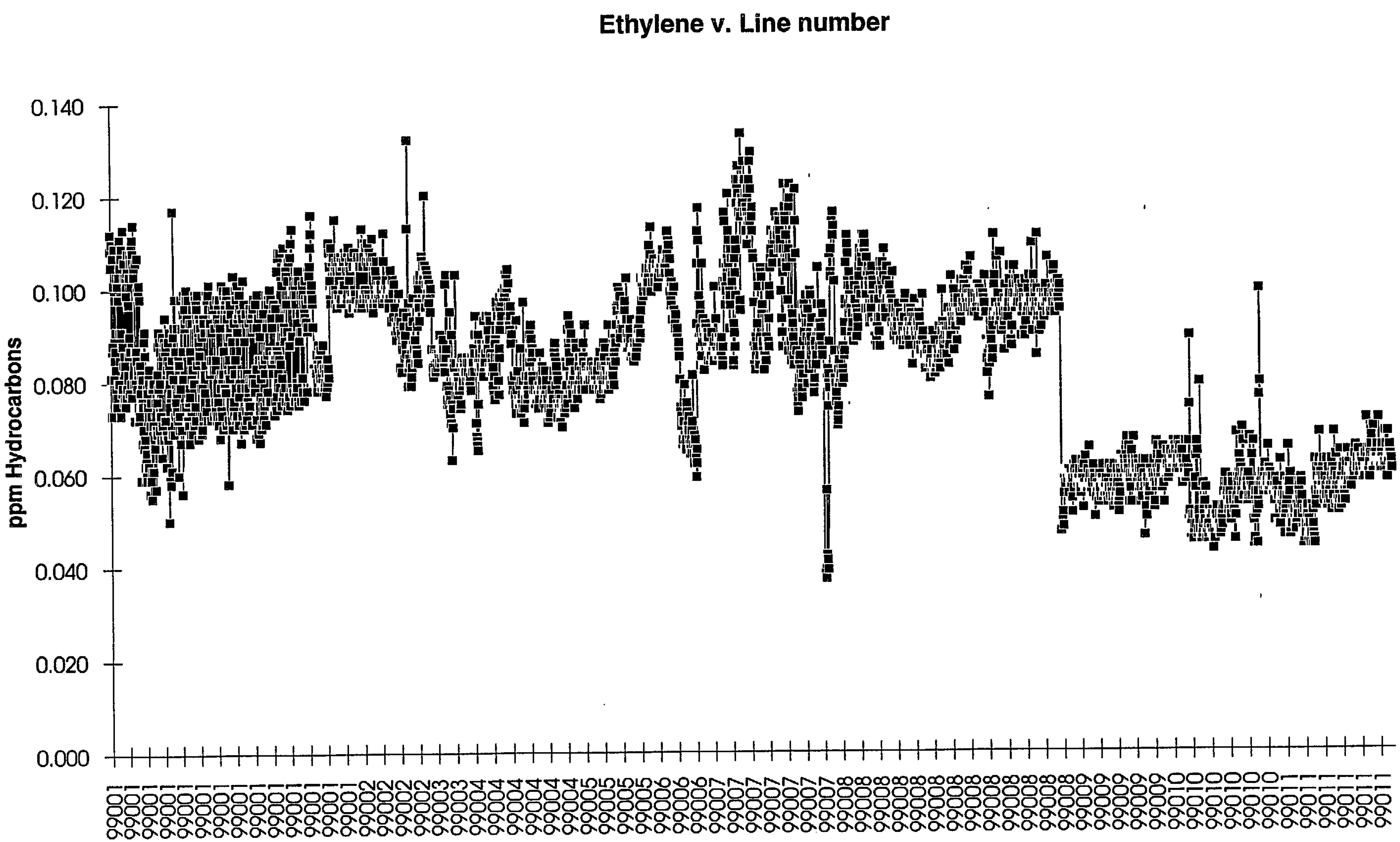

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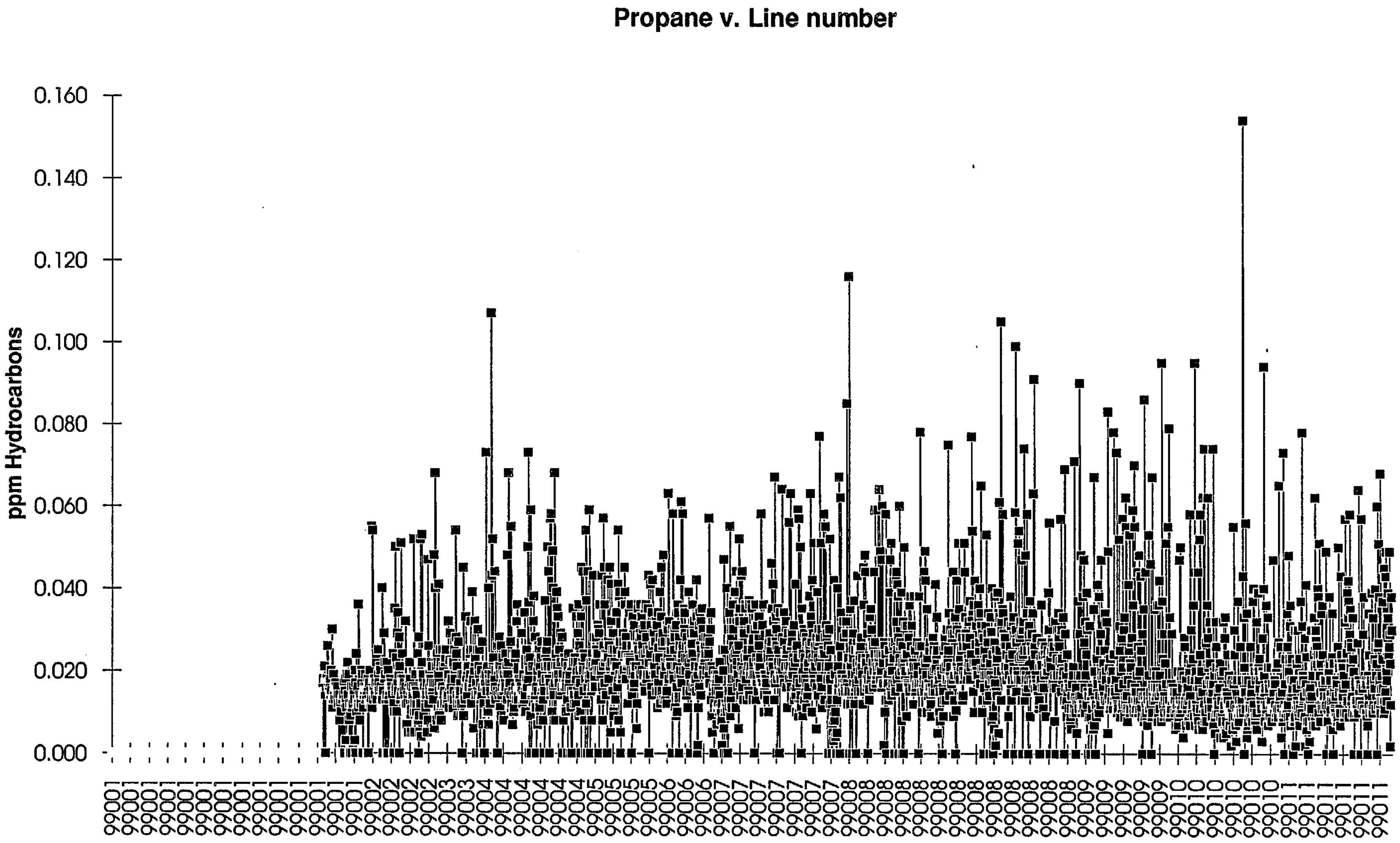

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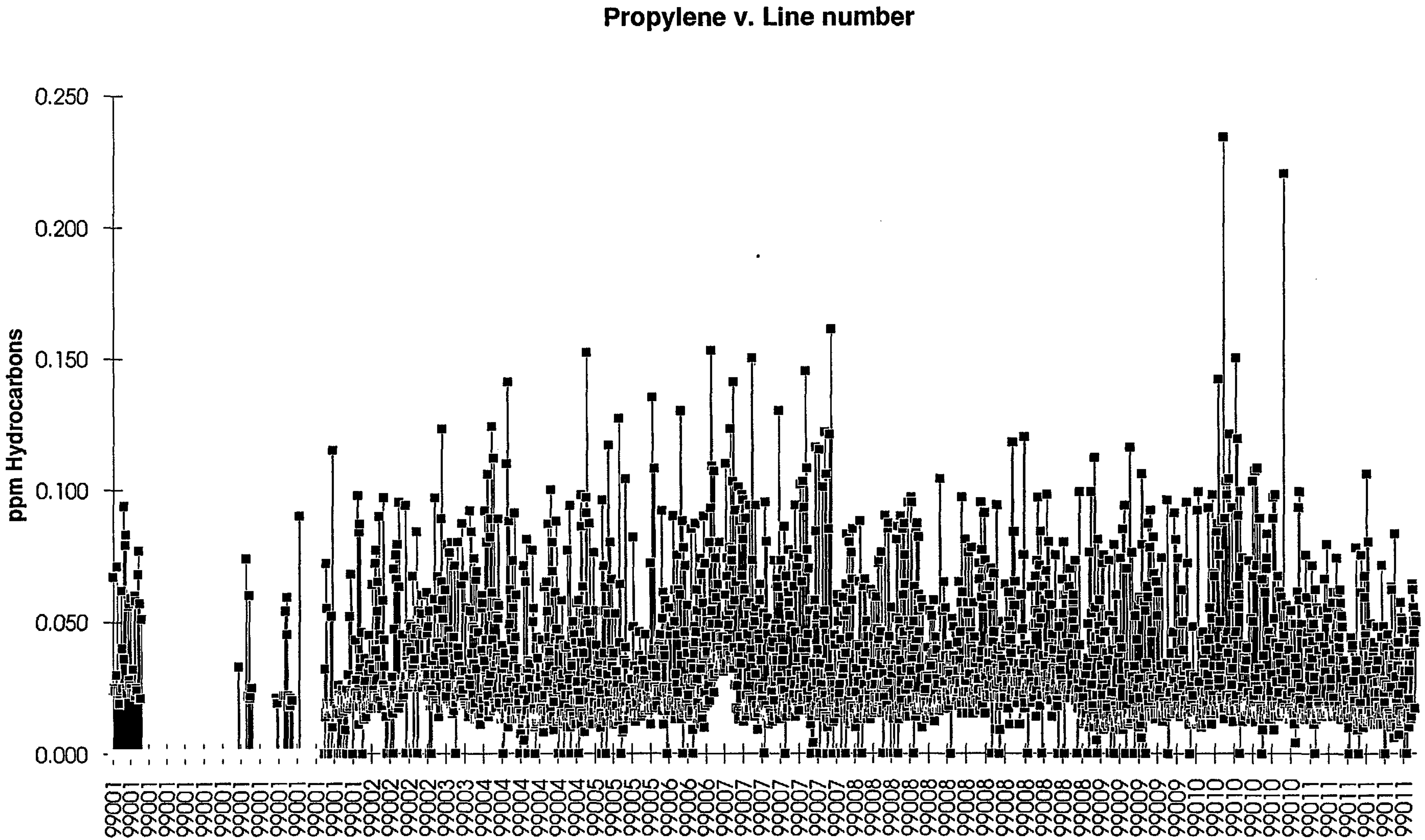

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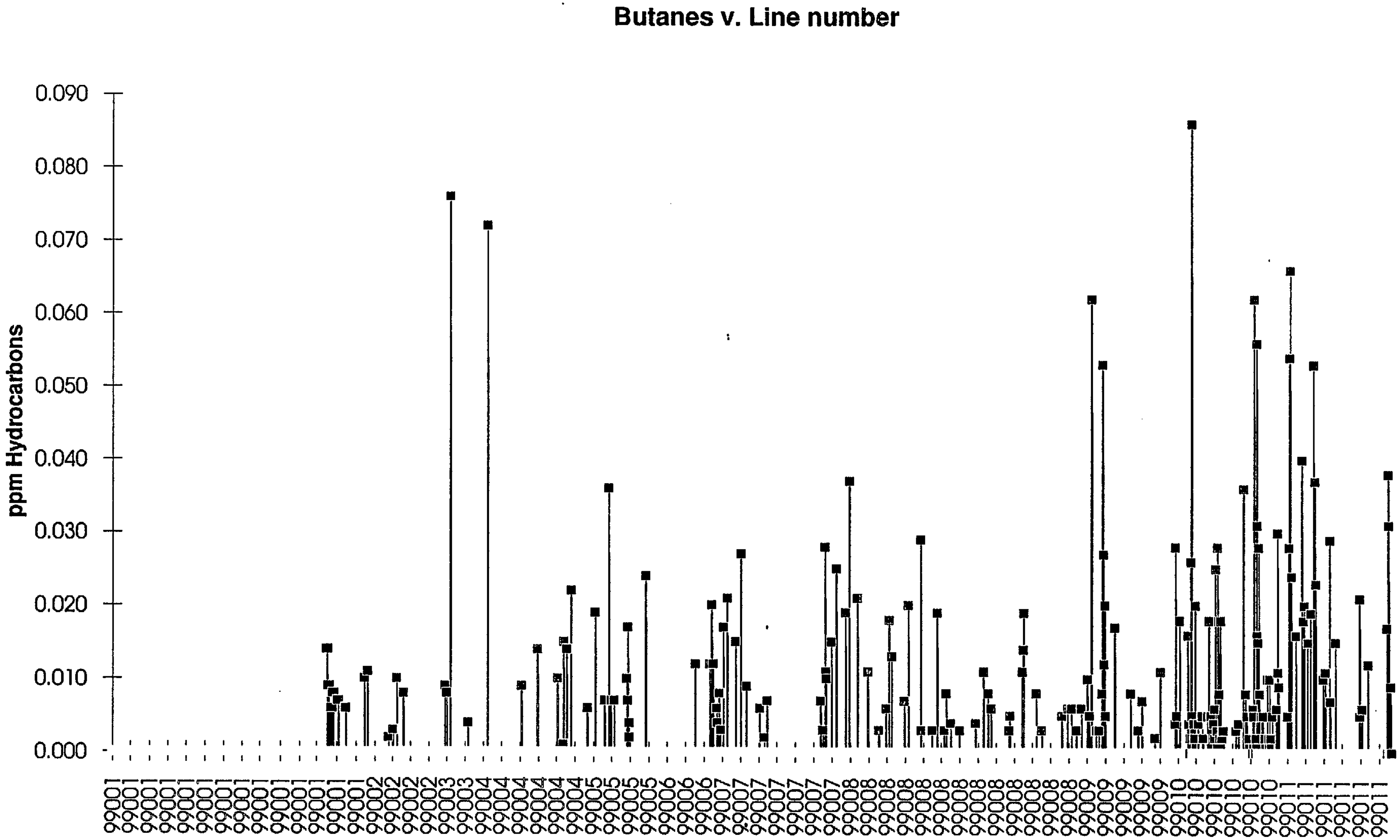

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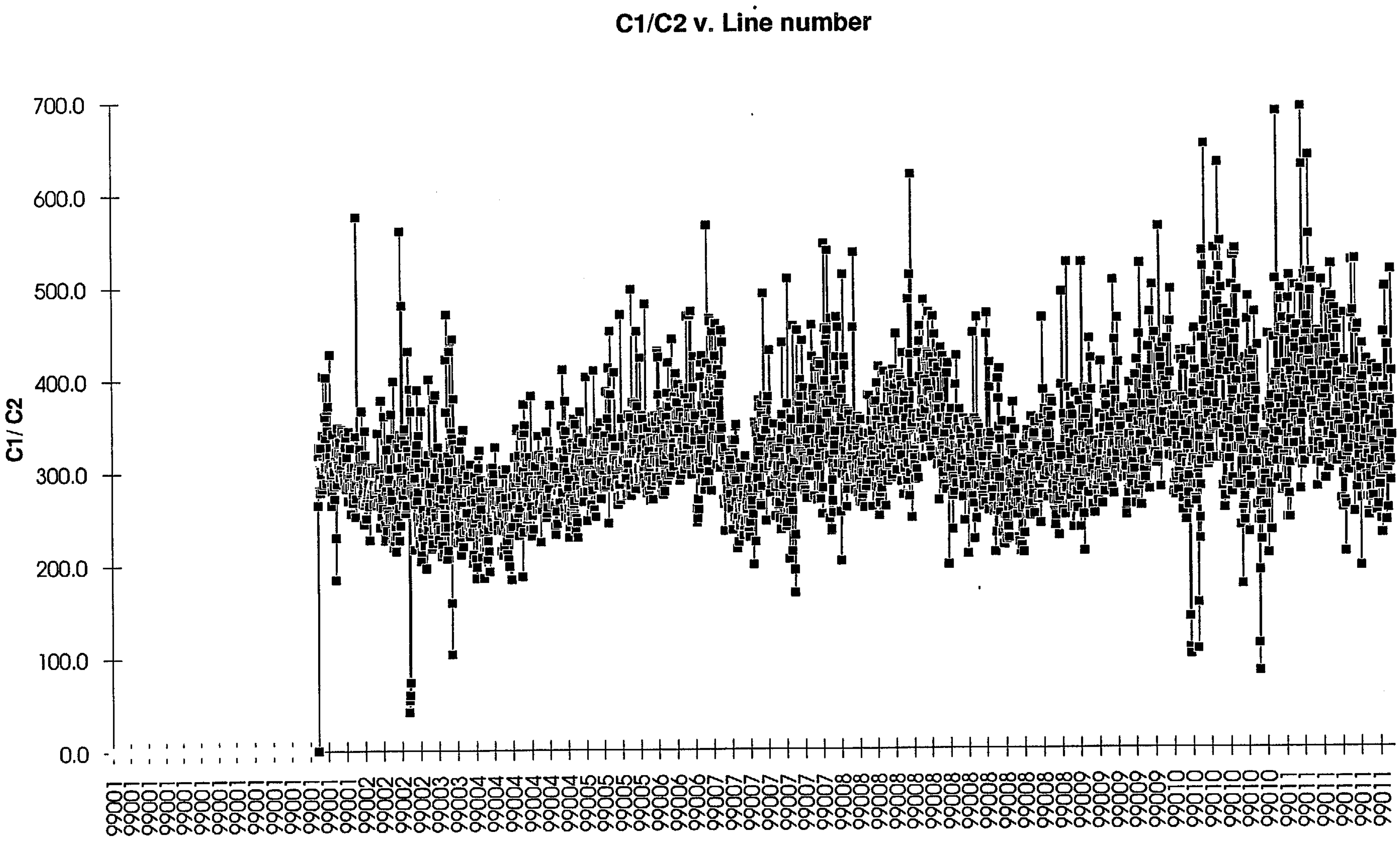

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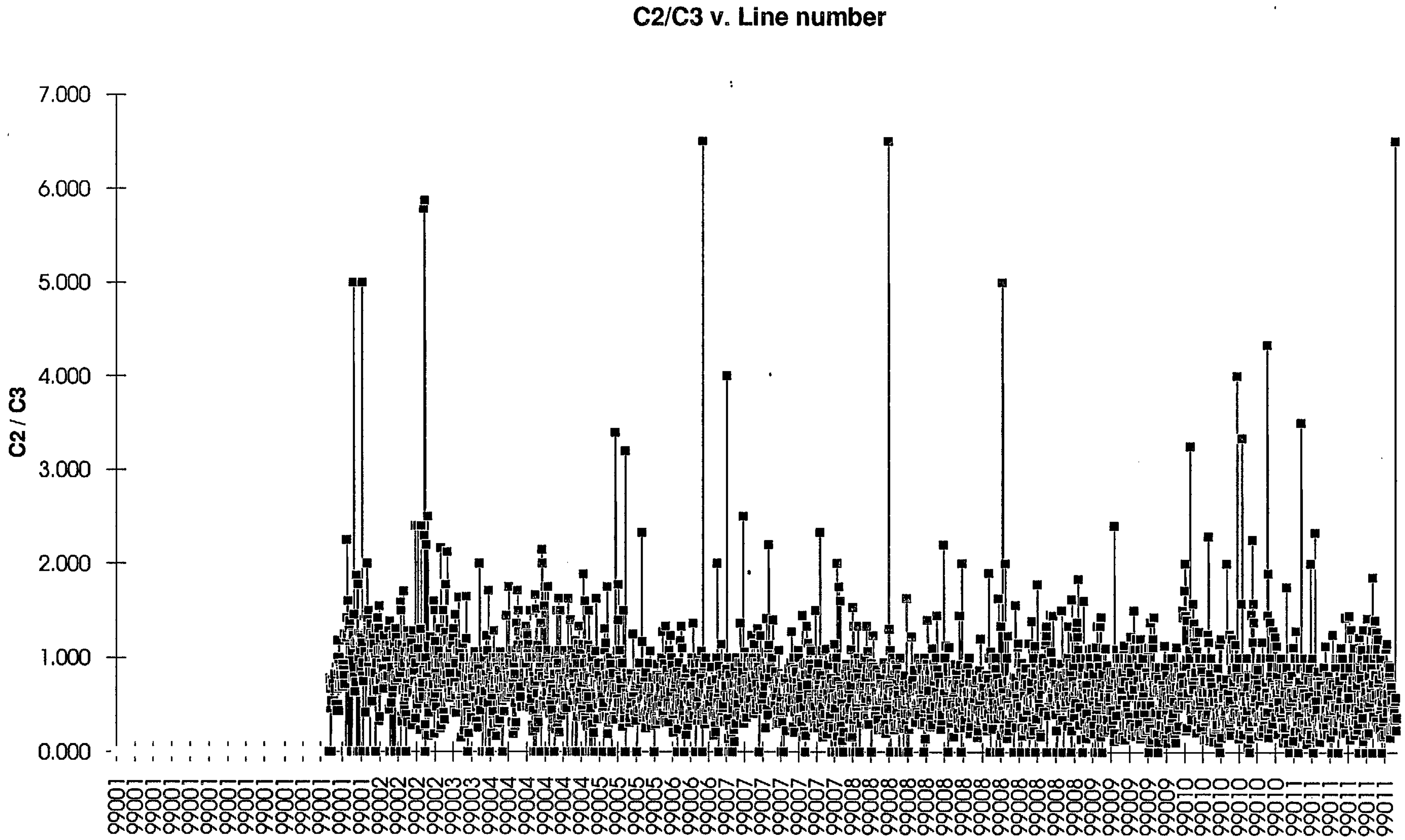

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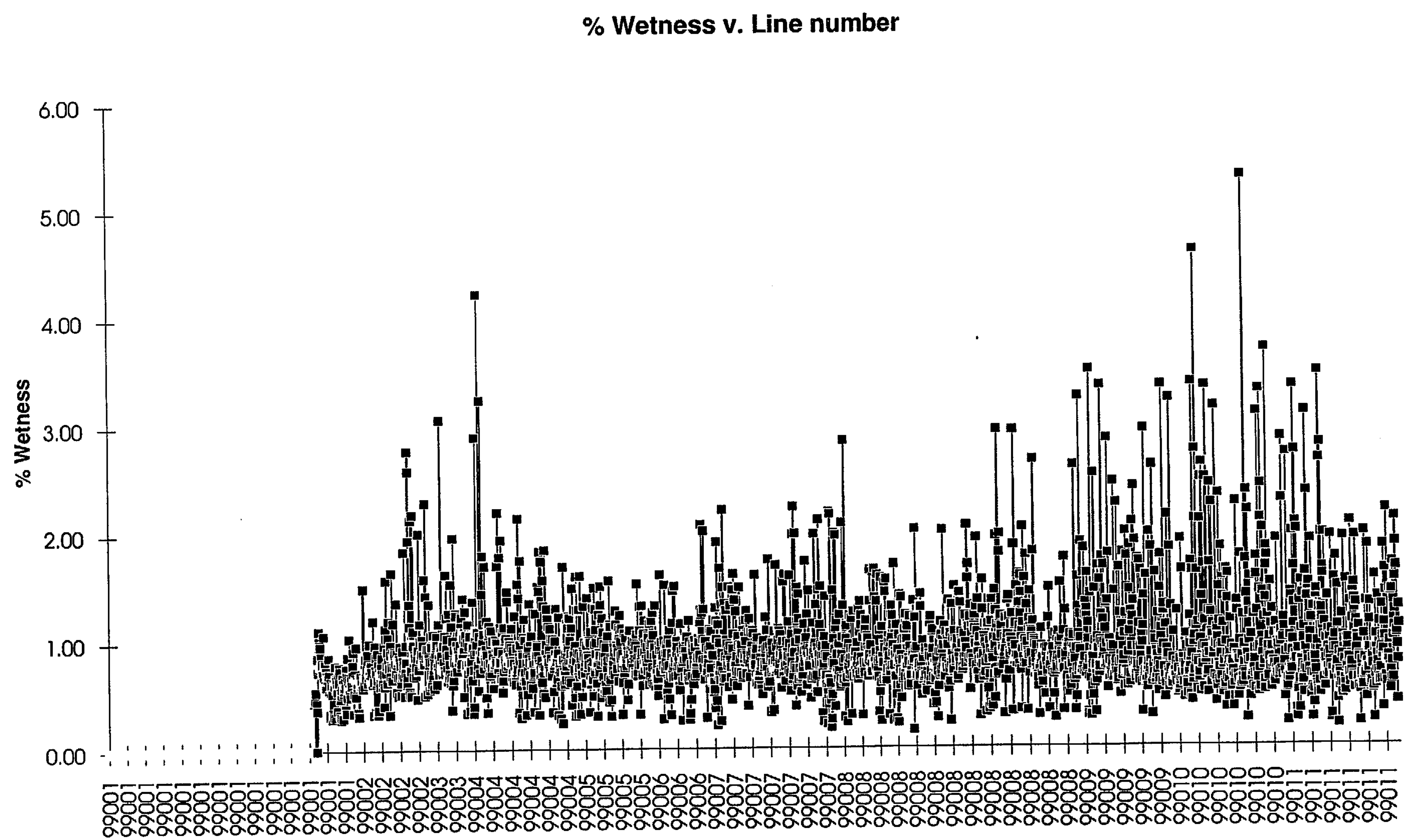

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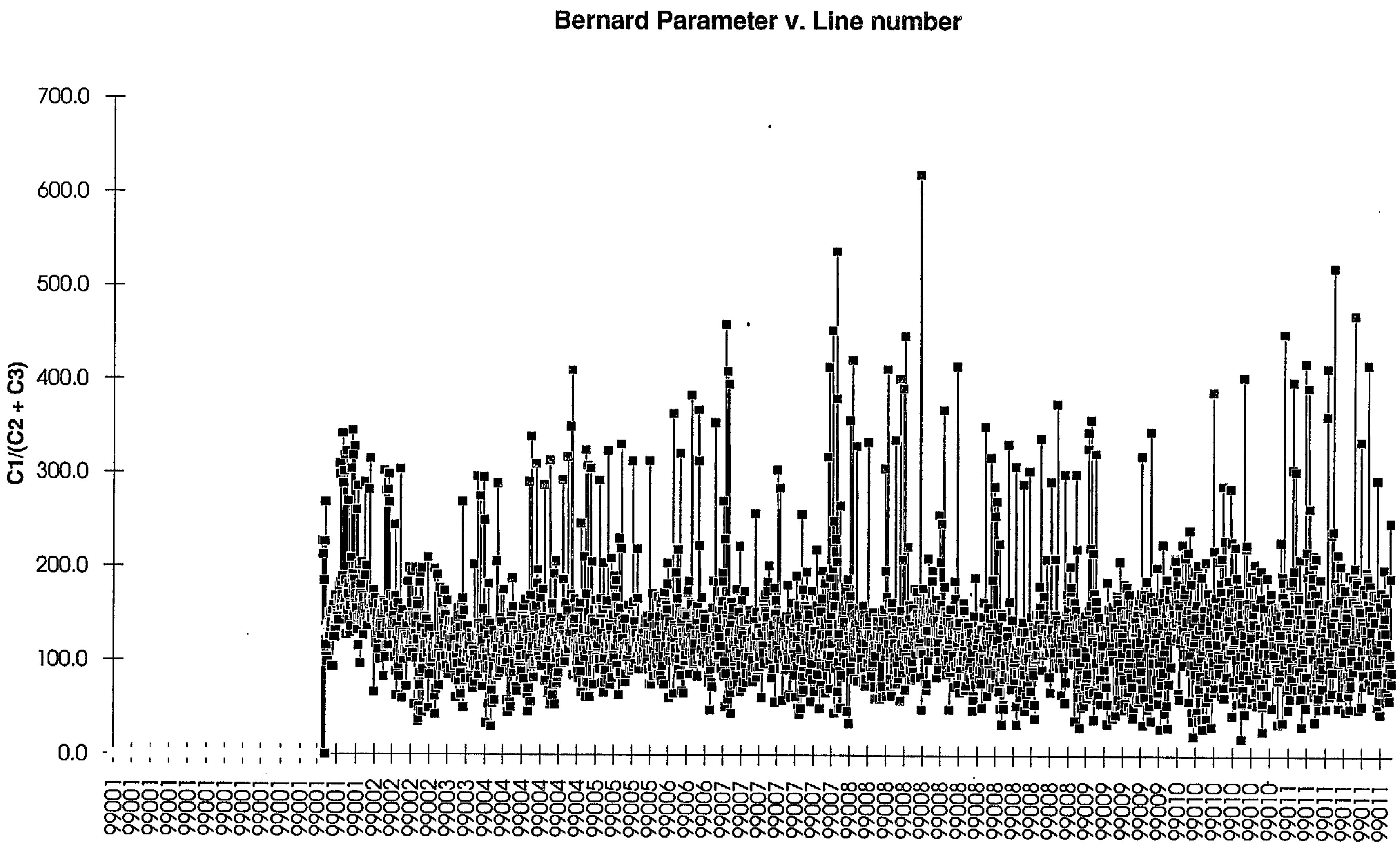

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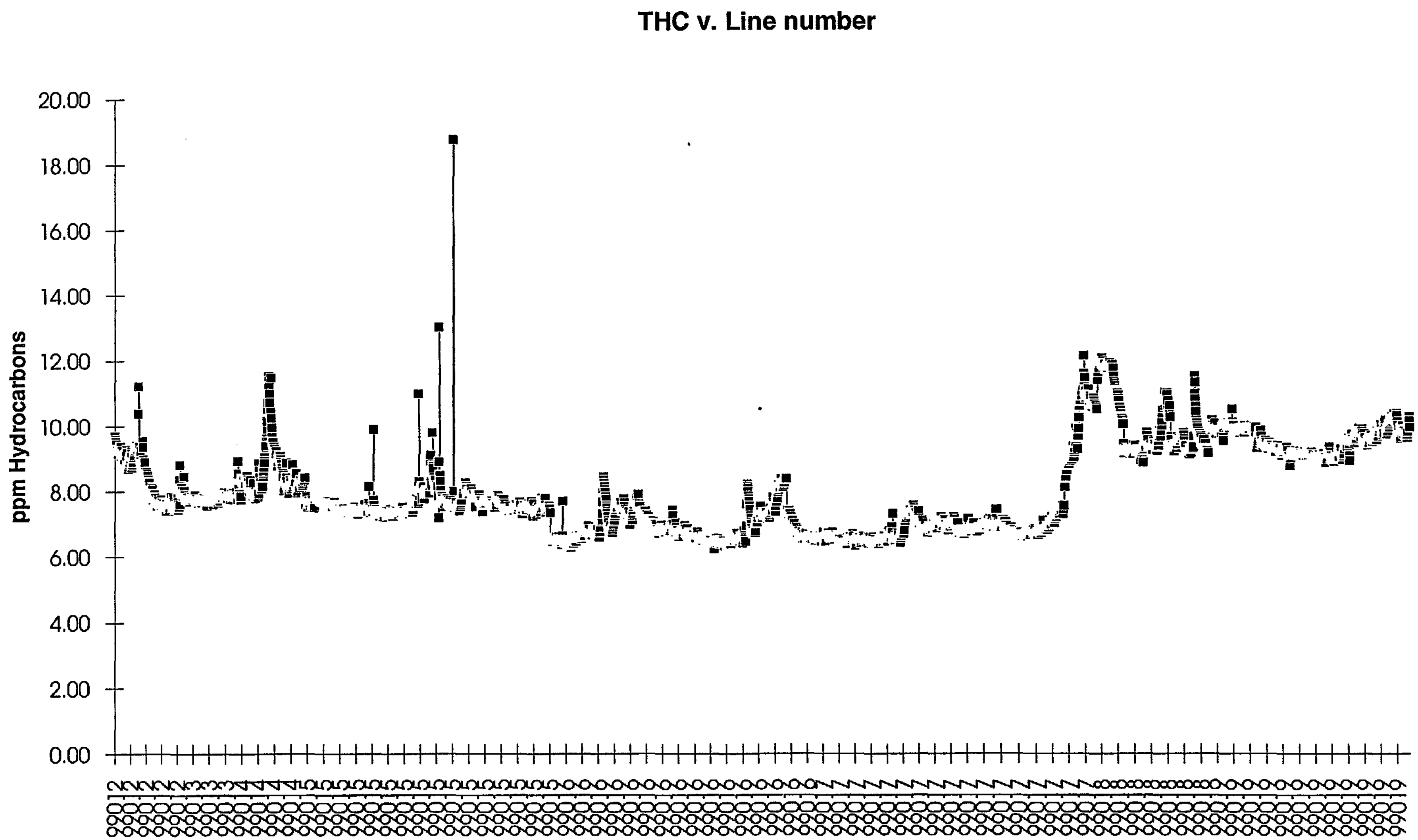

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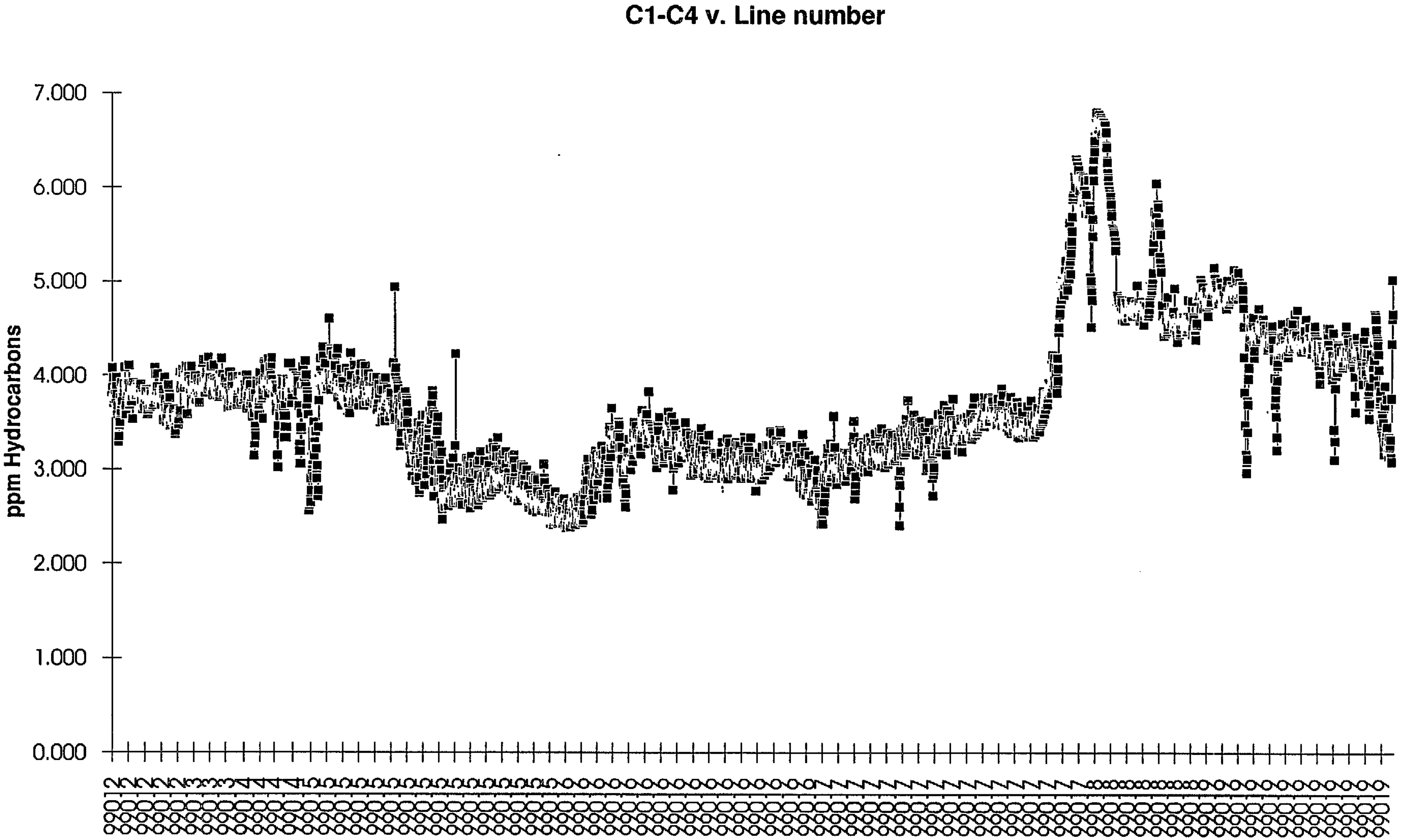

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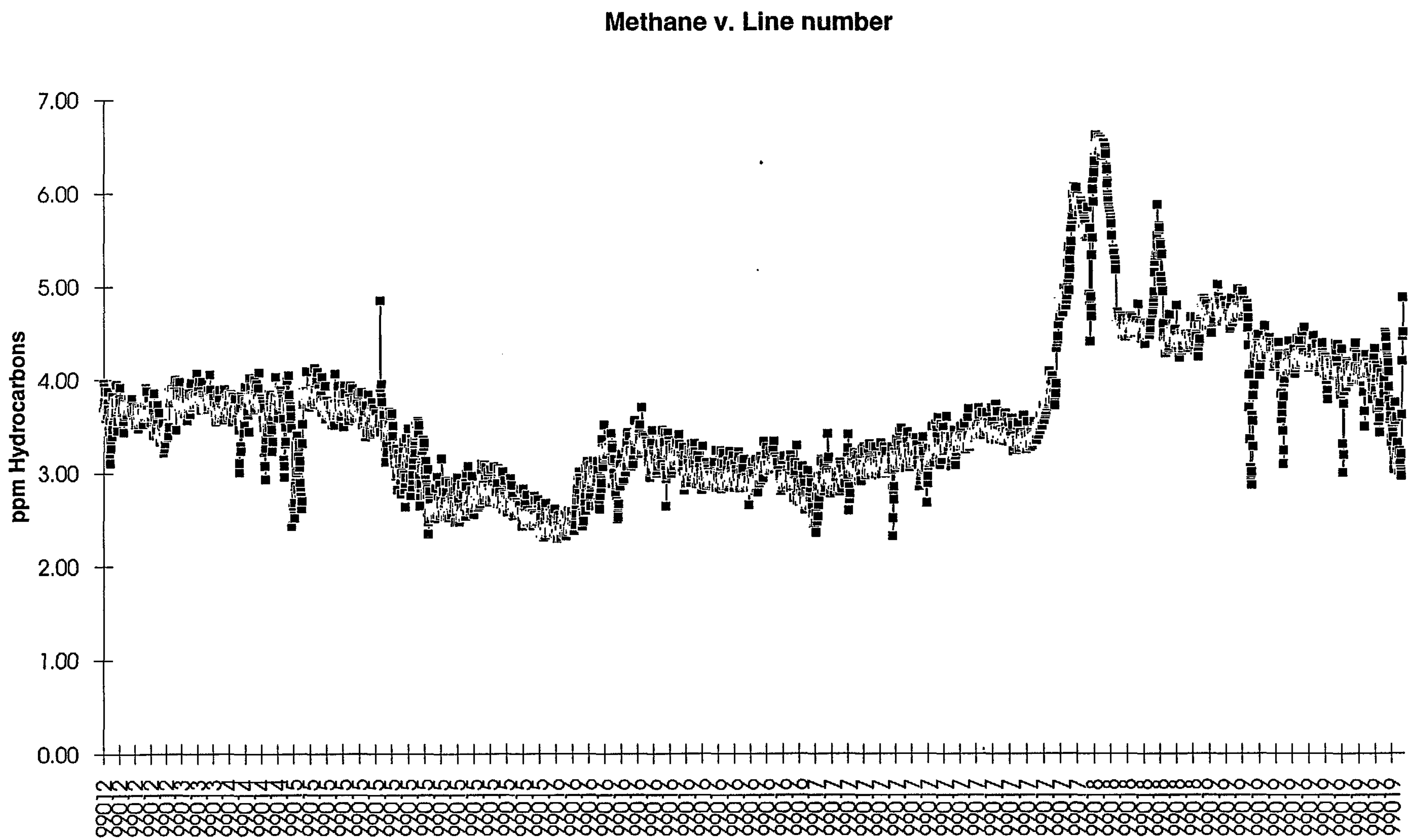

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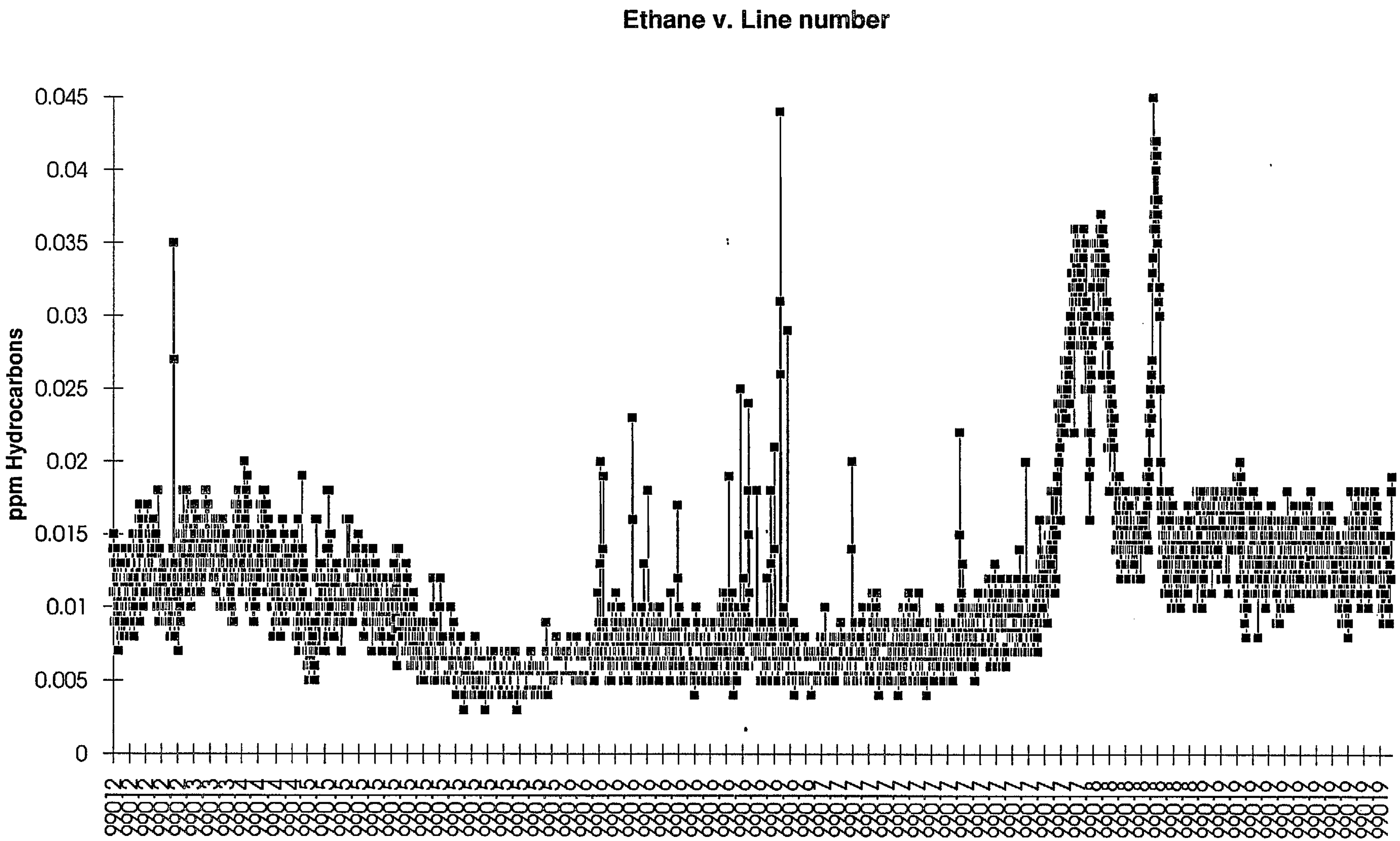

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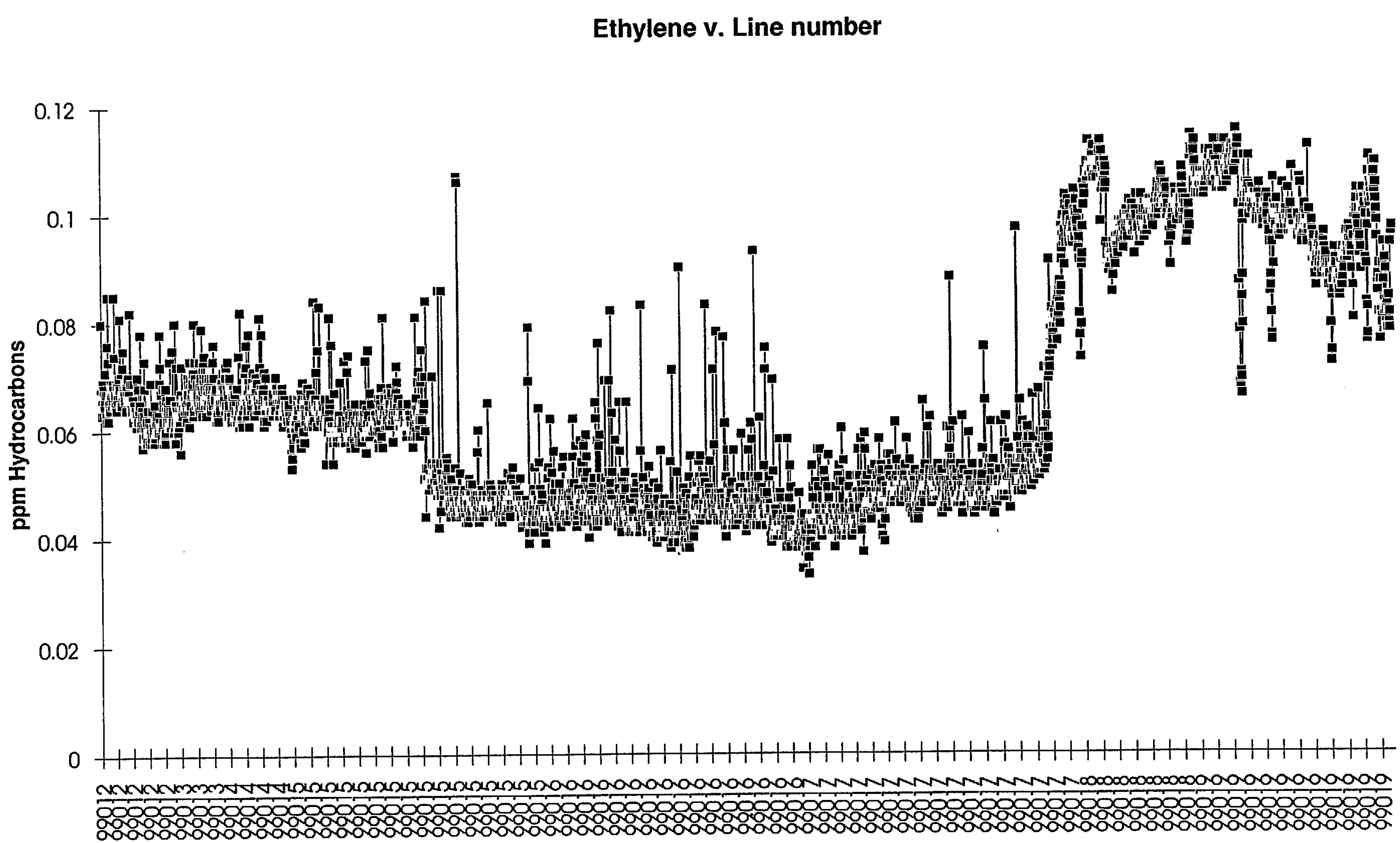

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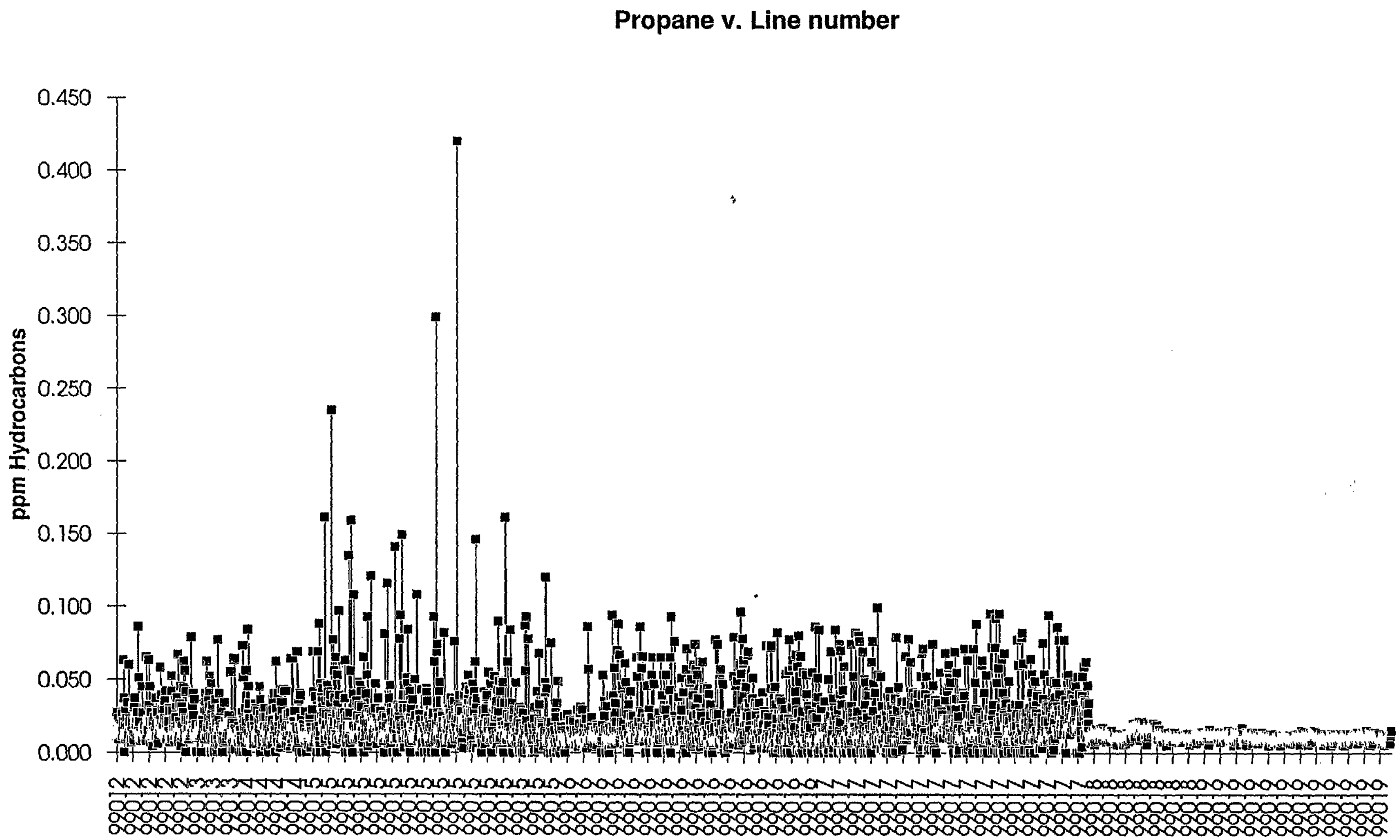

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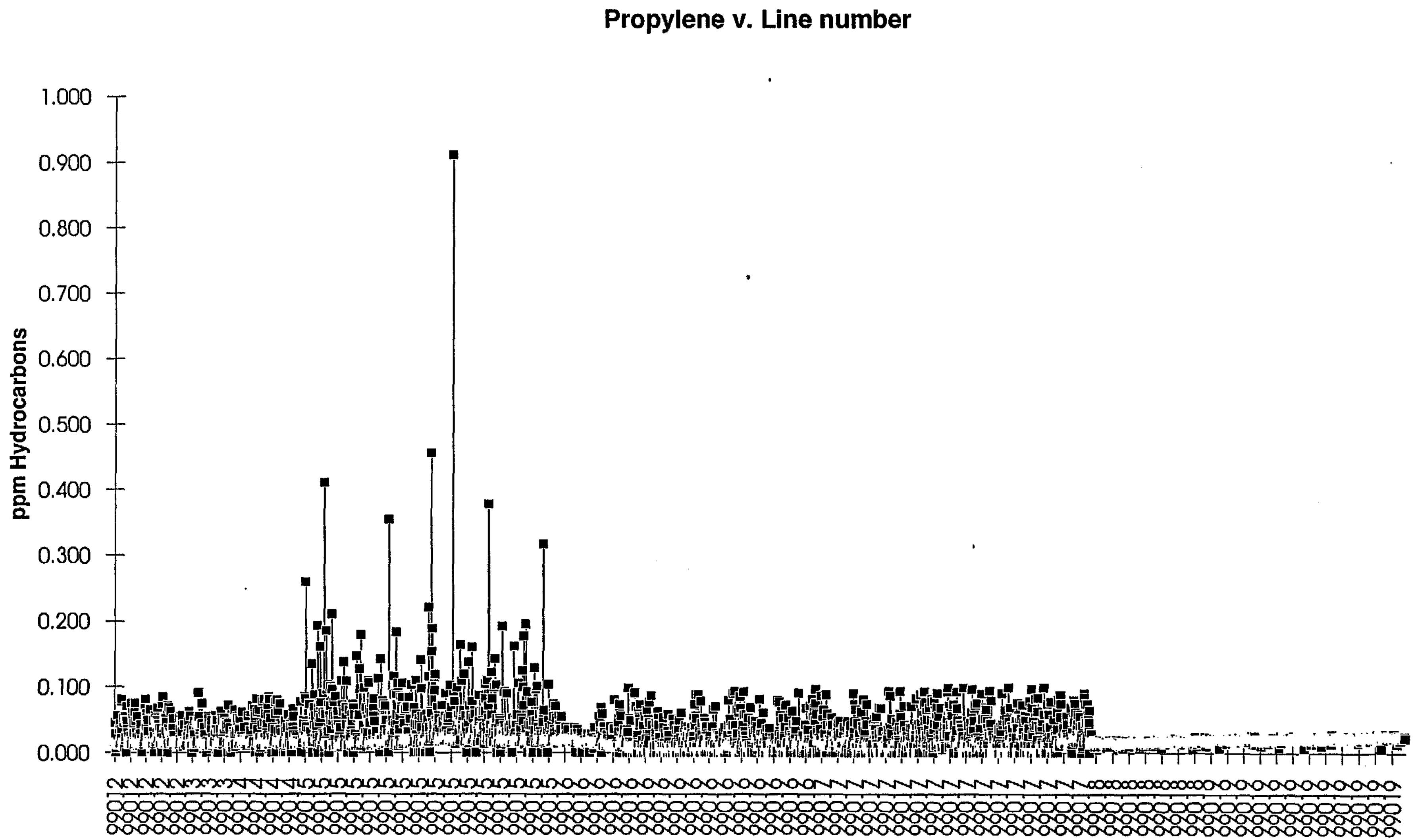

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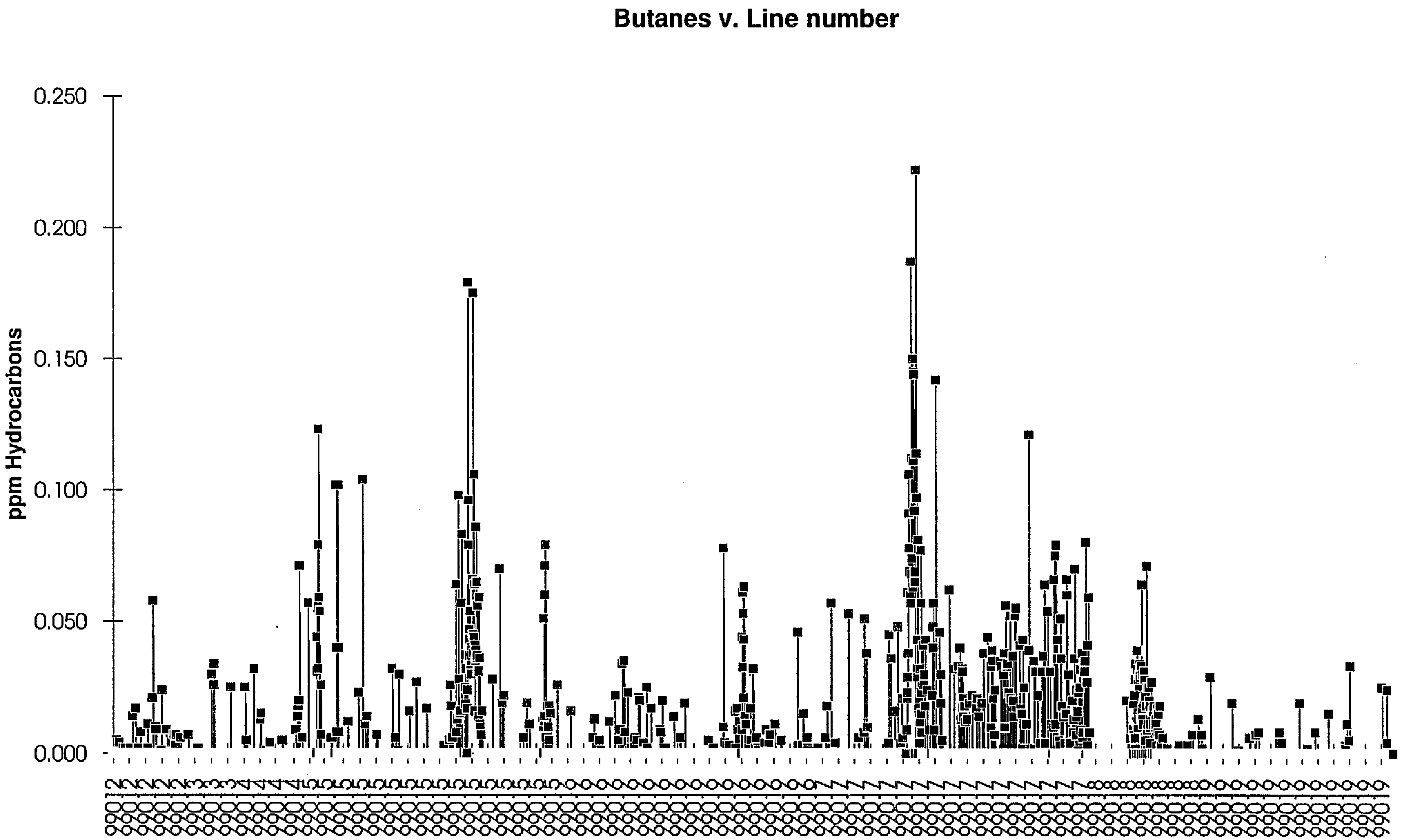

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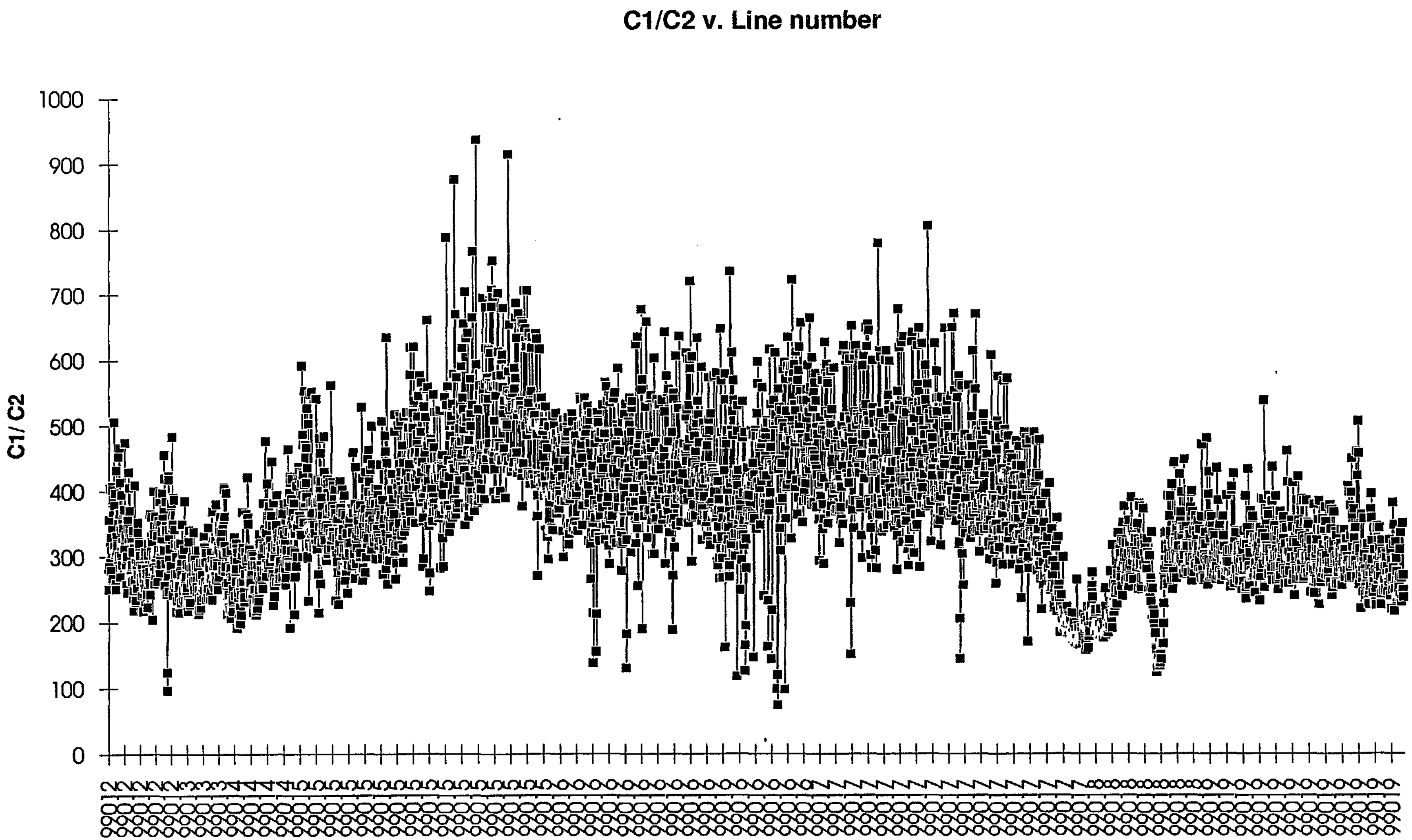

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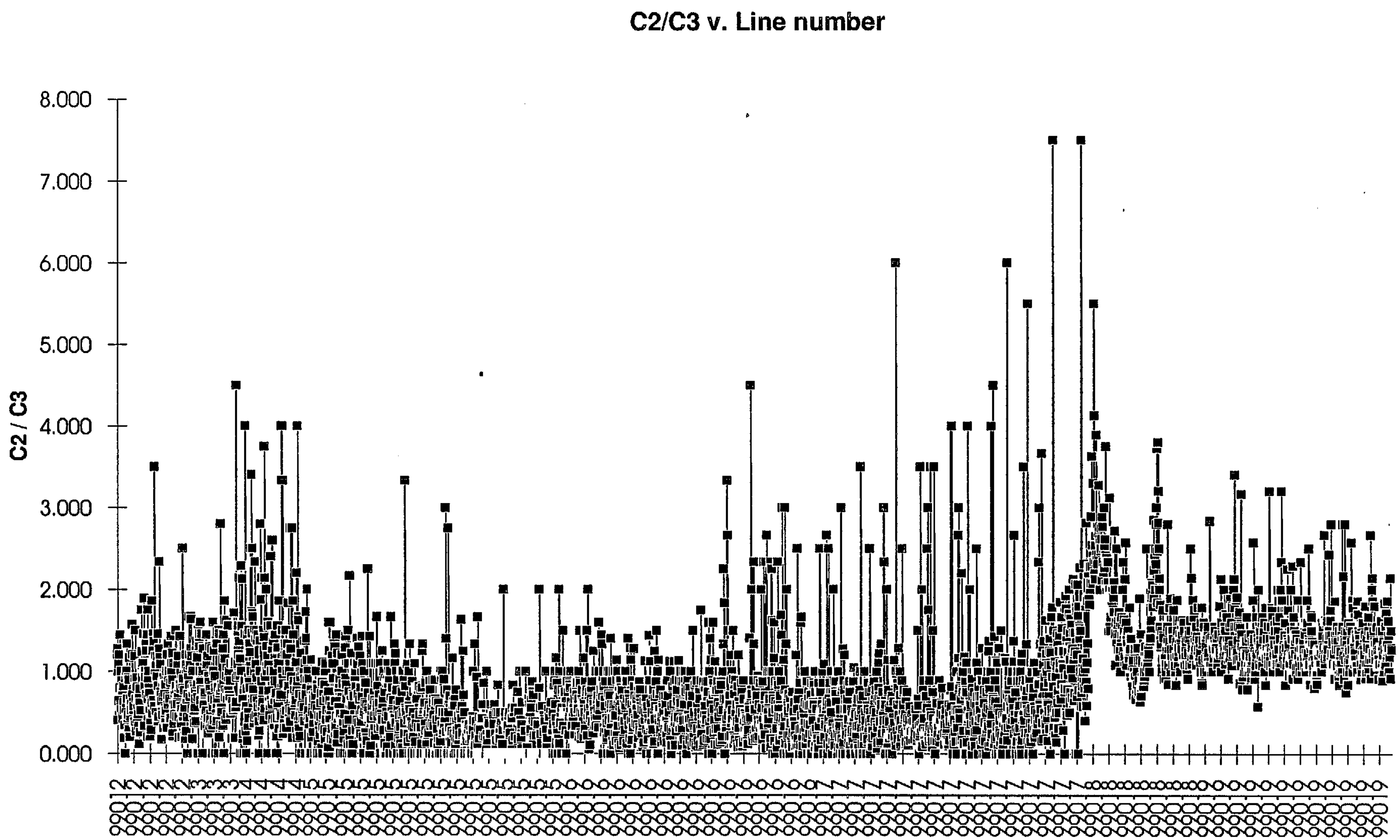

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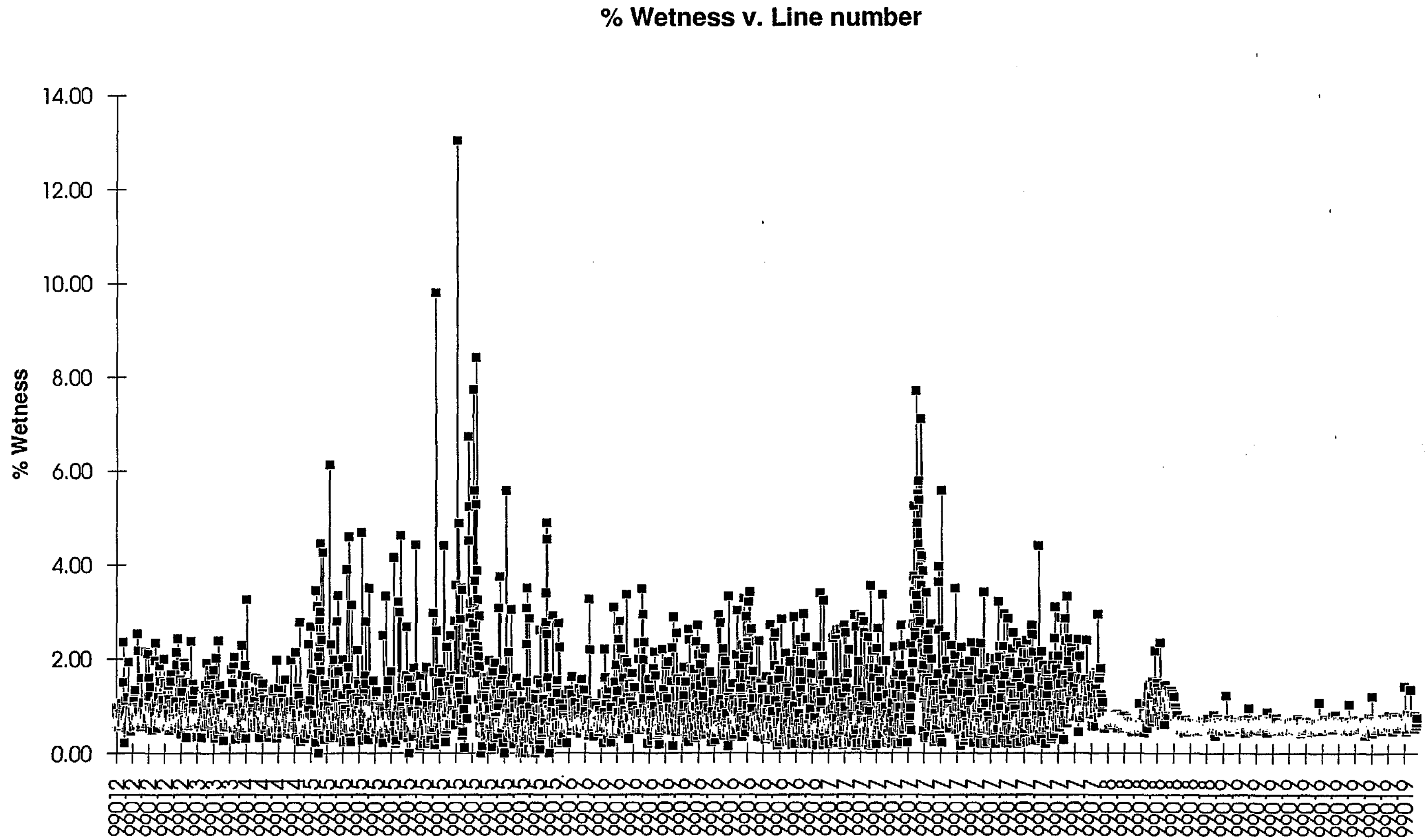

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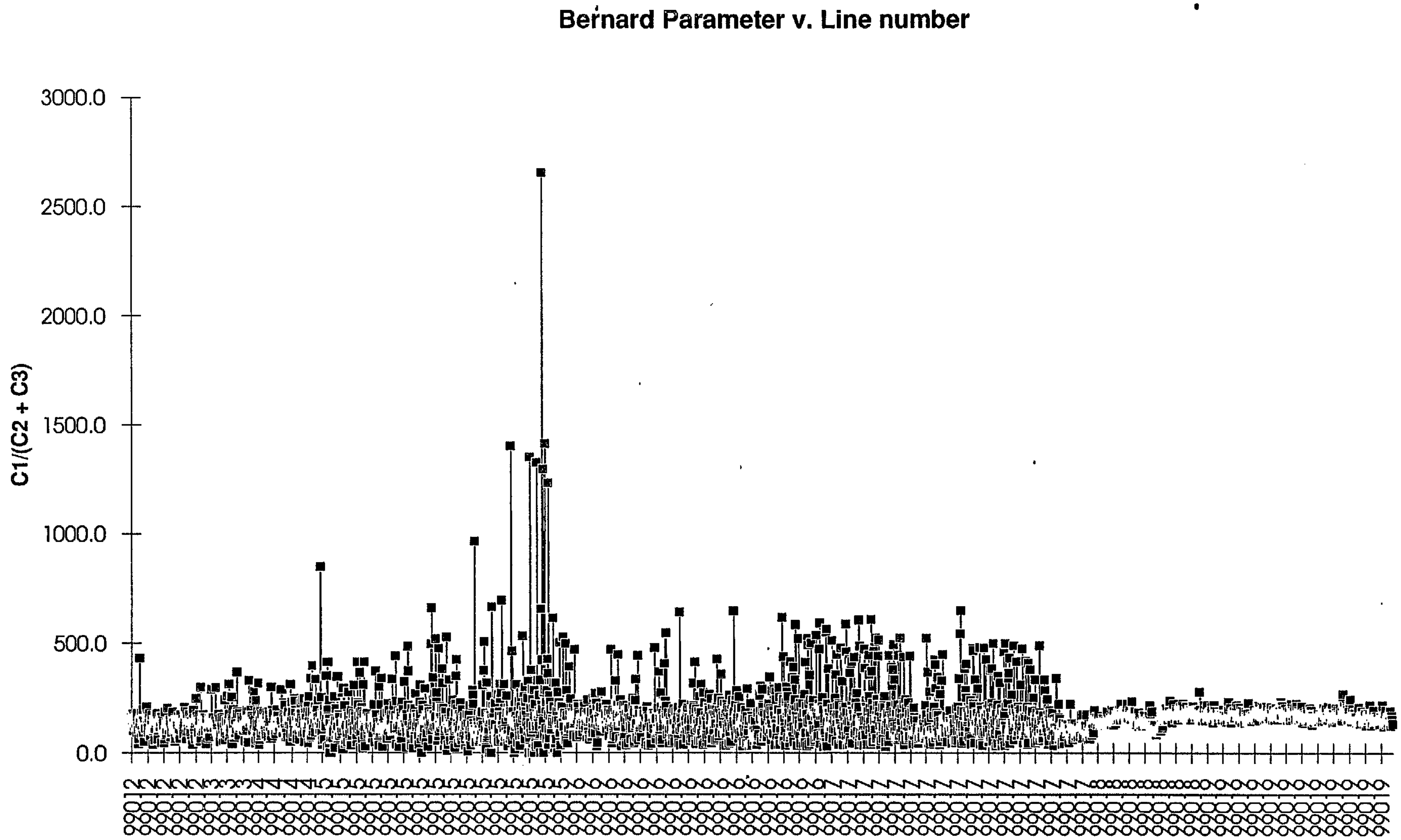

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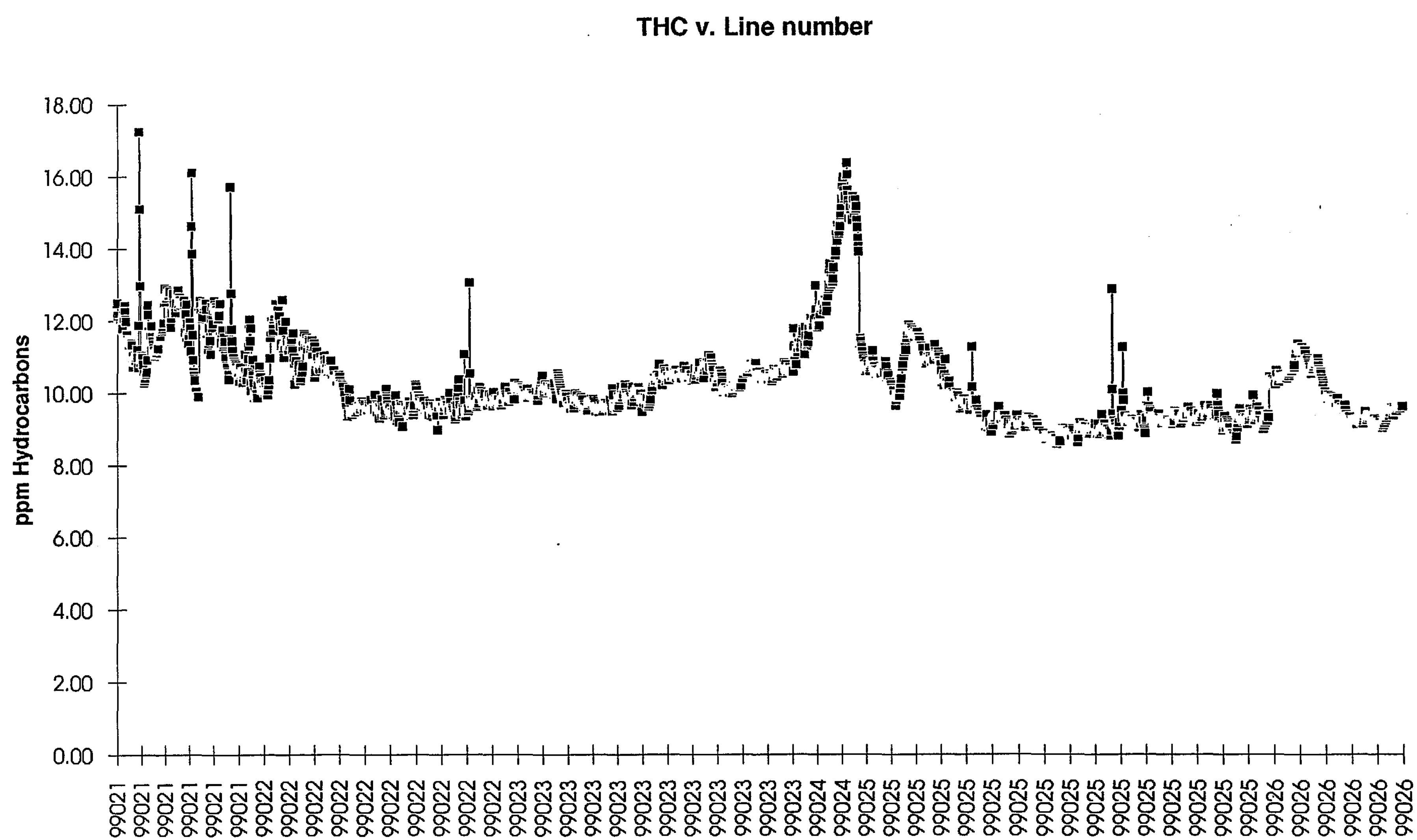

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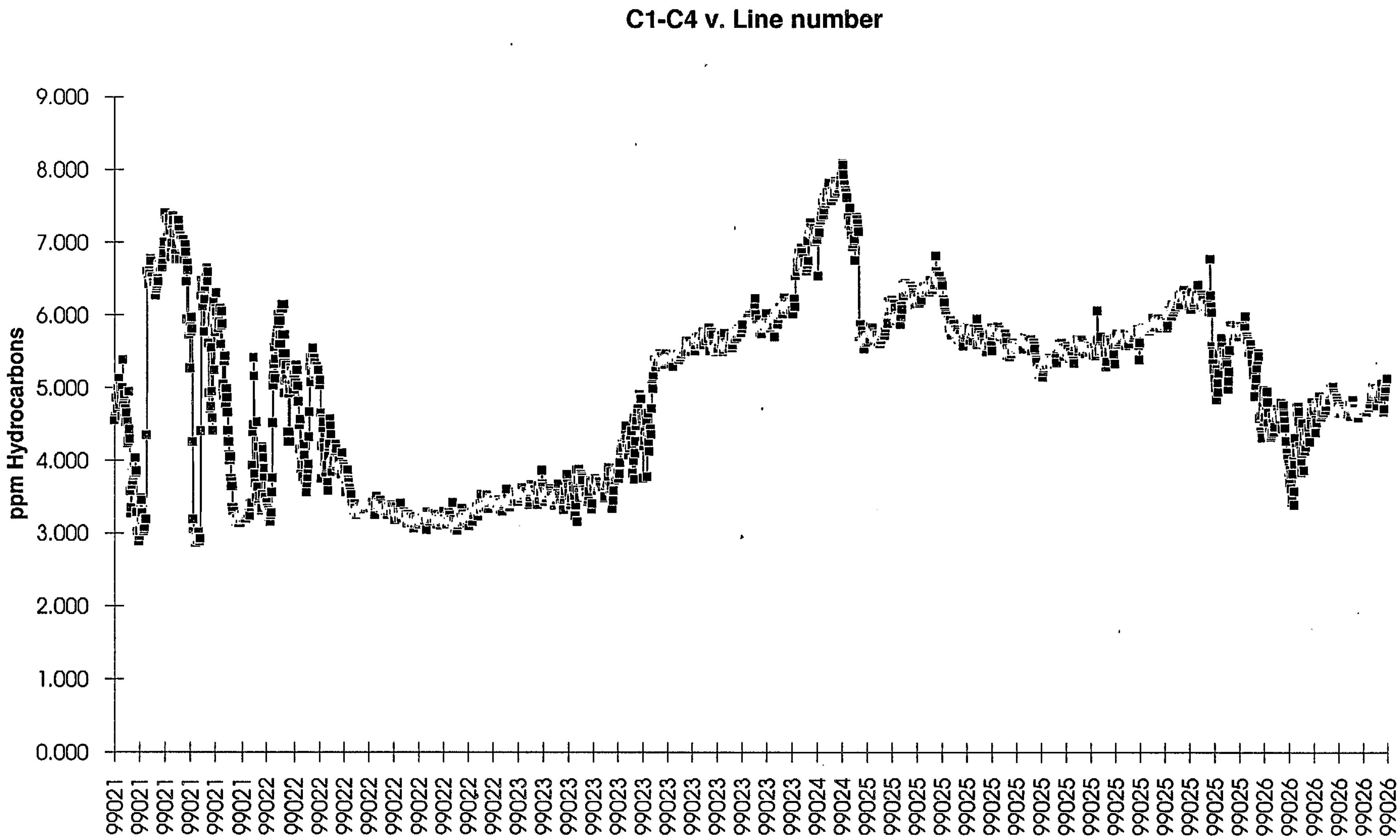

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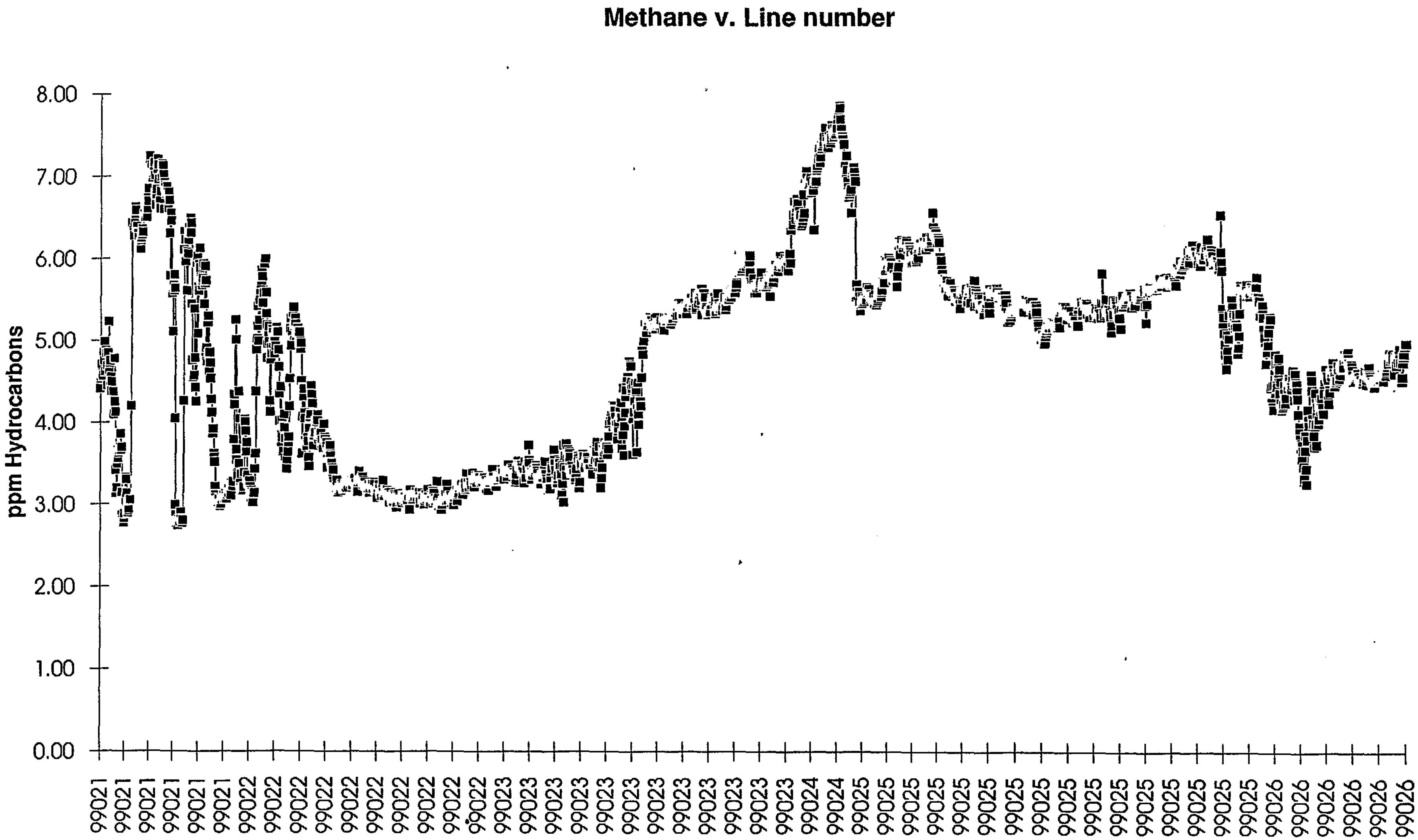

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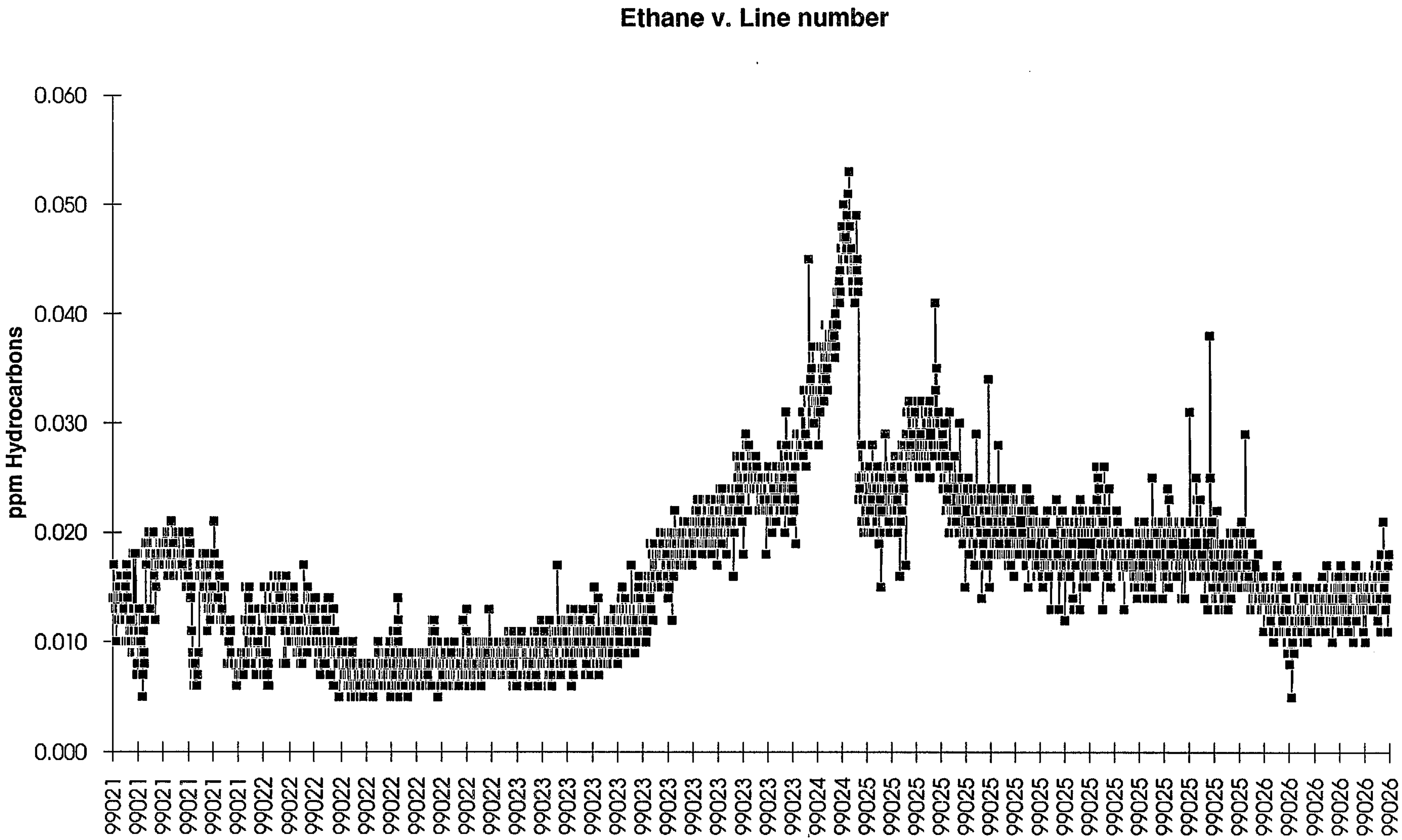

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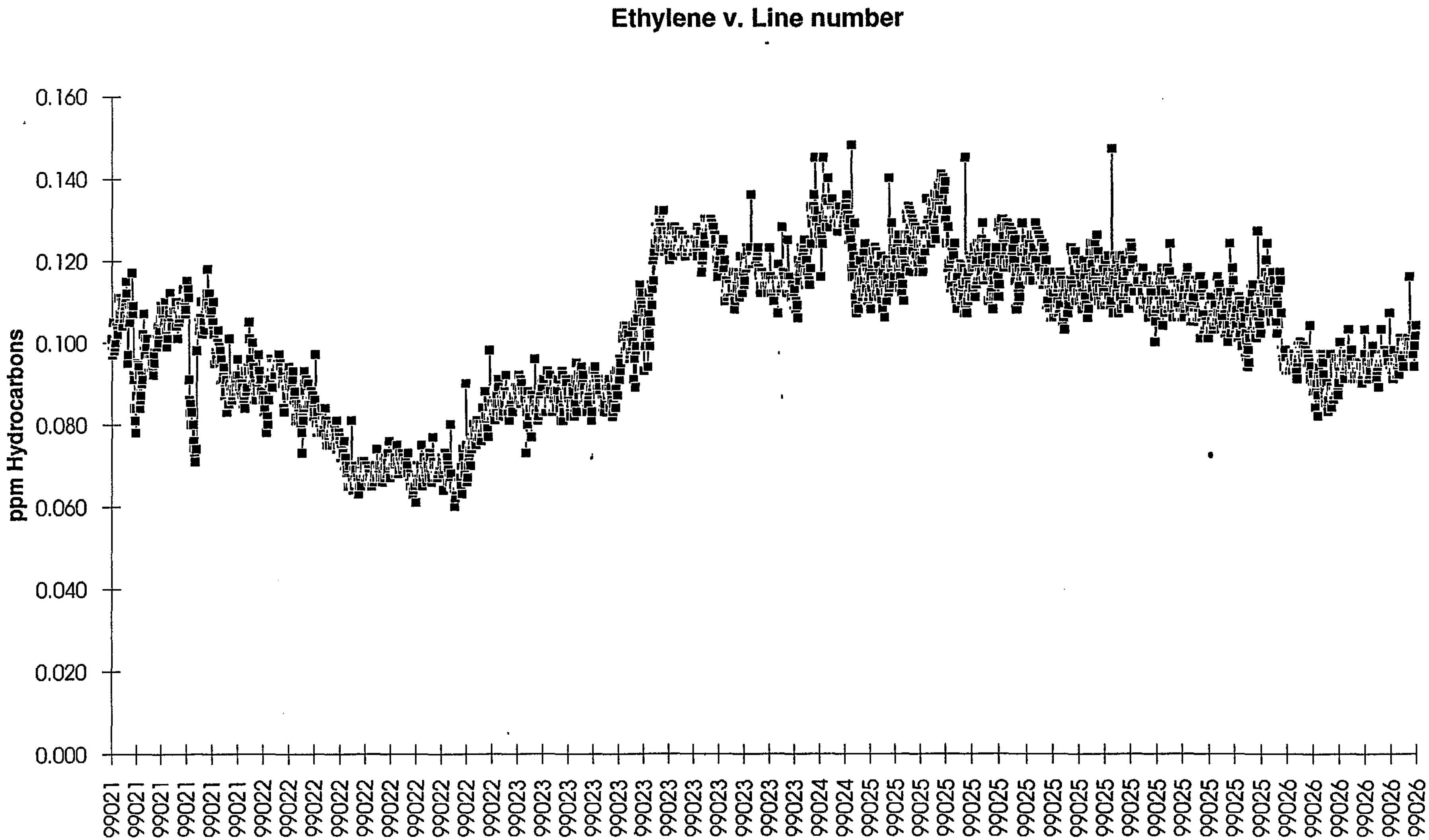

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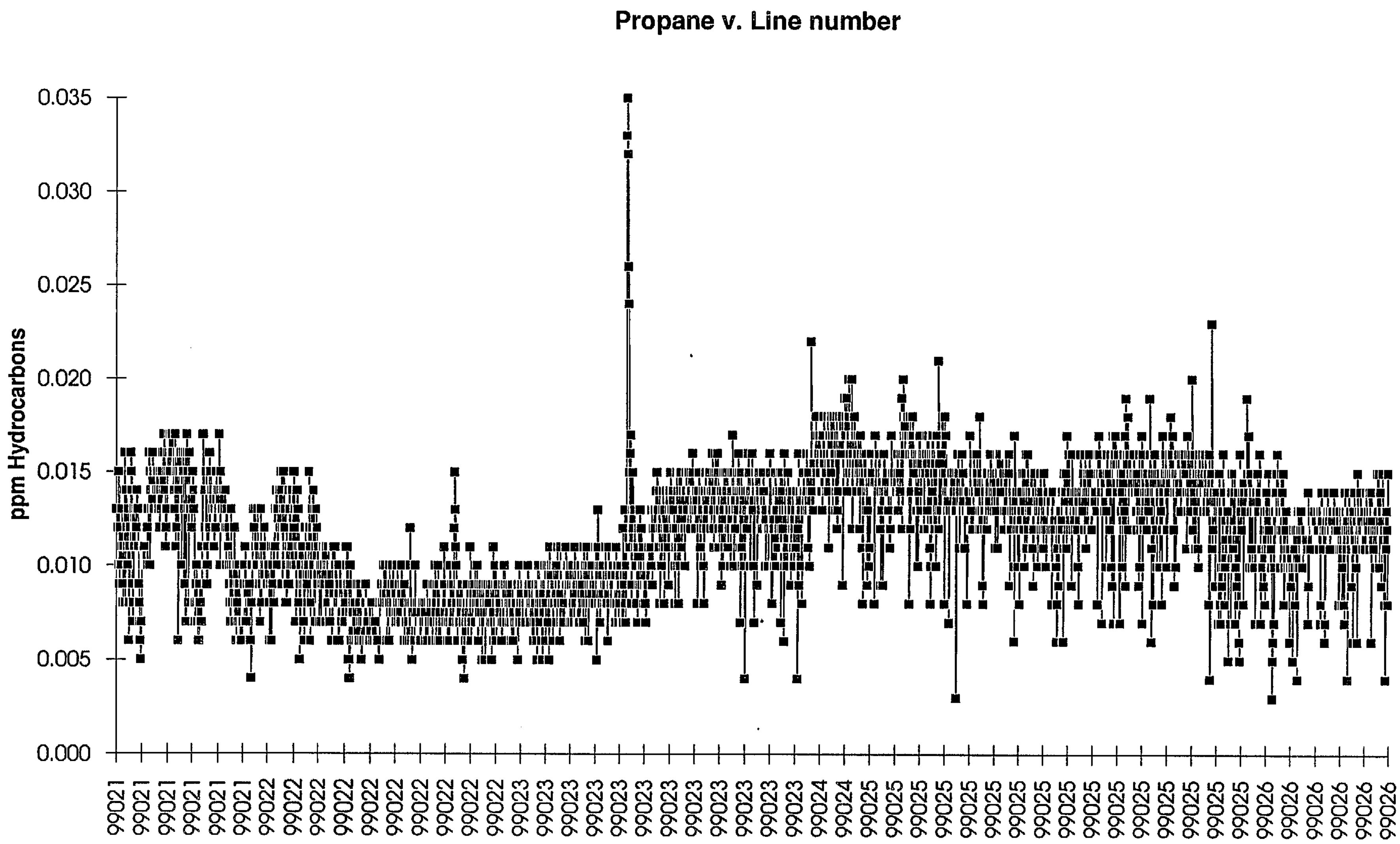

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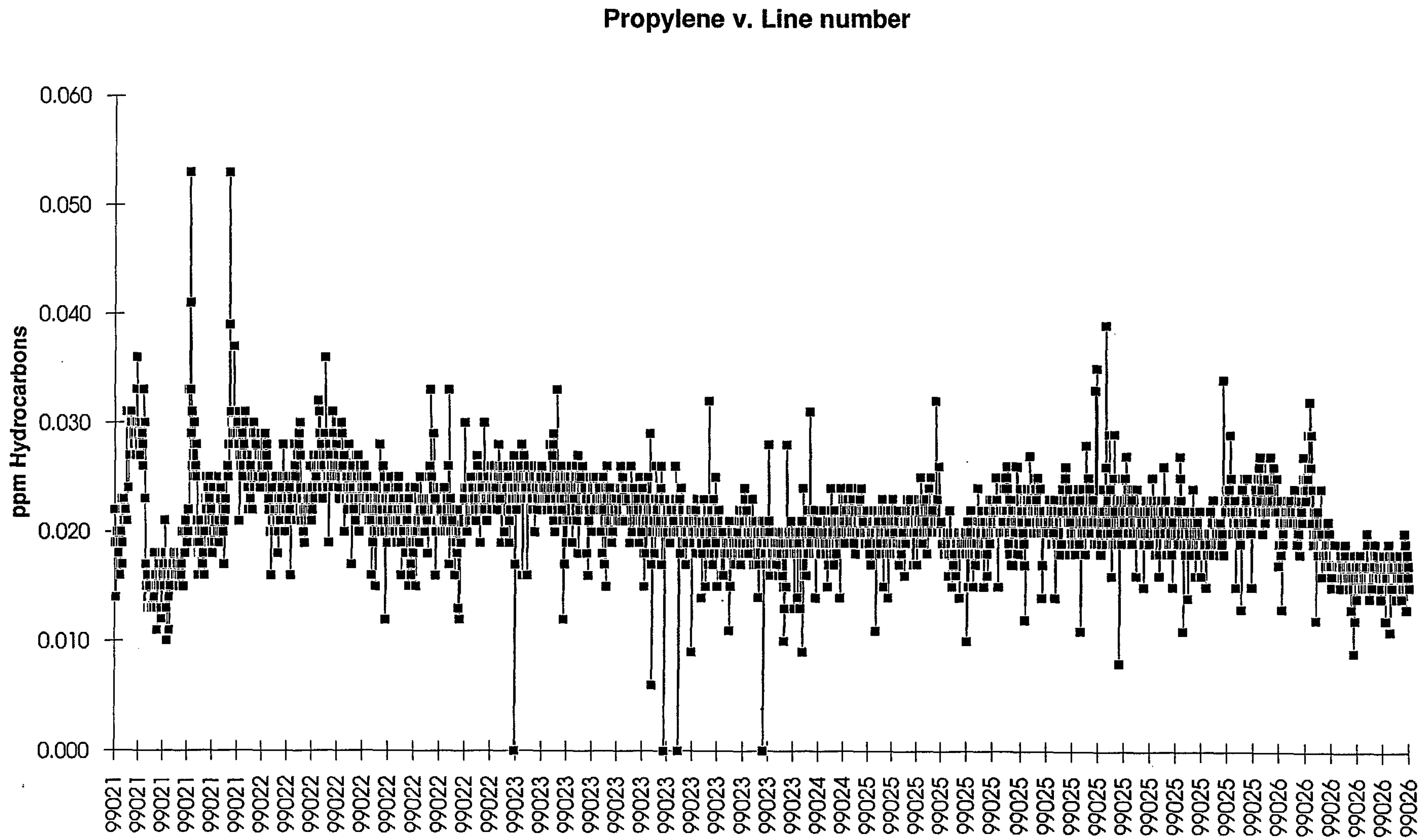

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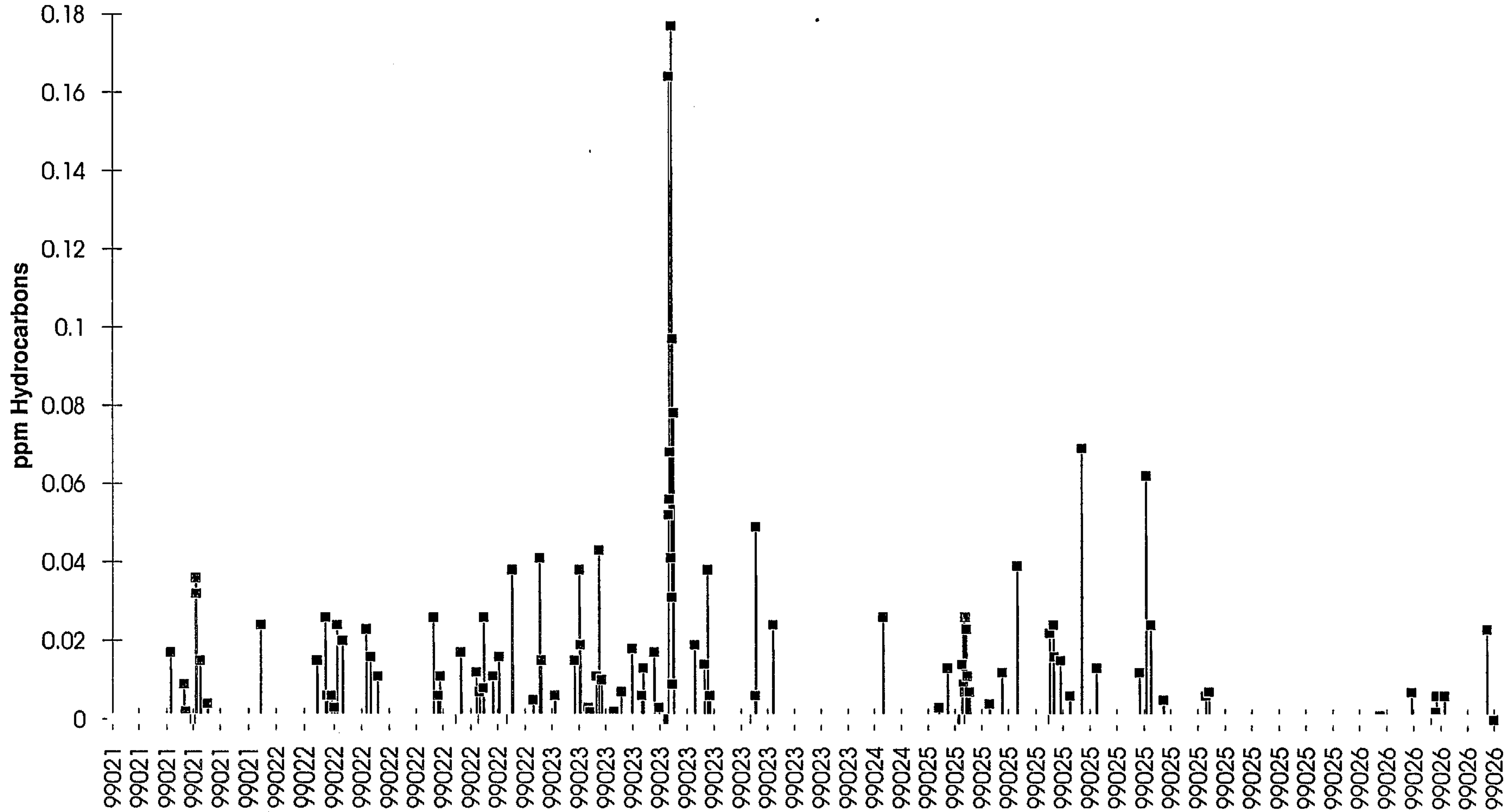
Butanes v. Line number



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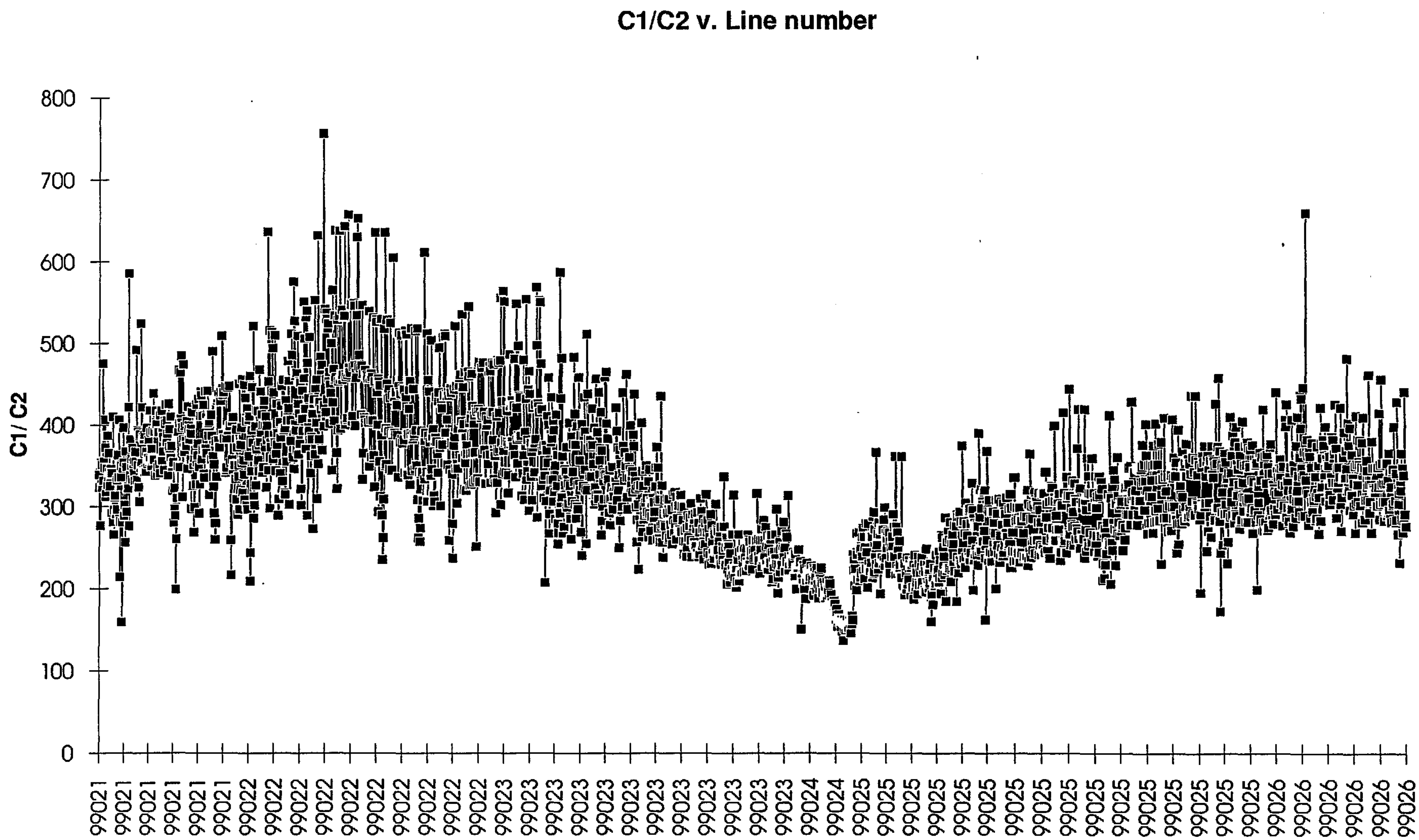

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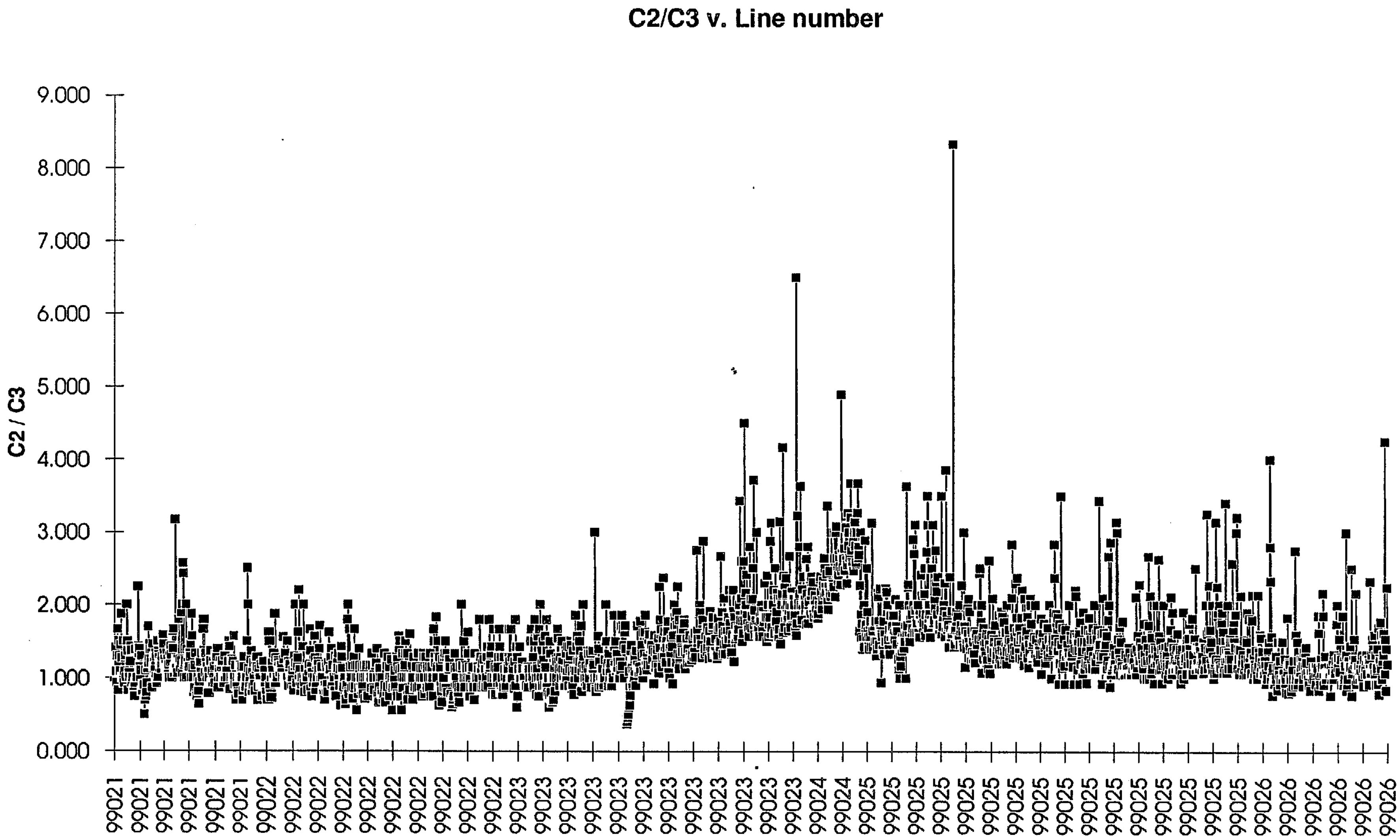

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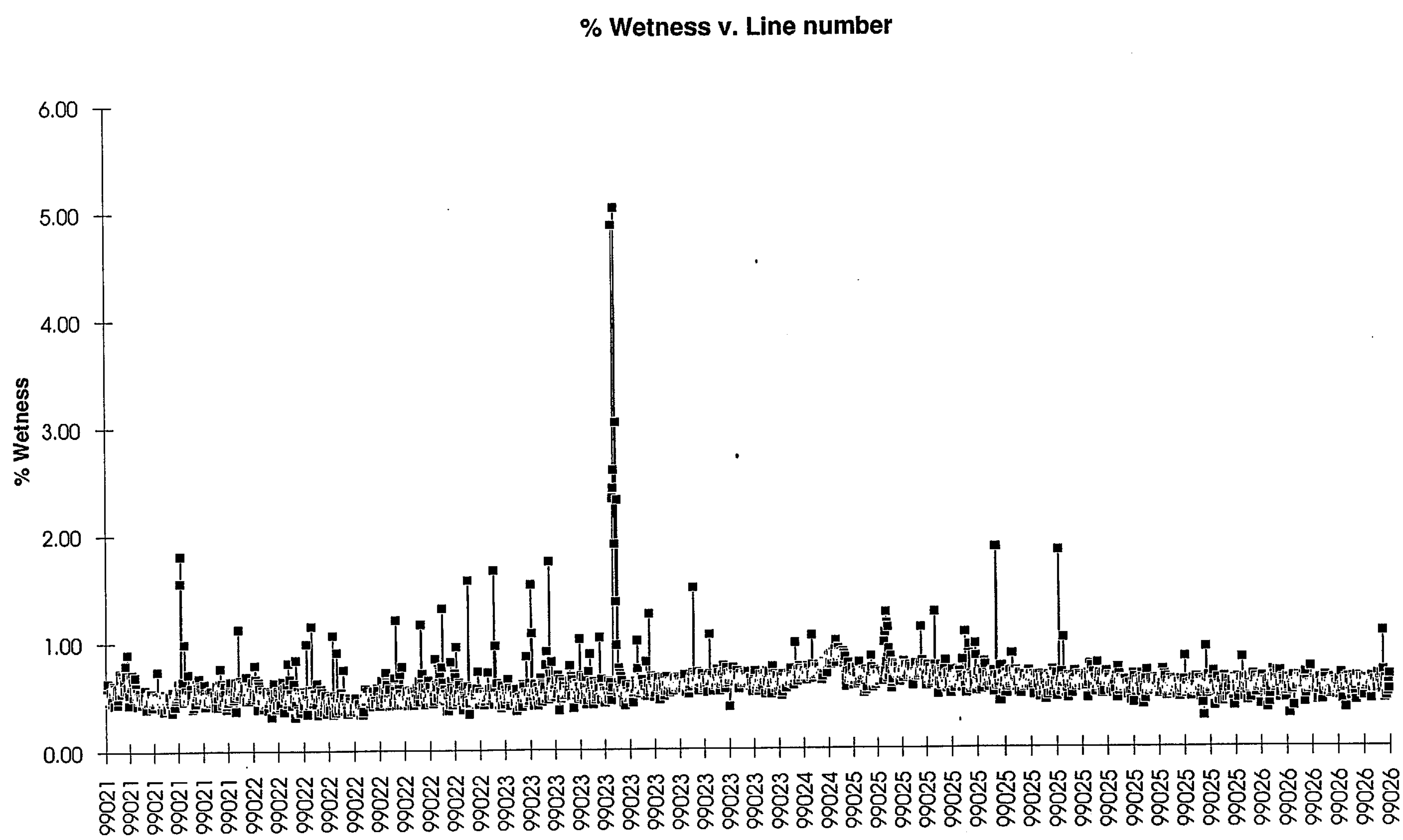

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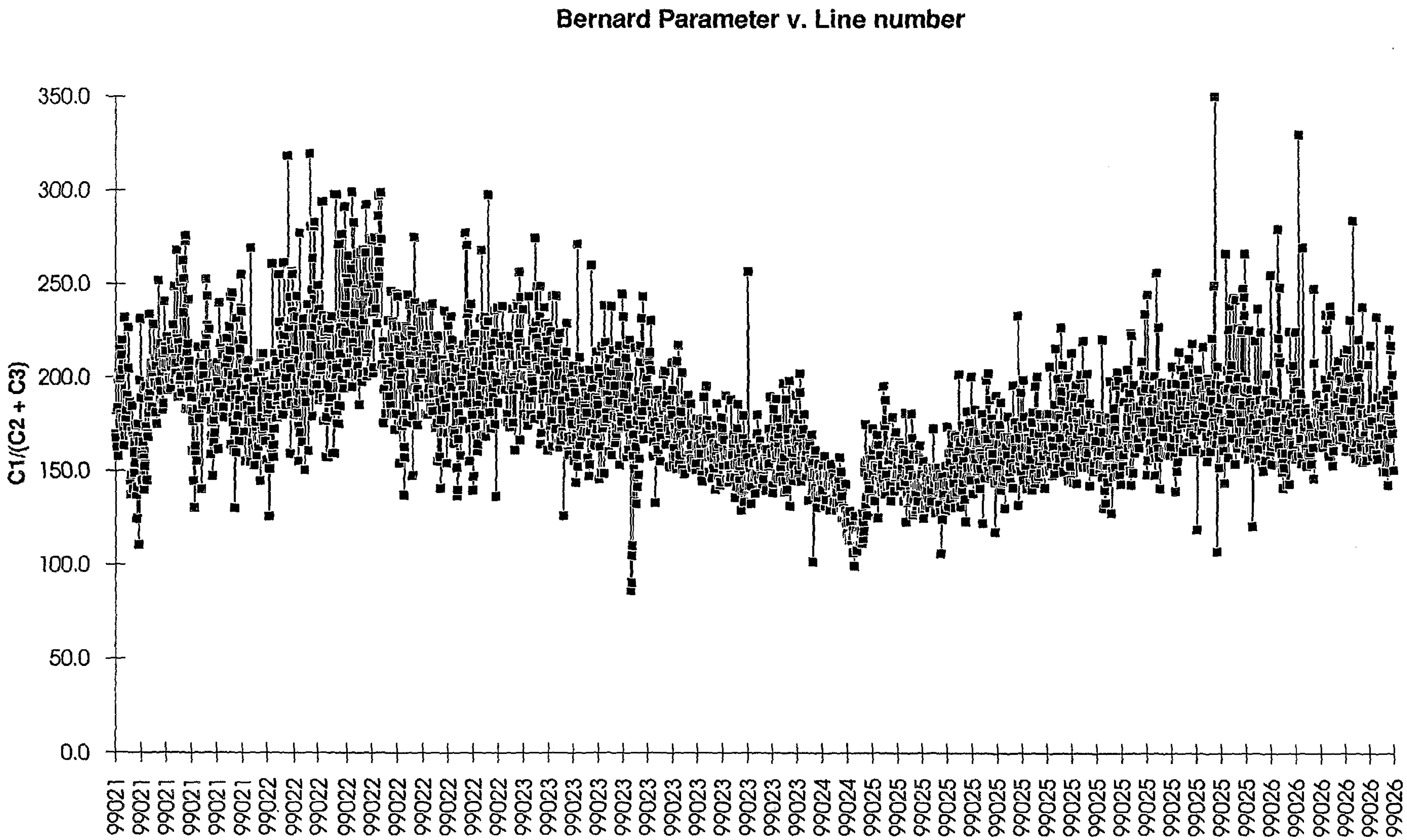

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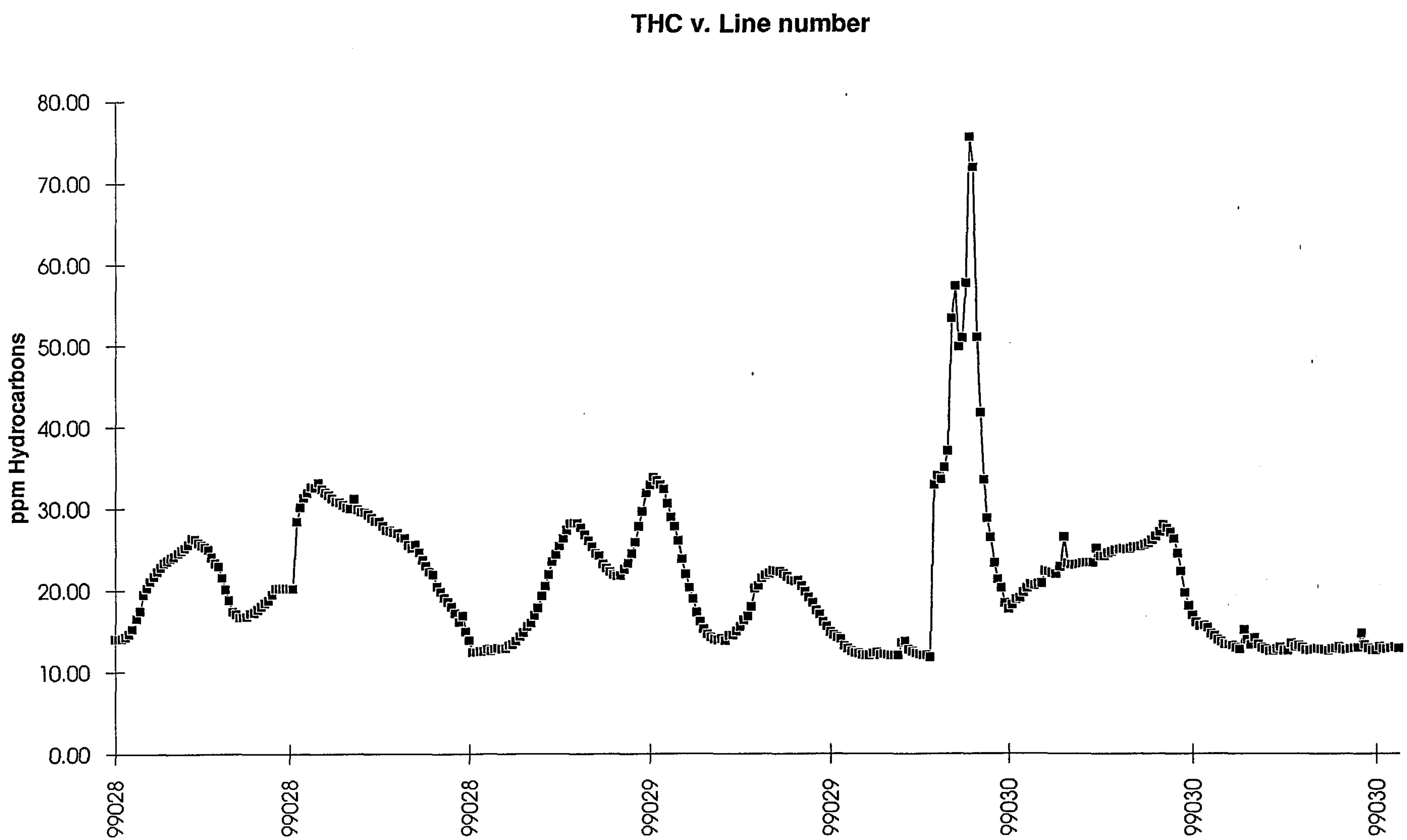
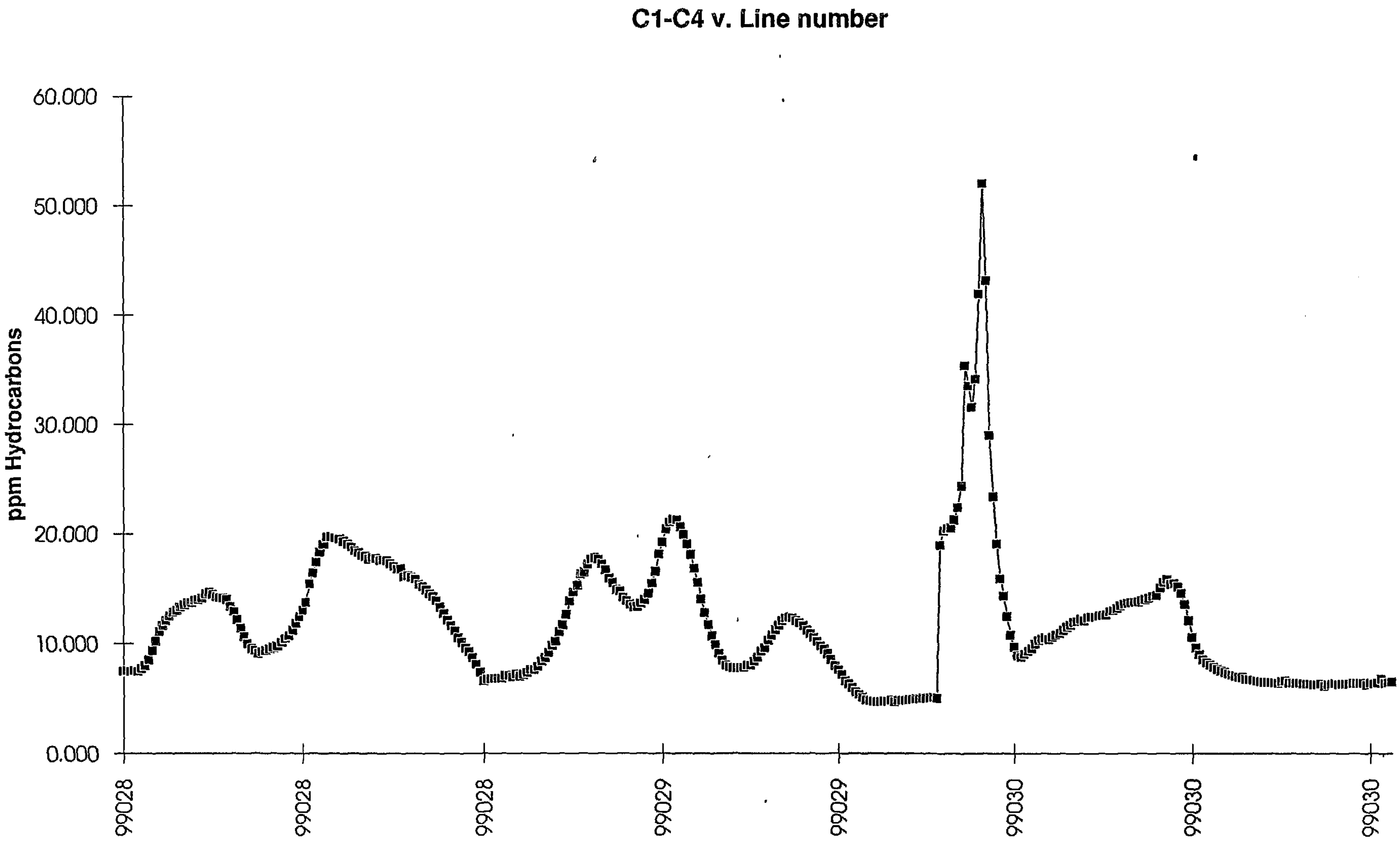


Figure 39. THC versus line number (survey lines 28-30).



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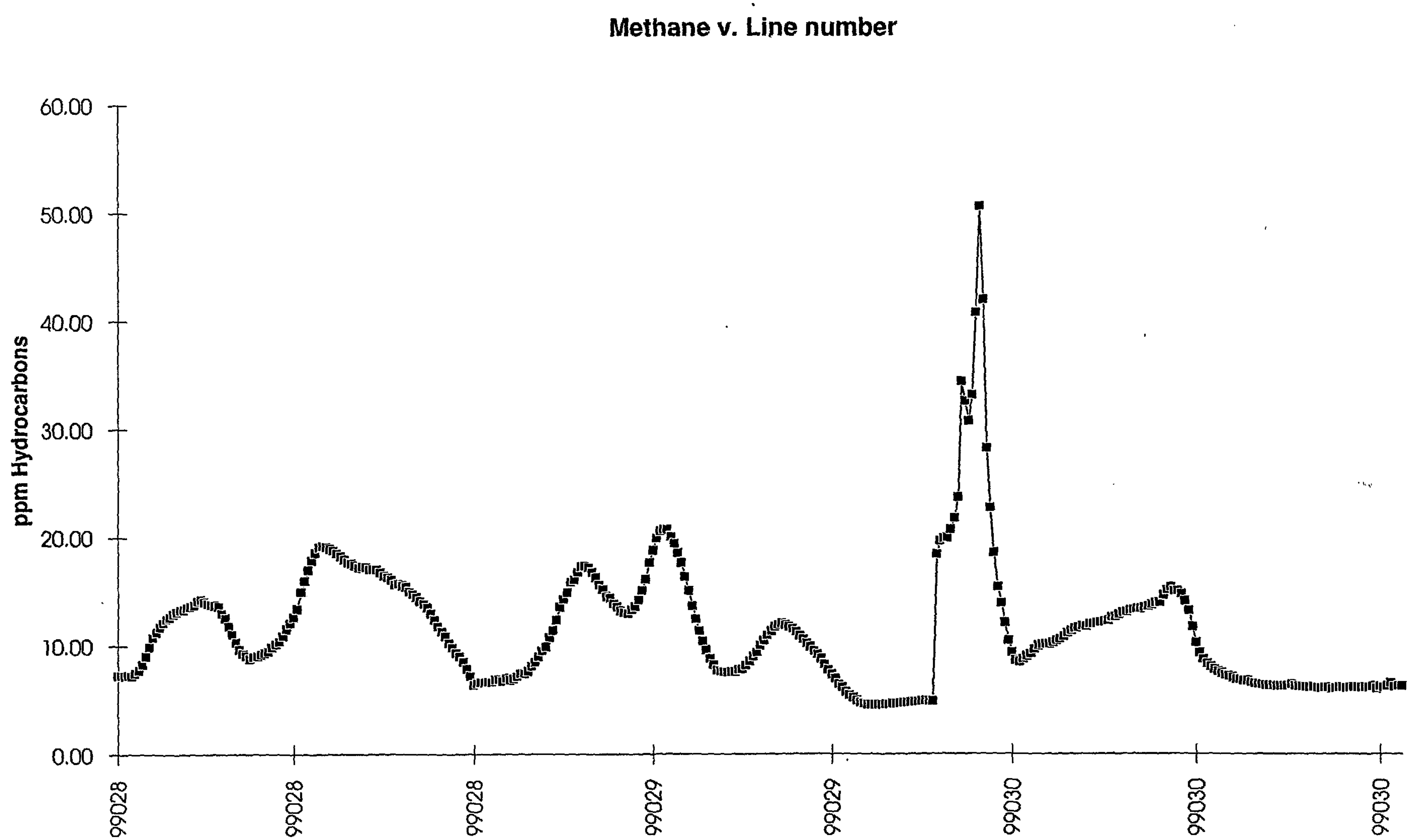

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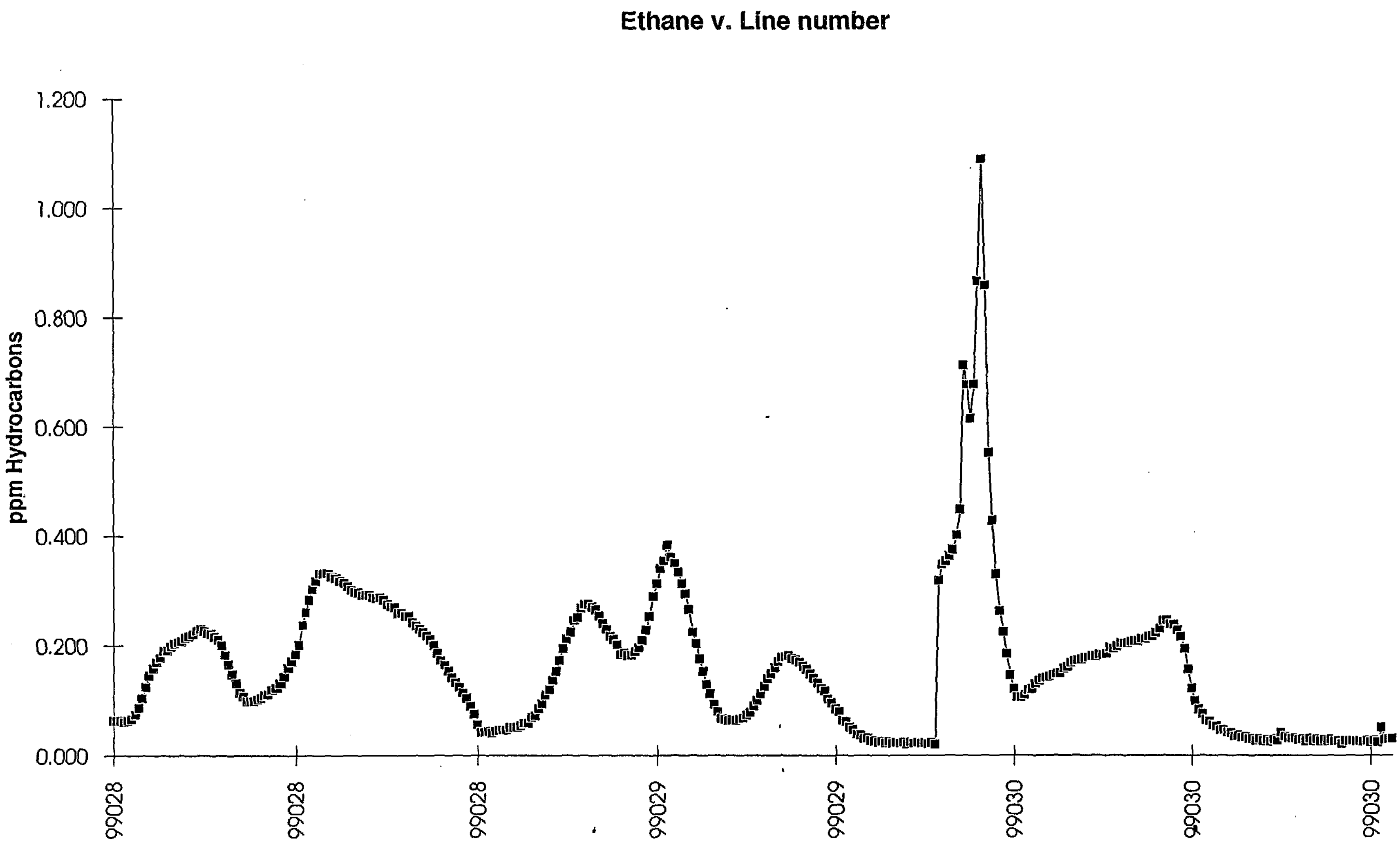

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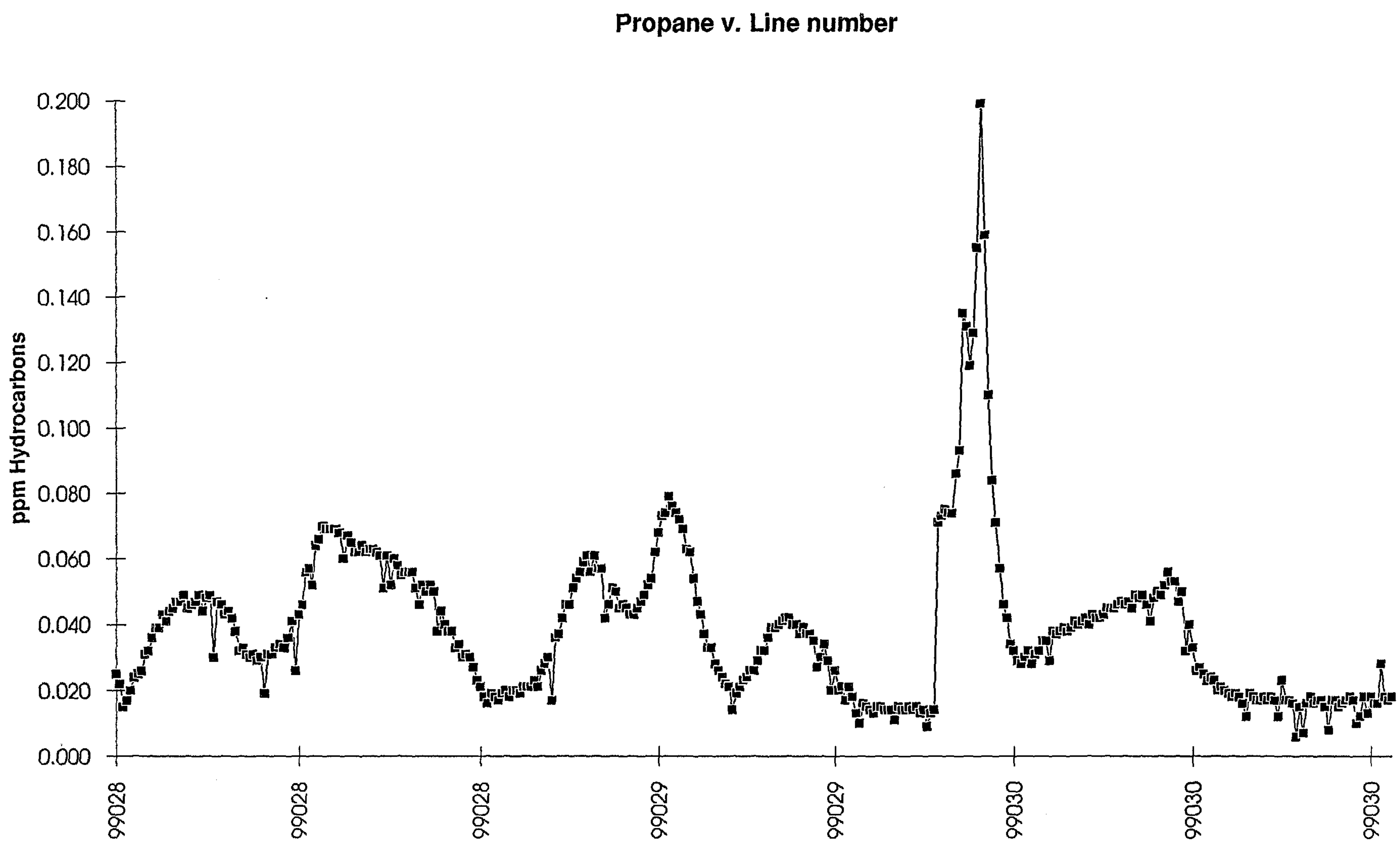

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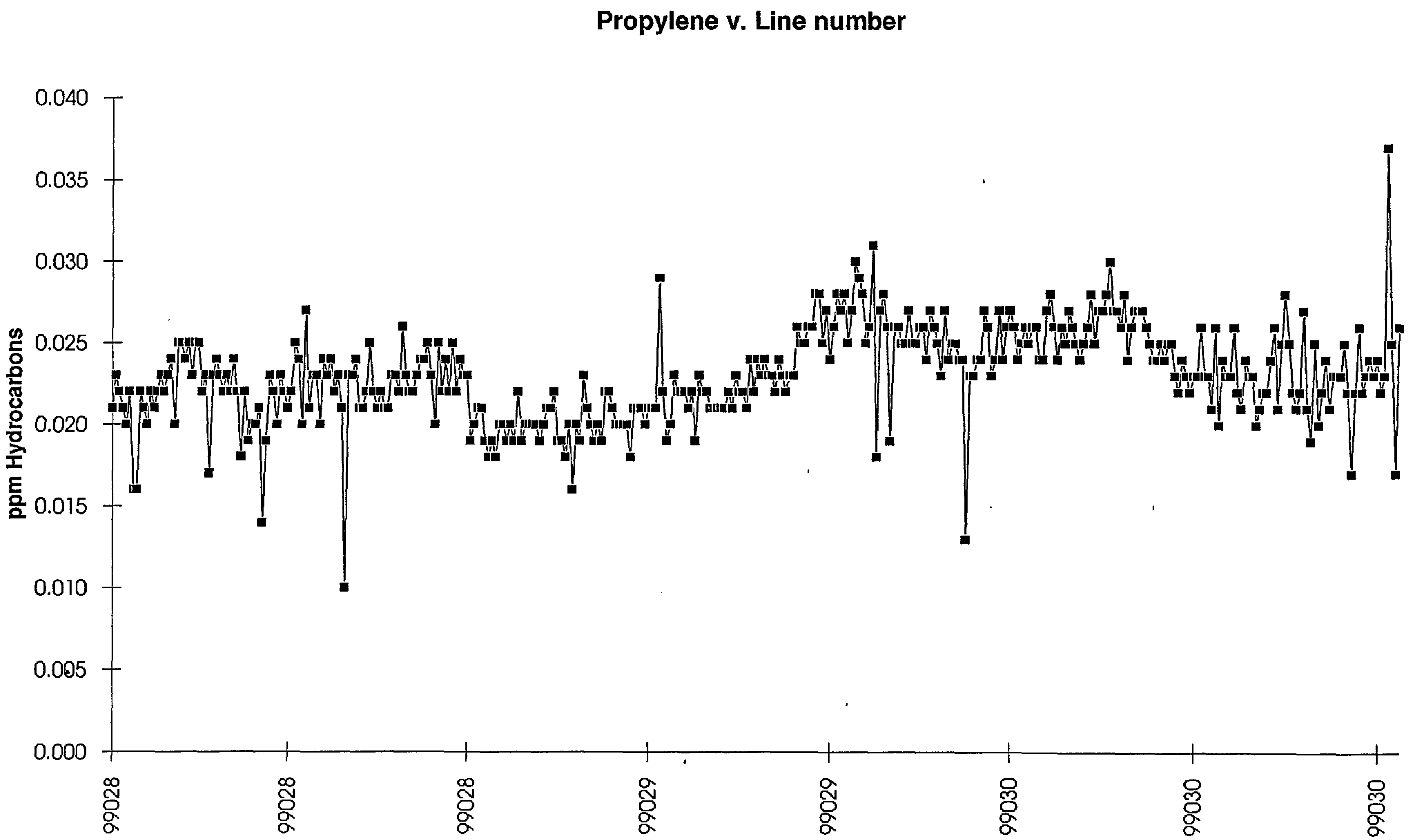

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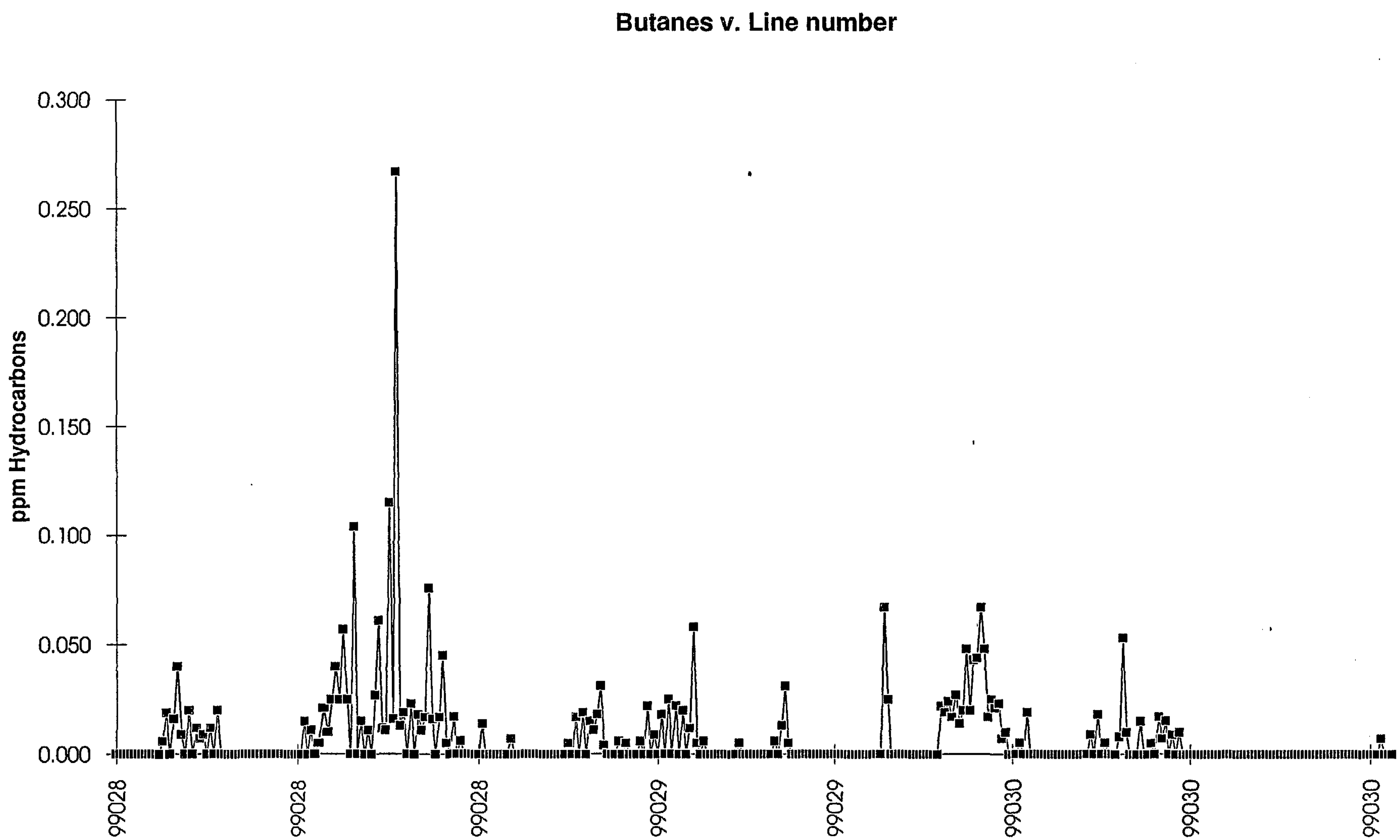

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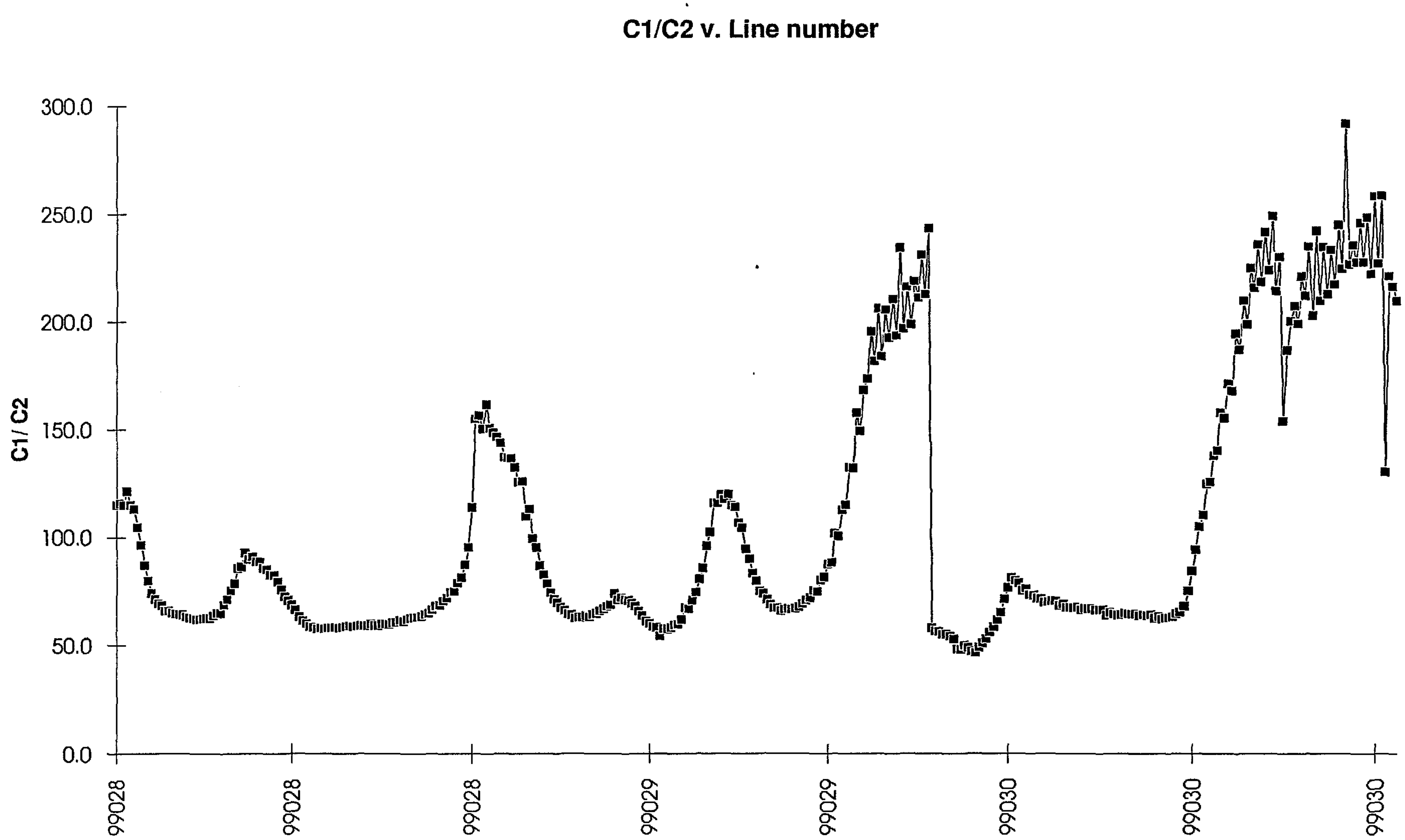

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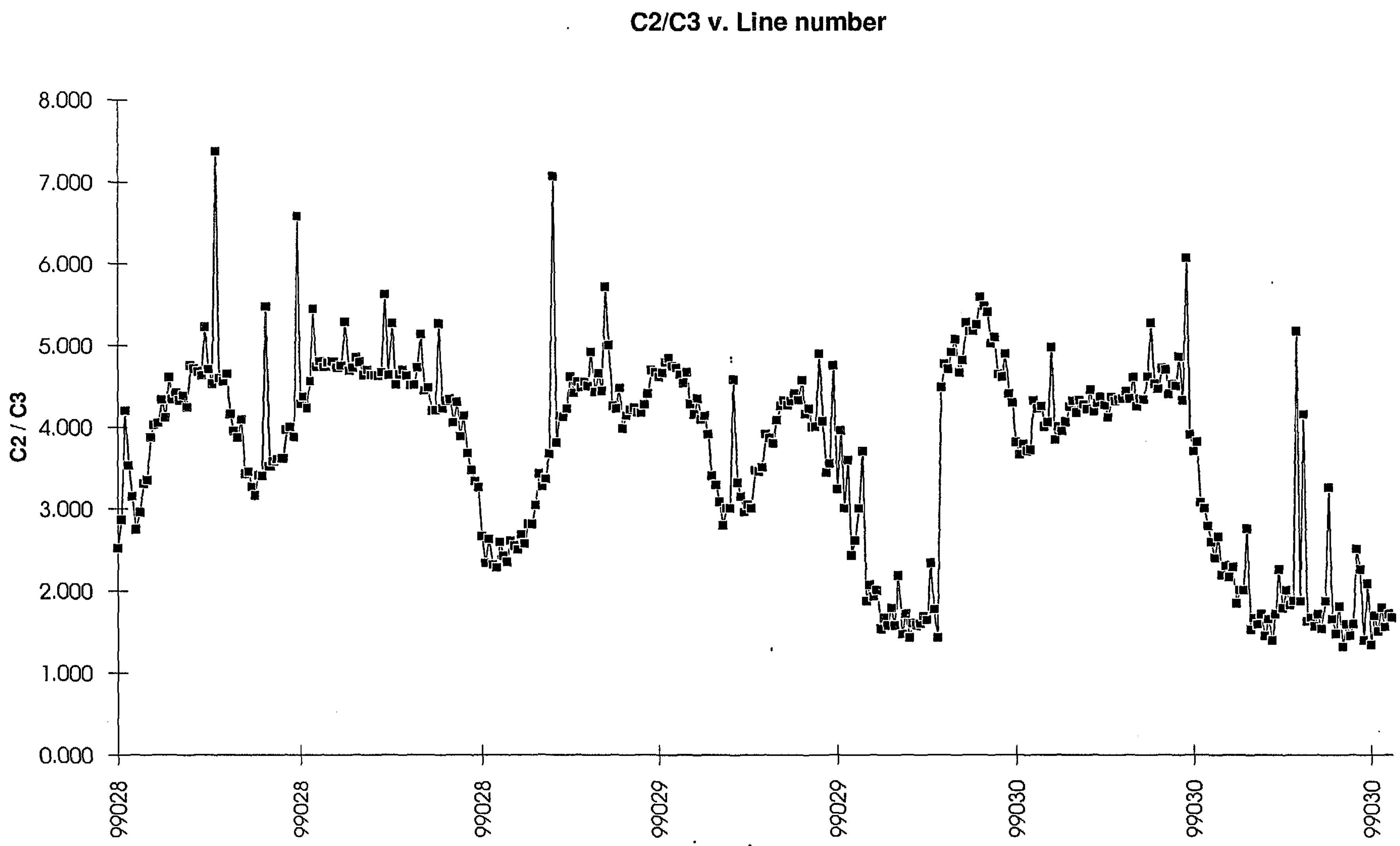

Figure 48. Ratio of C2/C3 versus line number (survey lines 28-30).

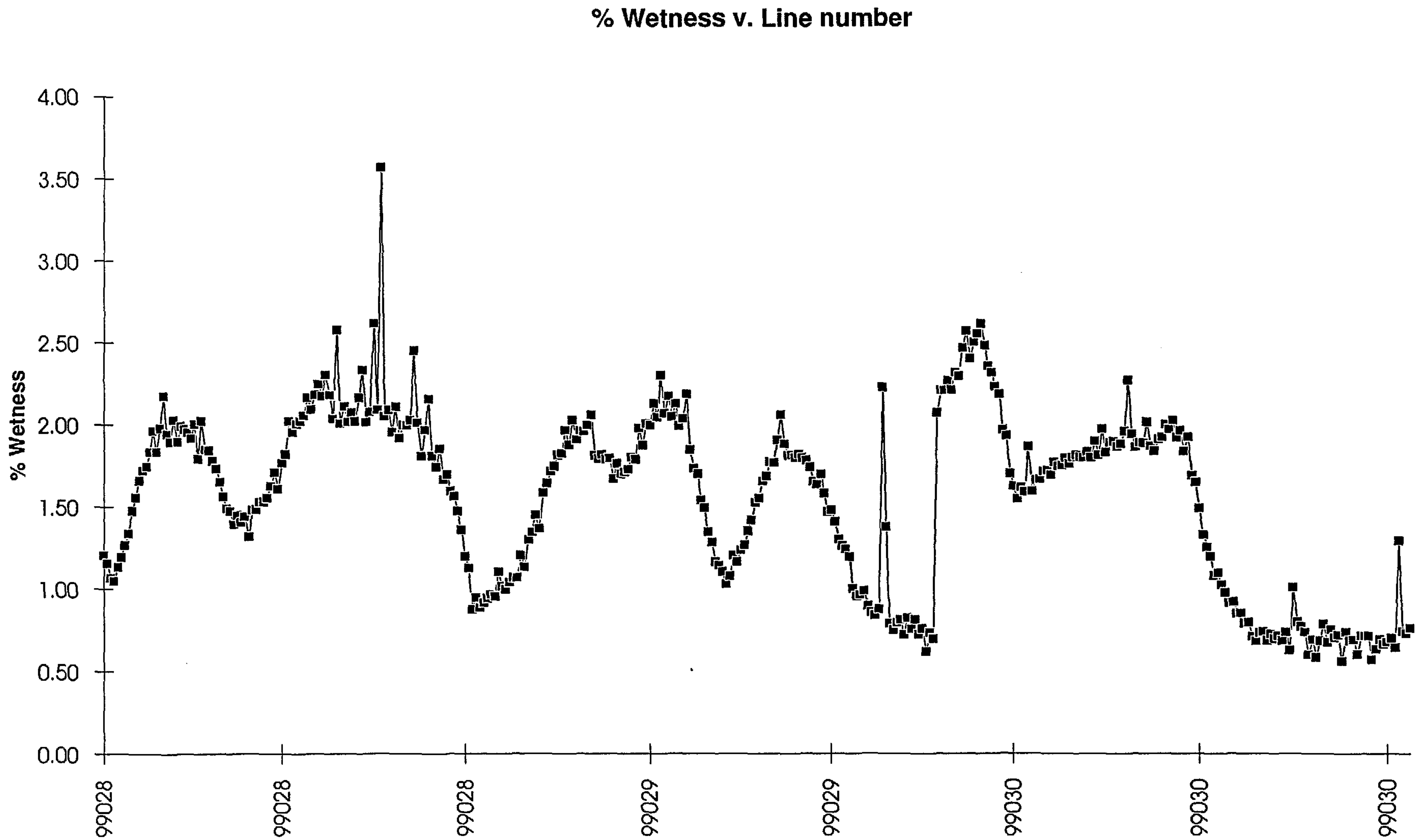

Figure 49. Percent hydrocarbon wetness versus line number (survey lines 28-30)

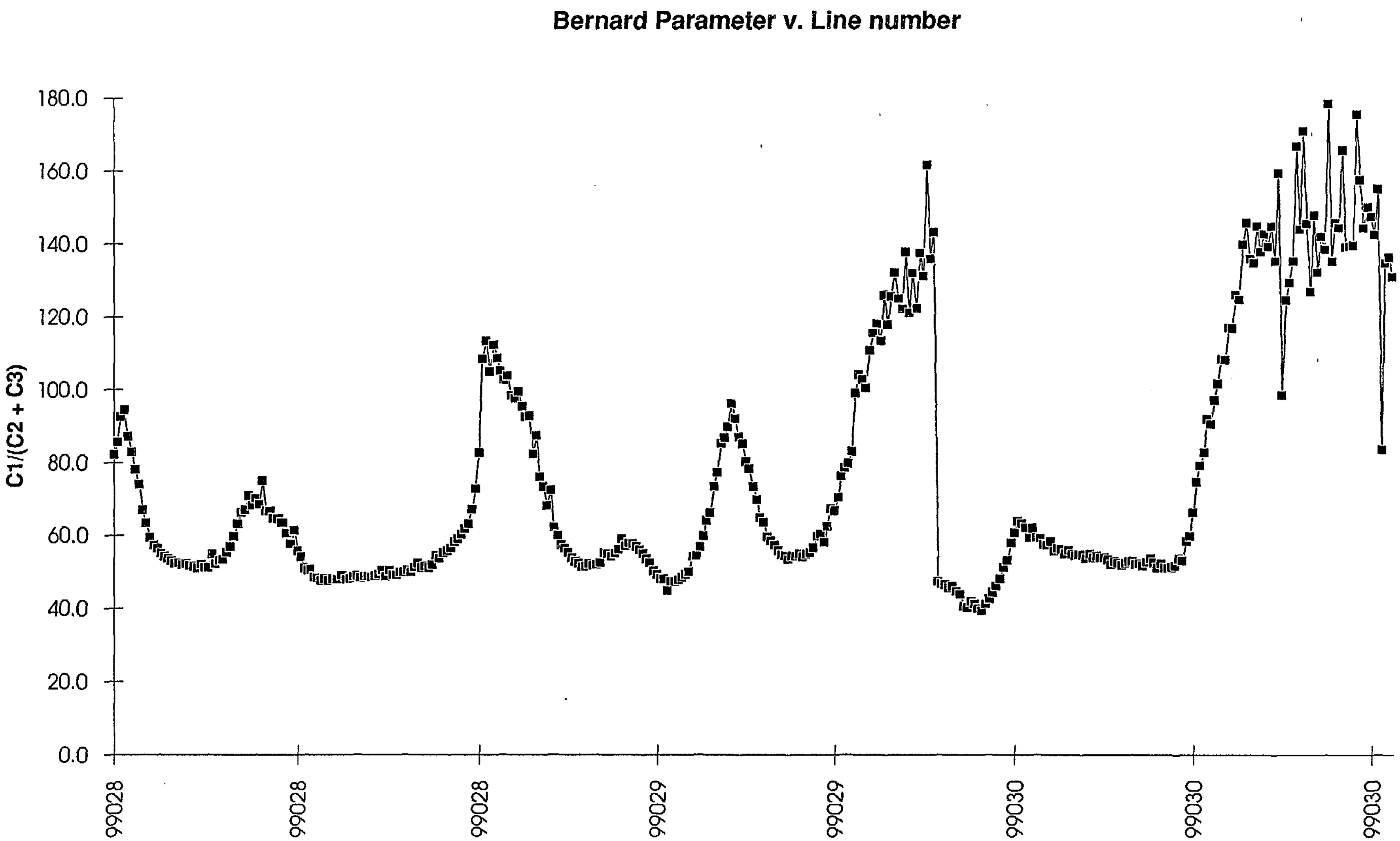

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Figure 51. THC versus tow-fish depth for a vertical profile.

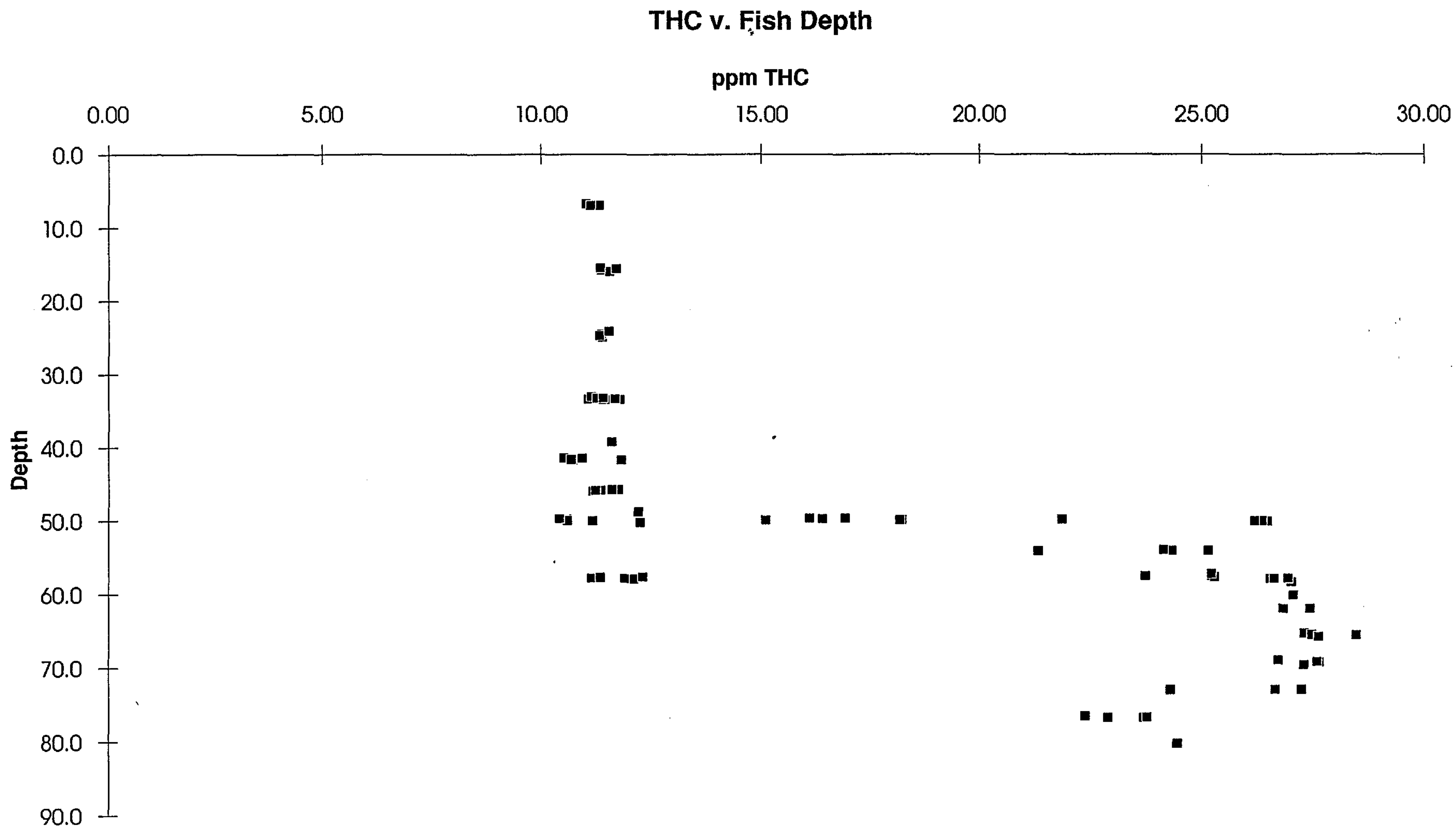
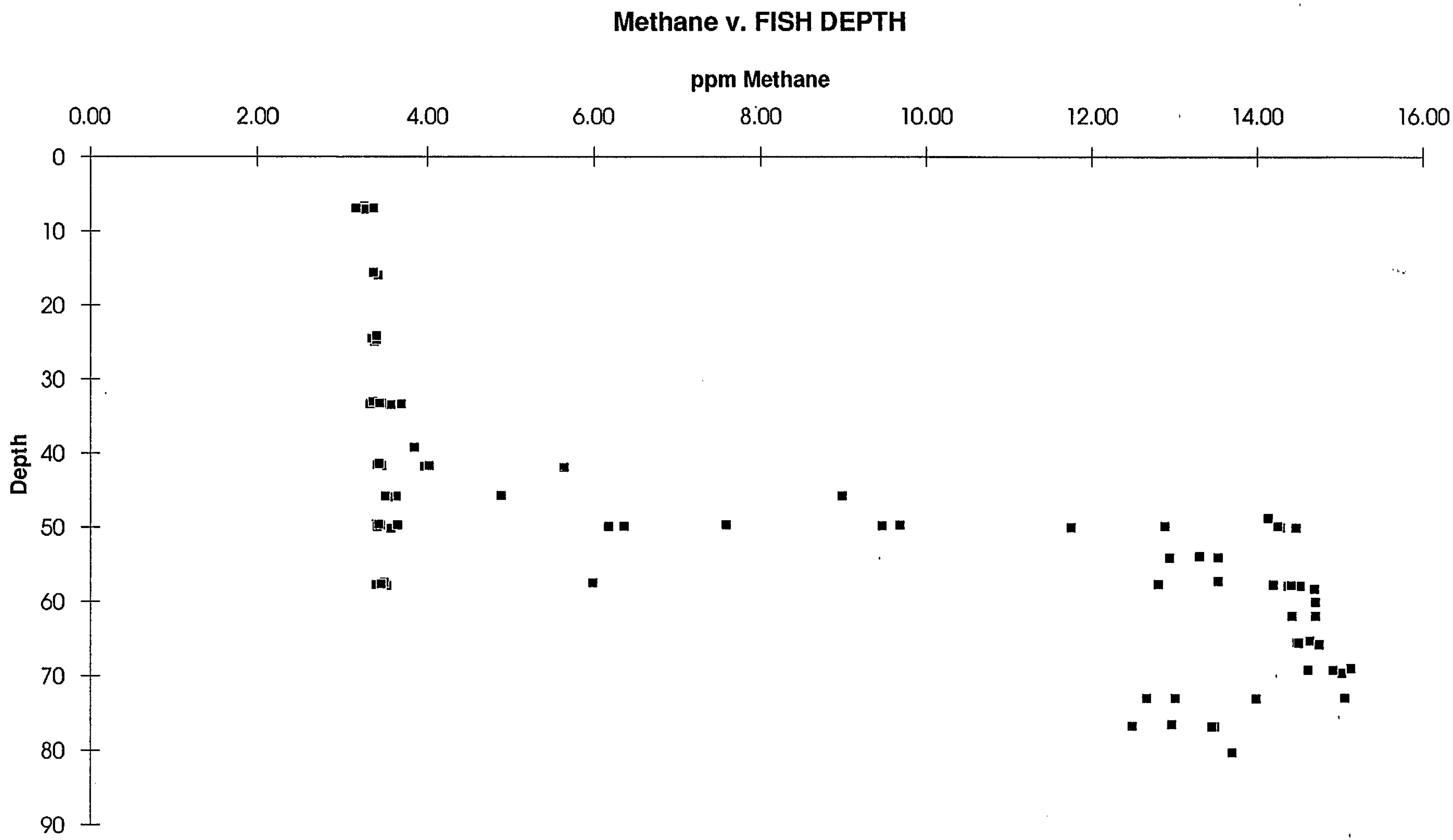


Figure 52. Methane versus tow-fish depth for a vertical profile.



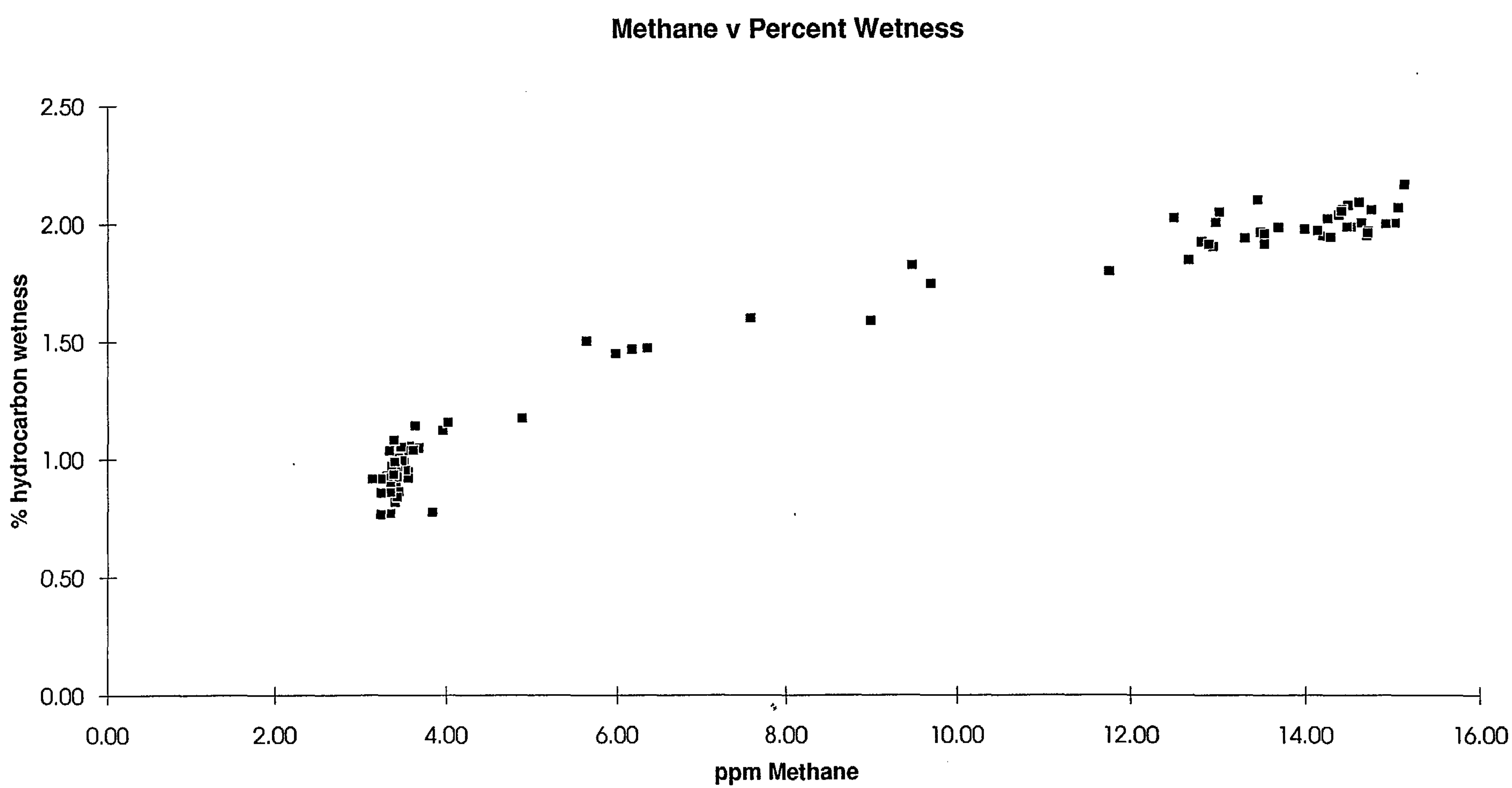
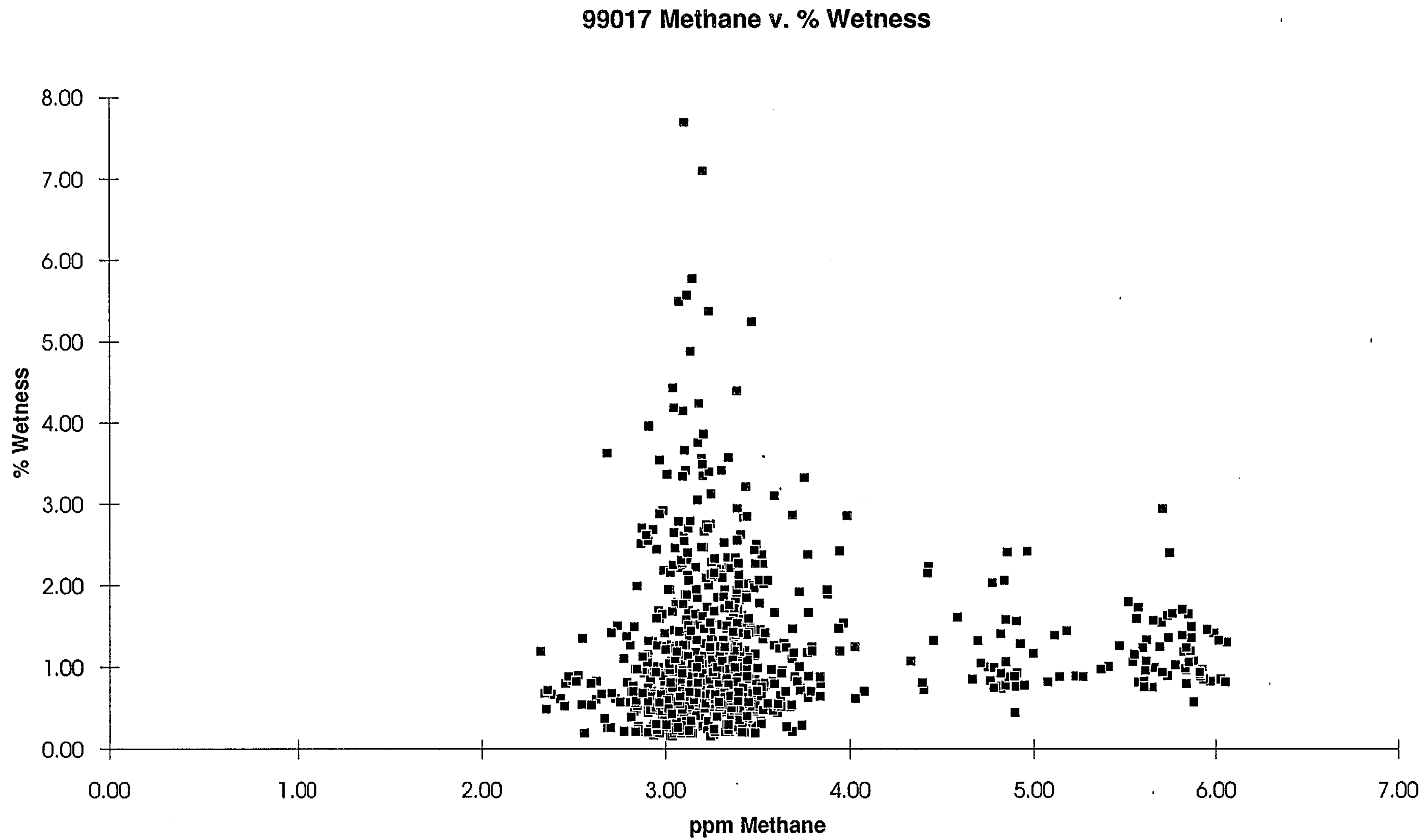


Figure 53. Methane versus percent hydrocarbon wetness for a vertical profile.



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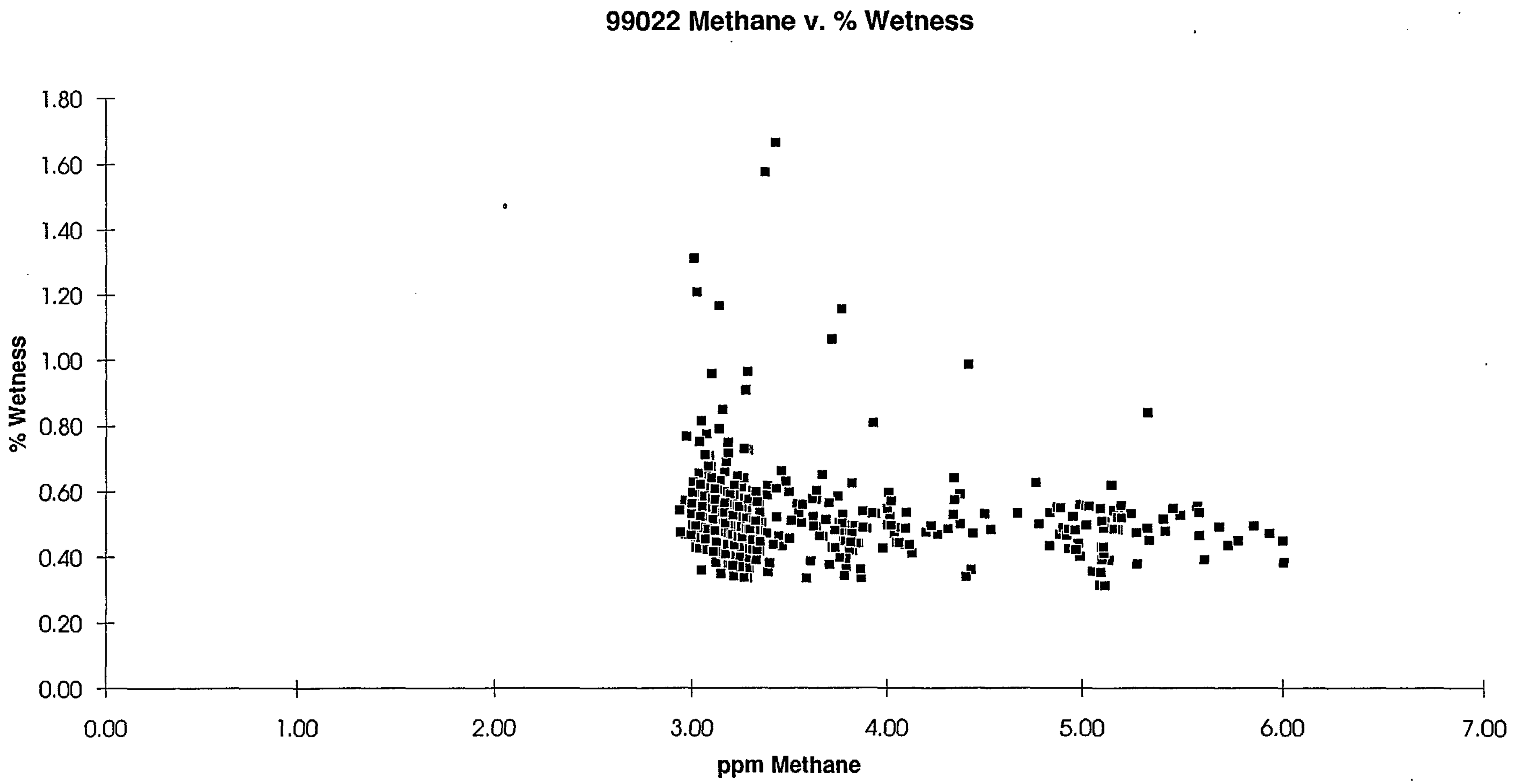


Figure 55. Methane versus percent hydrocarbon wetness (survey line 22).

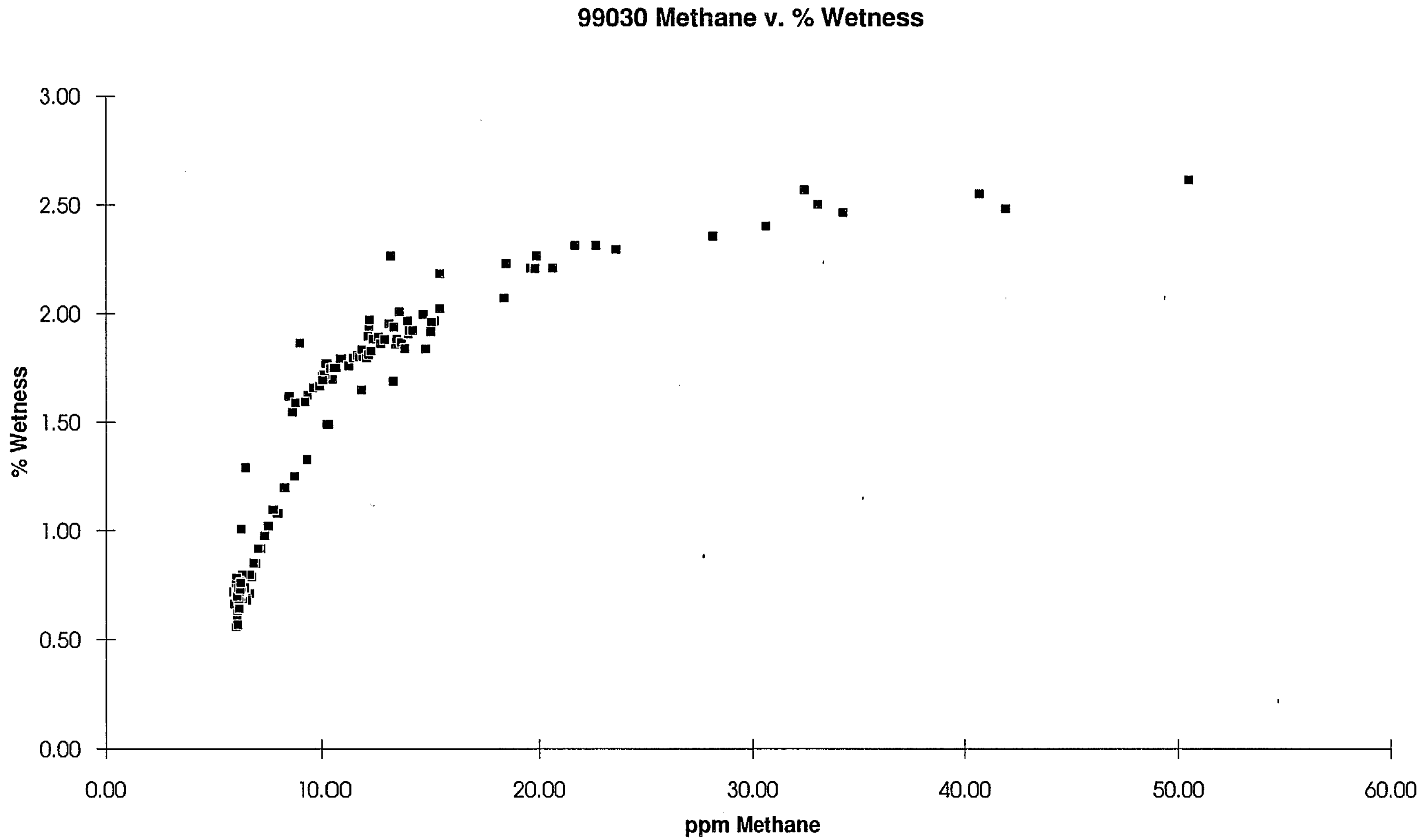


Figure 56. Methane versus percent hydrocarbon wetness (survey line 30).

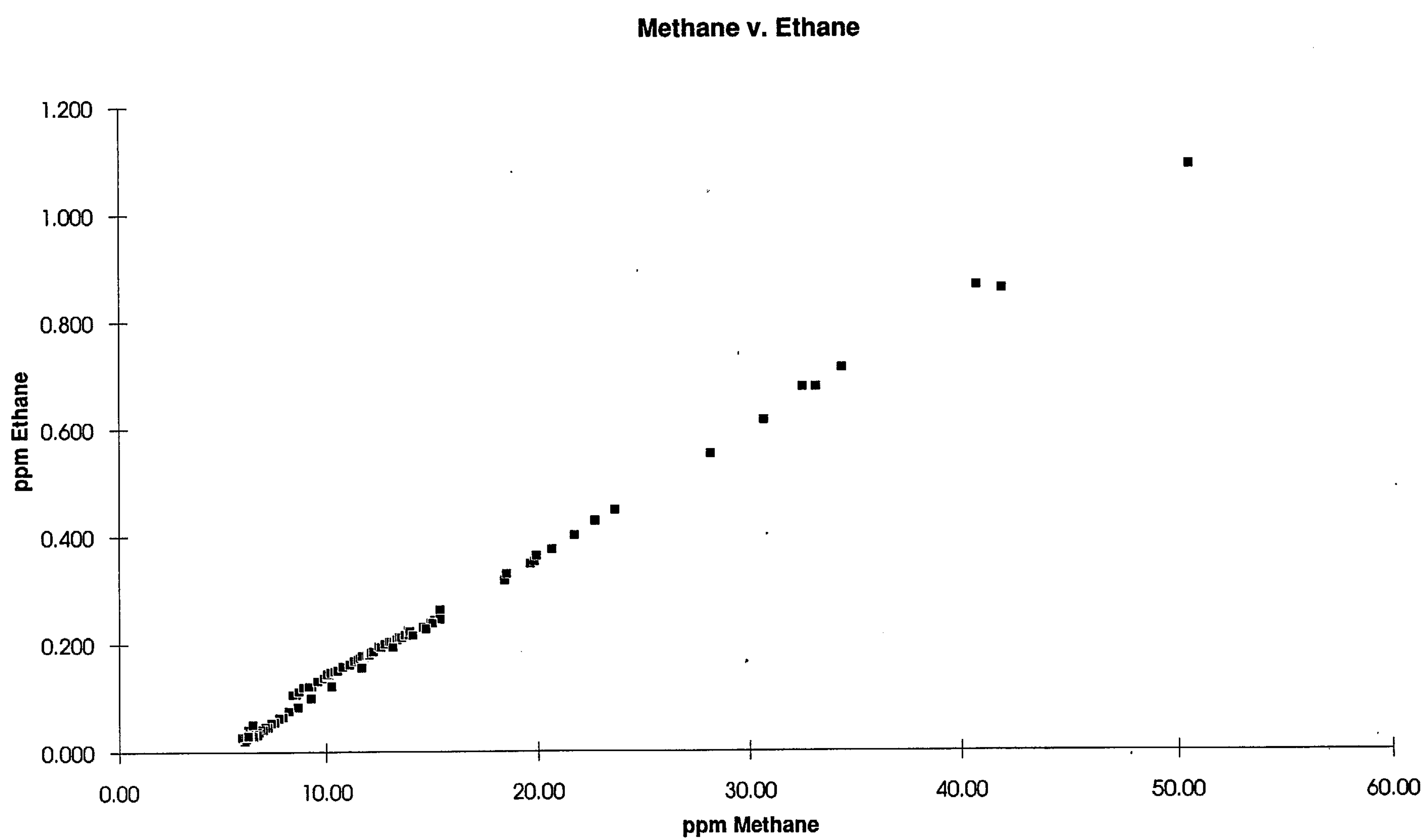


Figure 57. Methane versus ethane (survey line 30).

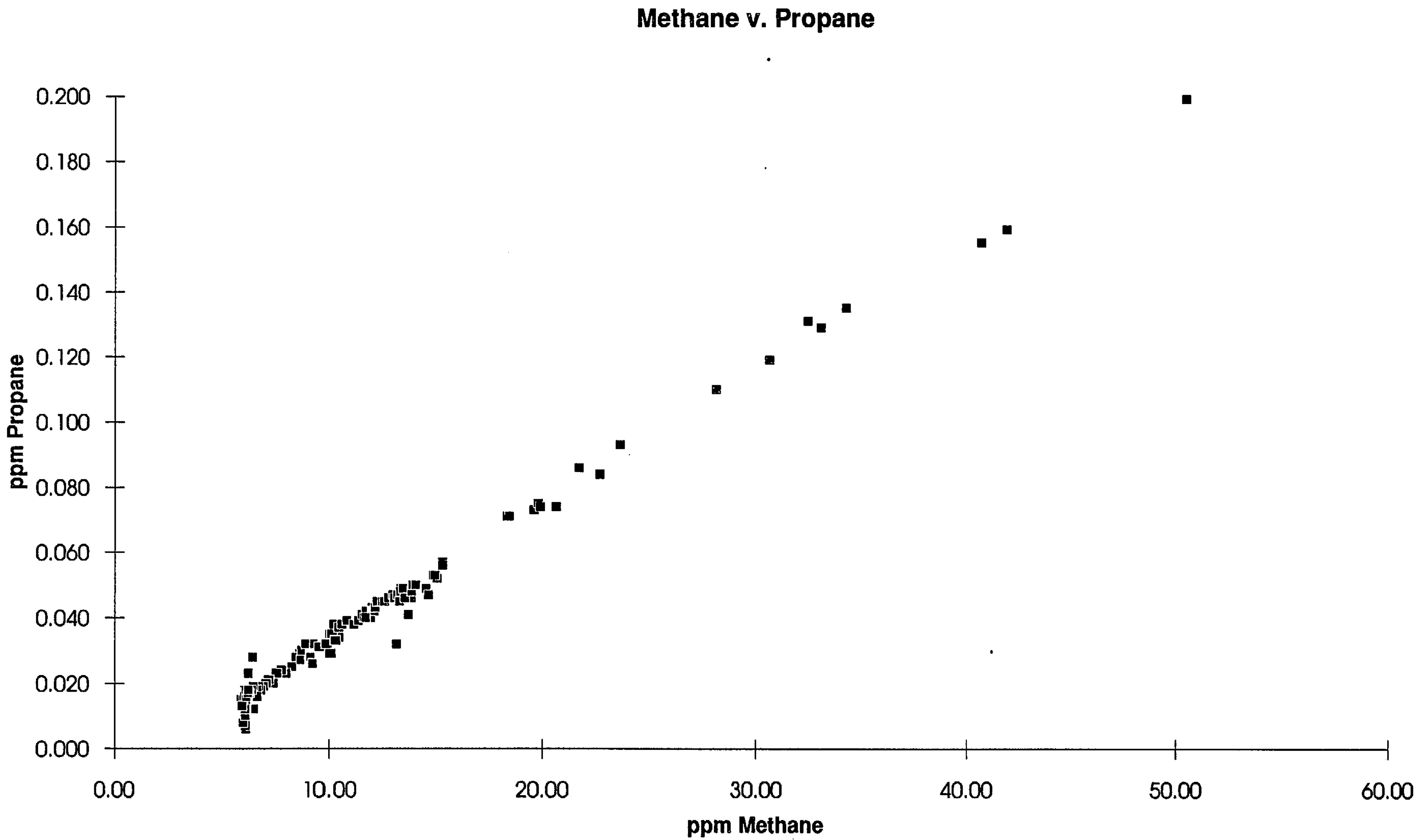


Figure 58. Methane versus propane (survey line 30).

APPENDIX I

GRAPHS OF HYDROCARBON CONCENTRATIONS VERSUS SHOTPOINT

DATA SUMMARY SHEETS

Line Summary

Line Number	99001
No. of Shotpoints	655

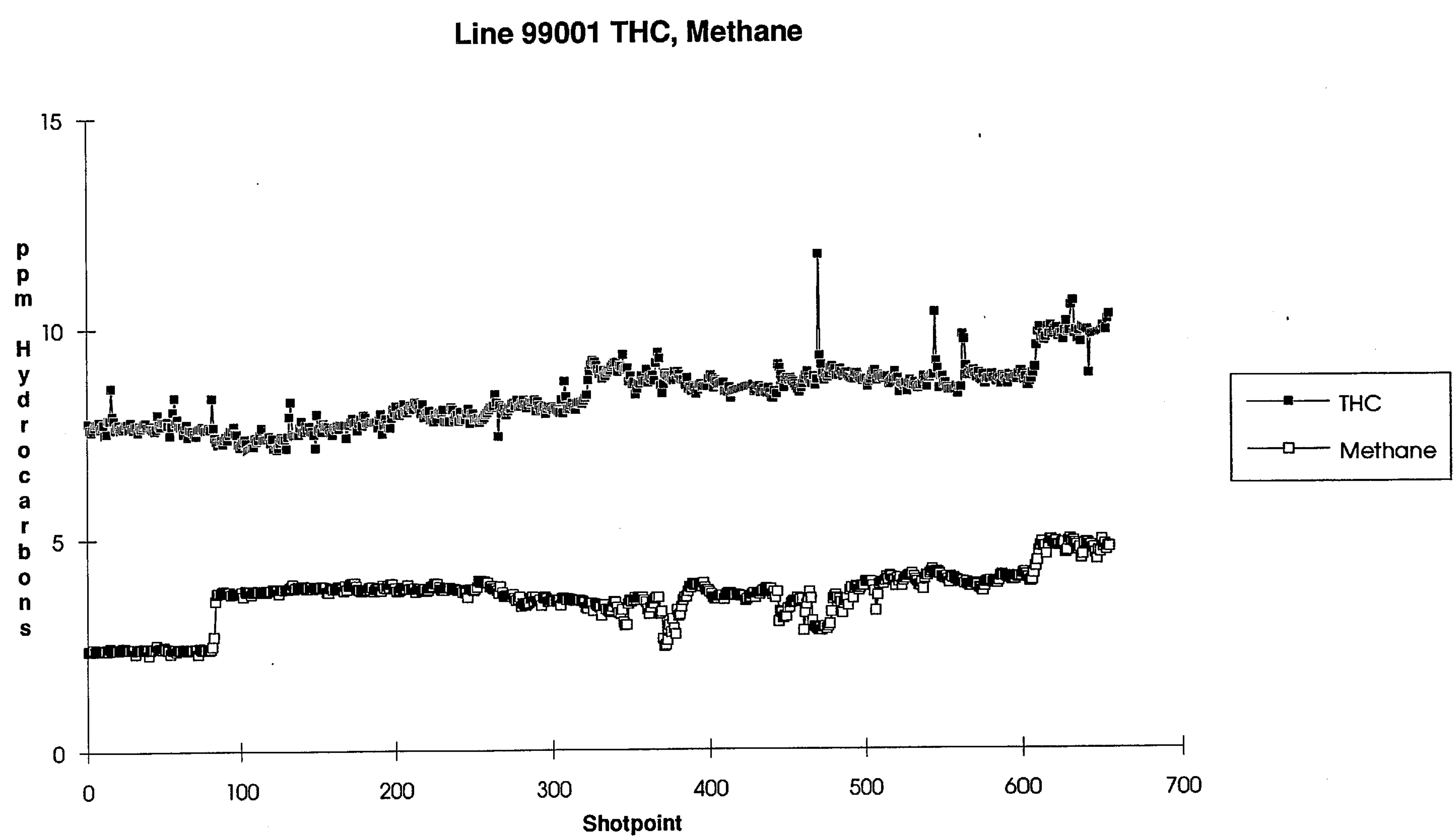
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	10-Feb-91	15:53:39	10	37.771	126	04.202
End	680	11-Feb-91	20:42:29	12	25.247	126	47.802

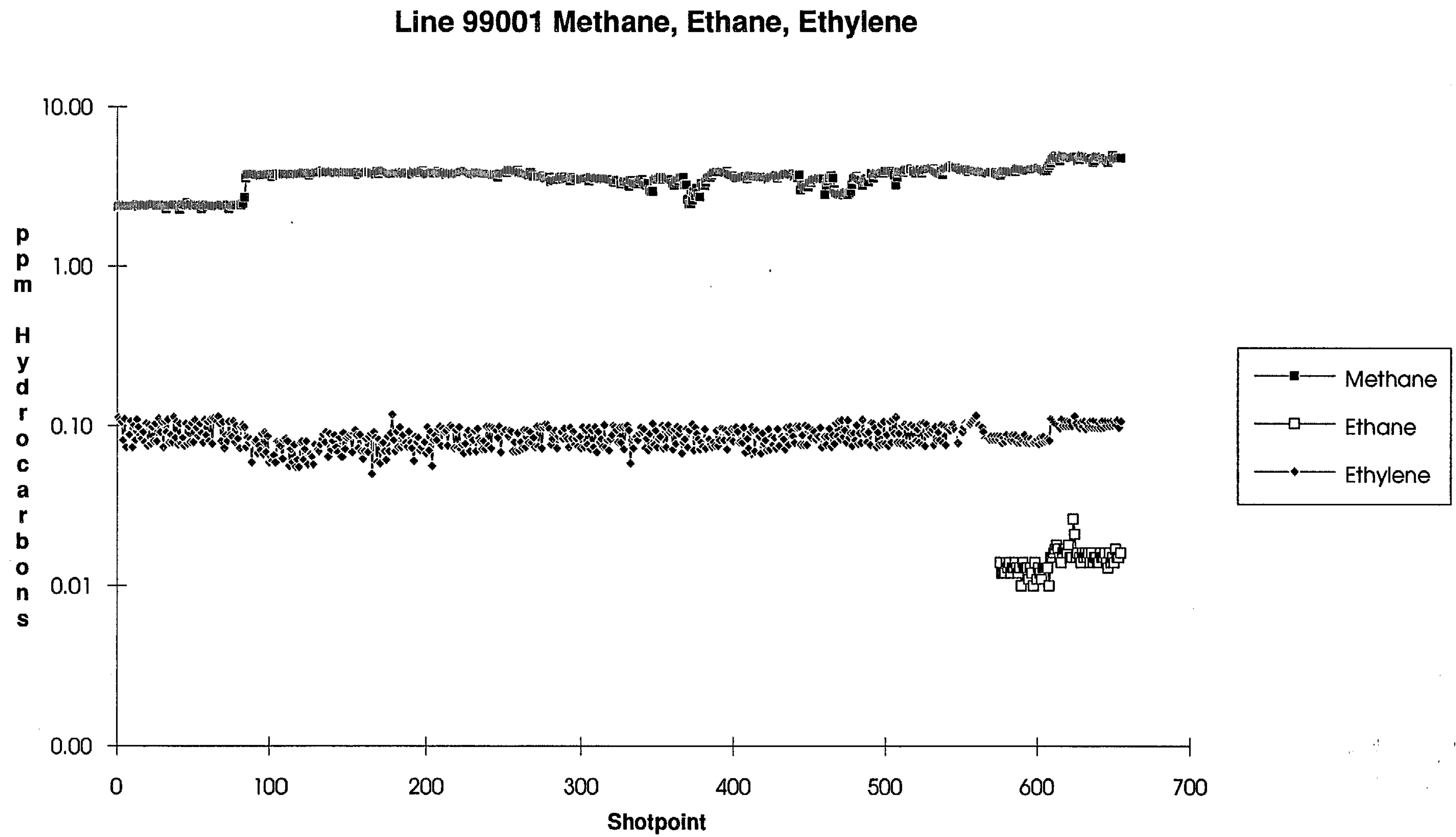
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.350	3.598	0.002	0.086	0.002	0.006	0.000	0.000	0.000	0.062	0.036	0.059	0.081
Std. Dev.	0.689	0.594	0.005	0.013	0.005	0.015	0.000	0.001	0.000	0.023	0.035	0.031	0.220
Minimum	7.106	2.264	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maximum	11.701	4.921	0.026	0.117	0.030	0.115	0.007	0.009	0.004	0.140	0.143	0.243	1.109

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.565	27.270	61.484	96.437	34.961
Std. Dev.	1.288	0.986	22.862	53.556	66.257
Minimum	57.490	24.950	9.800	22.800	3.800
Maximum	62.900	28.940	99.600	344.440	334.420

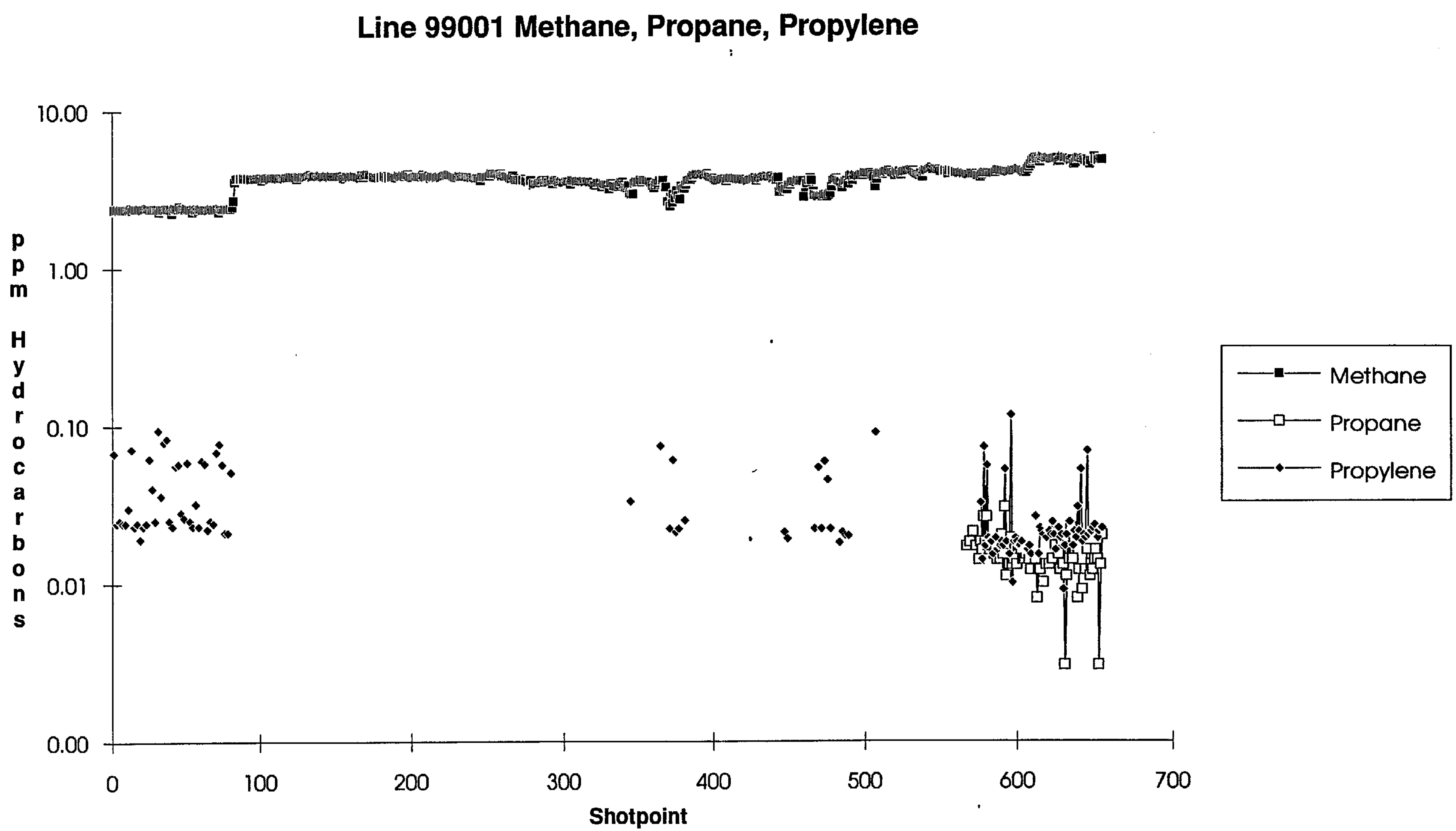
Notes

Variations in hydrocarbon values are due to variations in fish depths and water depths

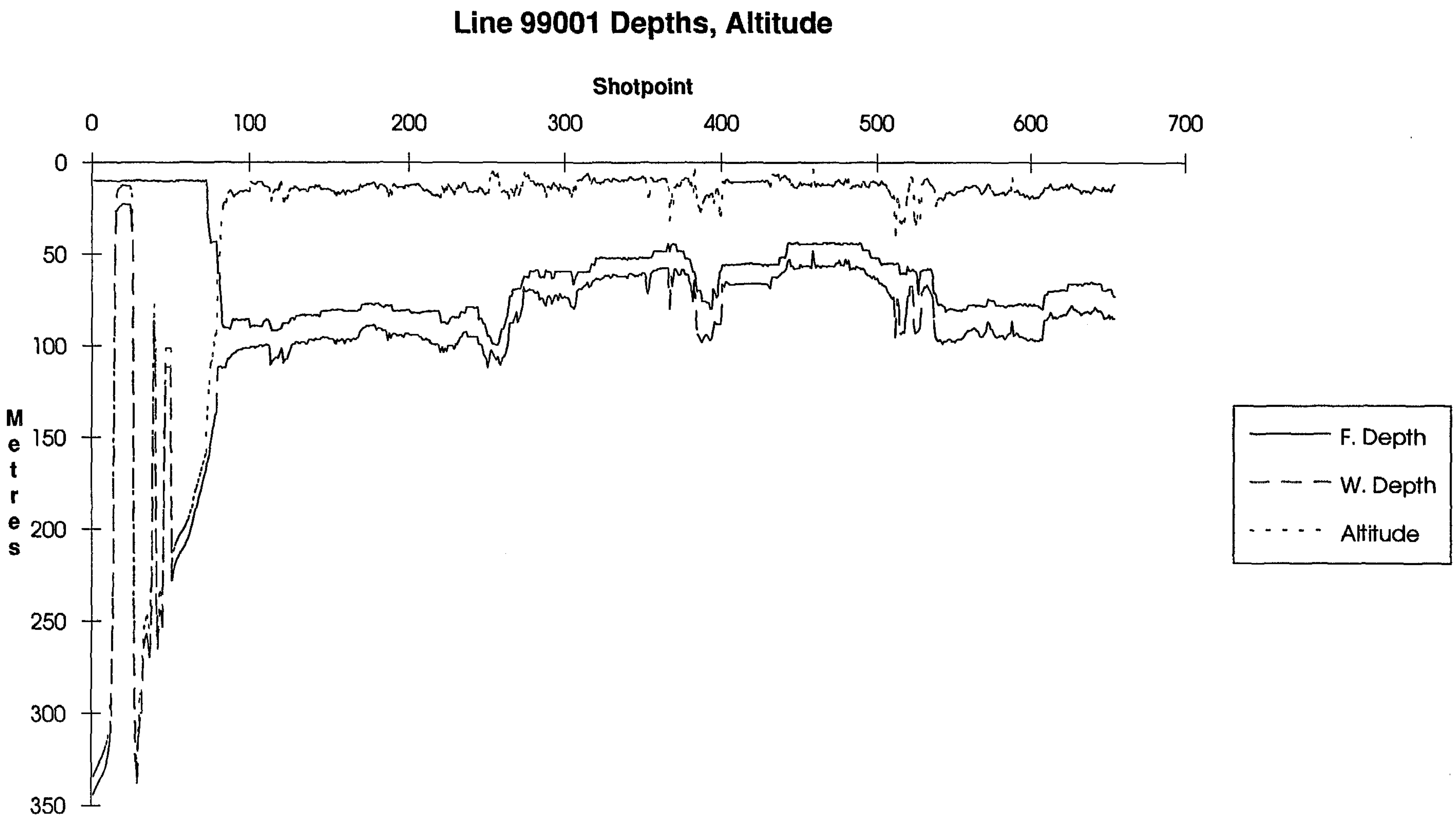

Line 99001 THC, Methane
ppm Hydrocarbons
15
10
5
0
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane



Line 99001 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
700
Shotpoint
Methane
Ethane
Ethylene



Line 99001 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
Shotpoint
Methane
Propane
Propylene



Line 99001 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
Metres
F. Depth
W. Depth
Altitude

Line Summary

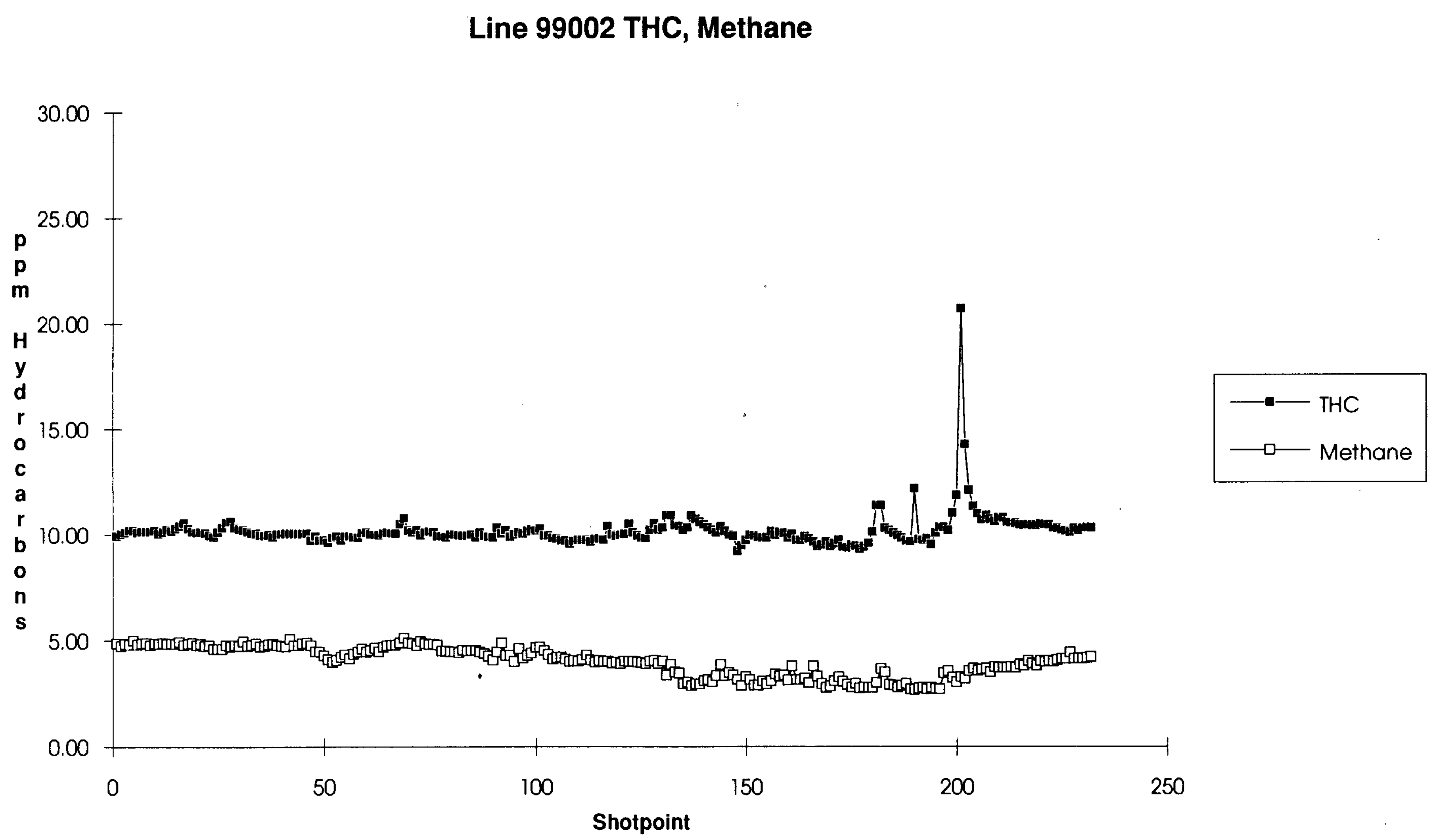
Line Number	99002
No. of Shotpoints	232

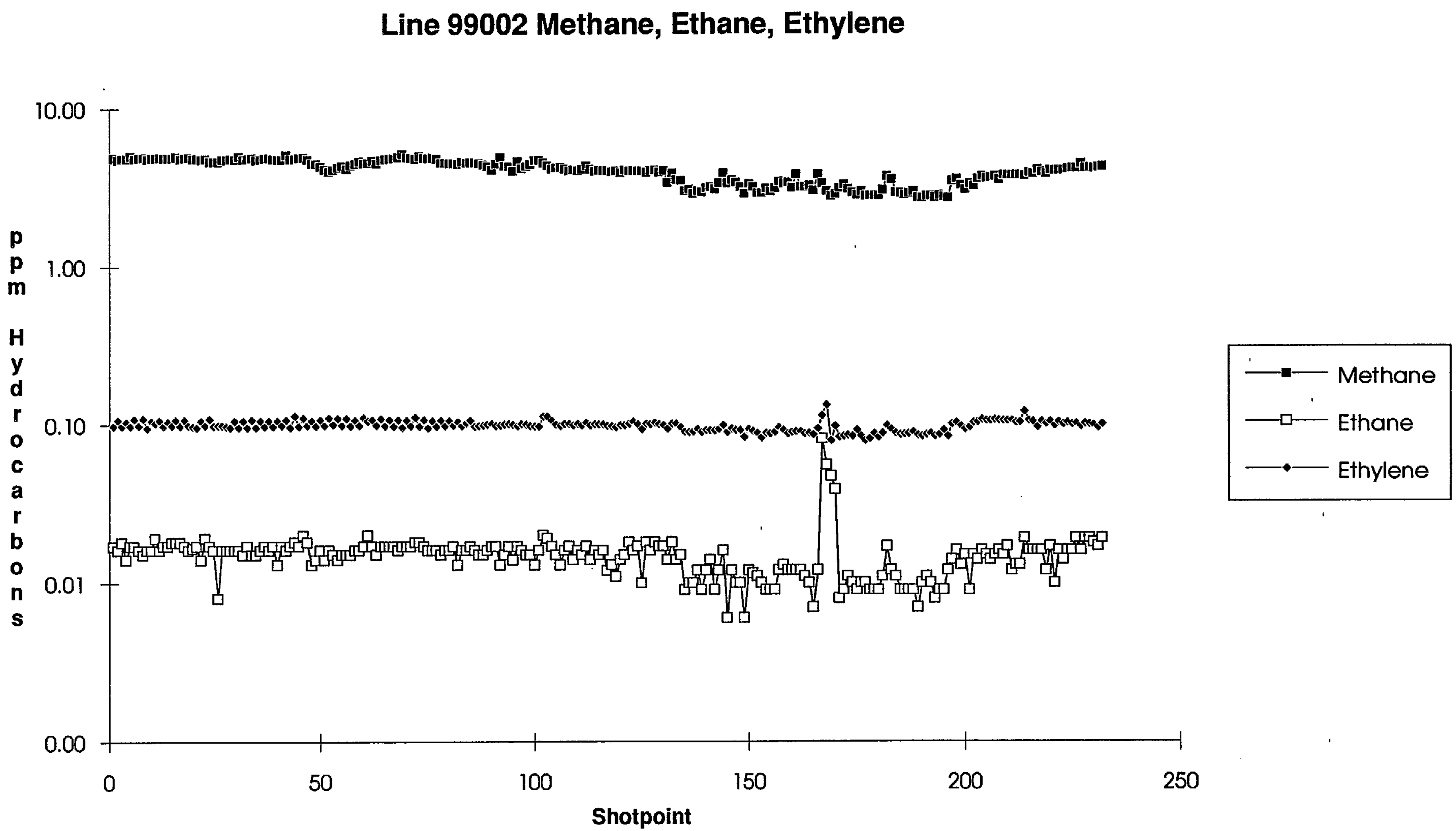
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	11-Feb-91	22:28:43	12	29.107	126	43.763
End	232	12-Feb-91	06:42:52	11	55.453	126	20.360

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	10.188	4.010	0.015	0.098	0.017	0.031	0.000	0.000	0.001	0.075	0.012	0.038	0.820
Std. Dev.	0.851	0.705	0.007	0.008	0.010	0.019	0.001	0.001	0.001	0.038	0.027	0.017	0.349
Minimum	9.220	2.690	0.006	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.317
Maximum	20.691	5.119	0.081	0.132	0.068	0.098	0.008	0.011	0.005	0.151	0.105	0.080	2.770

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.875	28.213	57.586	74.358	16.791
Std. Dev.	0.770	0.626	15.642	14.613	8.094
Minimum	60.550	27.070	34.700	49.100	6.700
Maximum	63.410	29.340	81.100	105.800	69.900

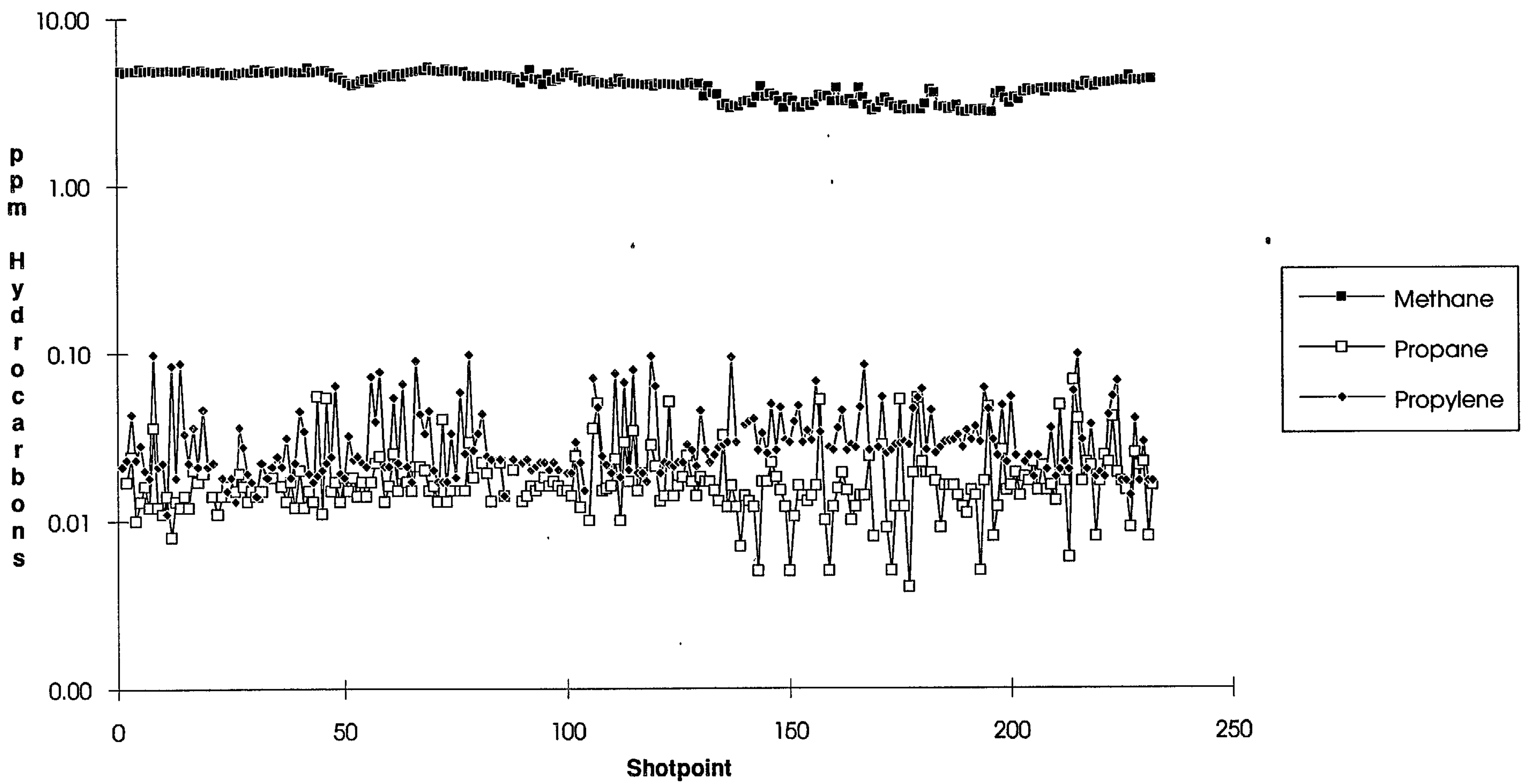
Notes
Ethane and Ethylene anomalies detected at shotpoint 166 to 170
THC amonalies at shotpoints 180 to 185, and at 199 to 205

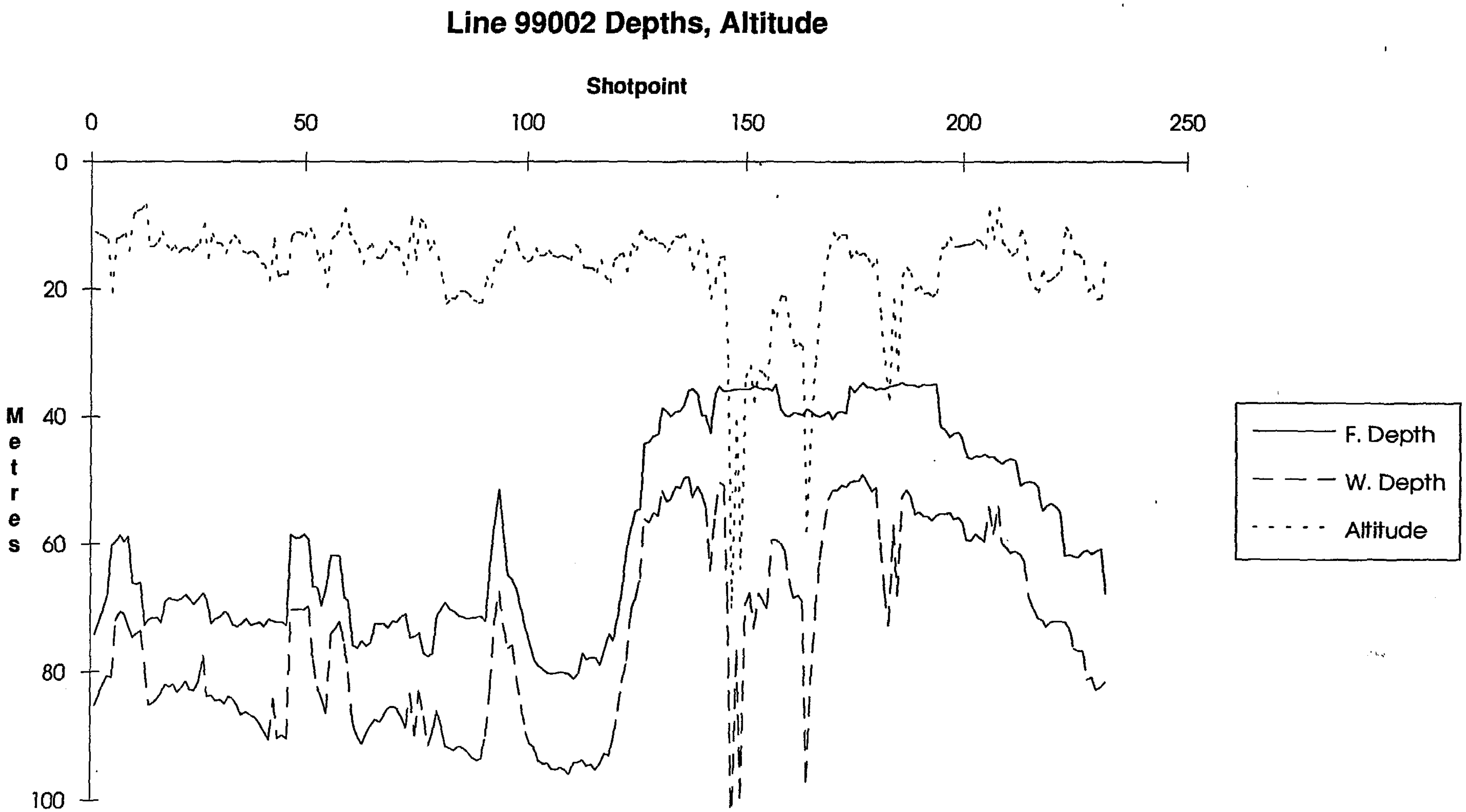

Line 99002 THC, Methane
ppm Hydrocarbons
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
50
100
150
200
250
Shotpoint
THC
Methane



Line 99002 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 99002 Methane, Propane, Propylene





Line 99002 Depths, Altitude
Shotpoint
0
50
100
150
200
250
0
20
40
60
80
100
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	99003
No. of Shotpoints	77

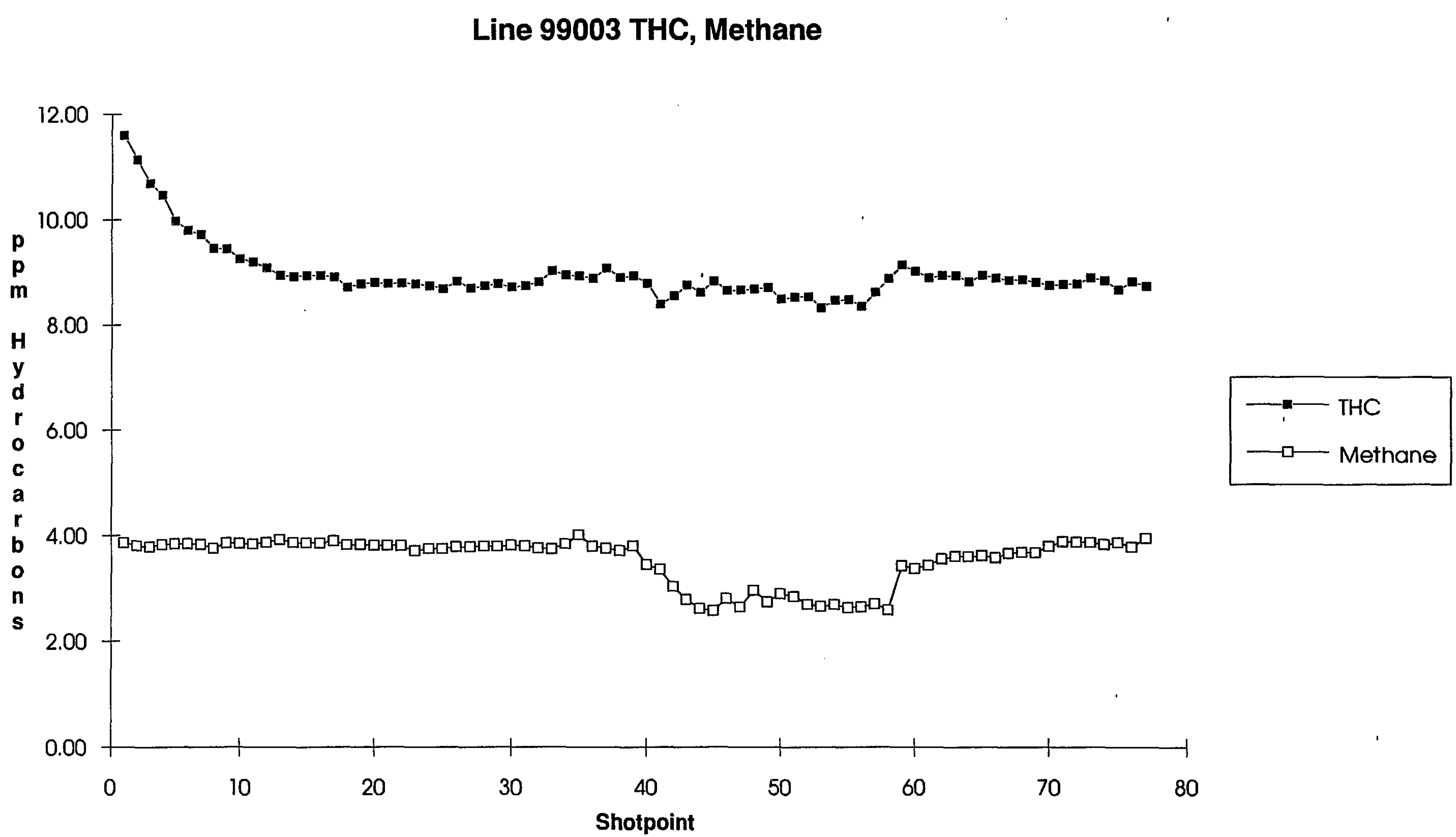
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	12-Feb-91	09:12:05	11	55.488	126	25.023
End	78	12-Feb-91	11:49:10	12	00.054	126	12.556

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.959	3.535	0.013	0.083	0.018	0.034	0.000	0.001	0.000	0.076	0.006	0.043	0.912
Std. Dev.	0.560	0.448	0.004	0.007	0.008	0.023	0.000	0.009	0.001	0.030	0.018	0.022	0.346
Minimum	8.320	2.580	0.006	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.370
Maximum	11.590	4.010	0.028	0.103	0.054	0.123	0.004	0.076	0.006	0.158	0.085	0.093	3.057

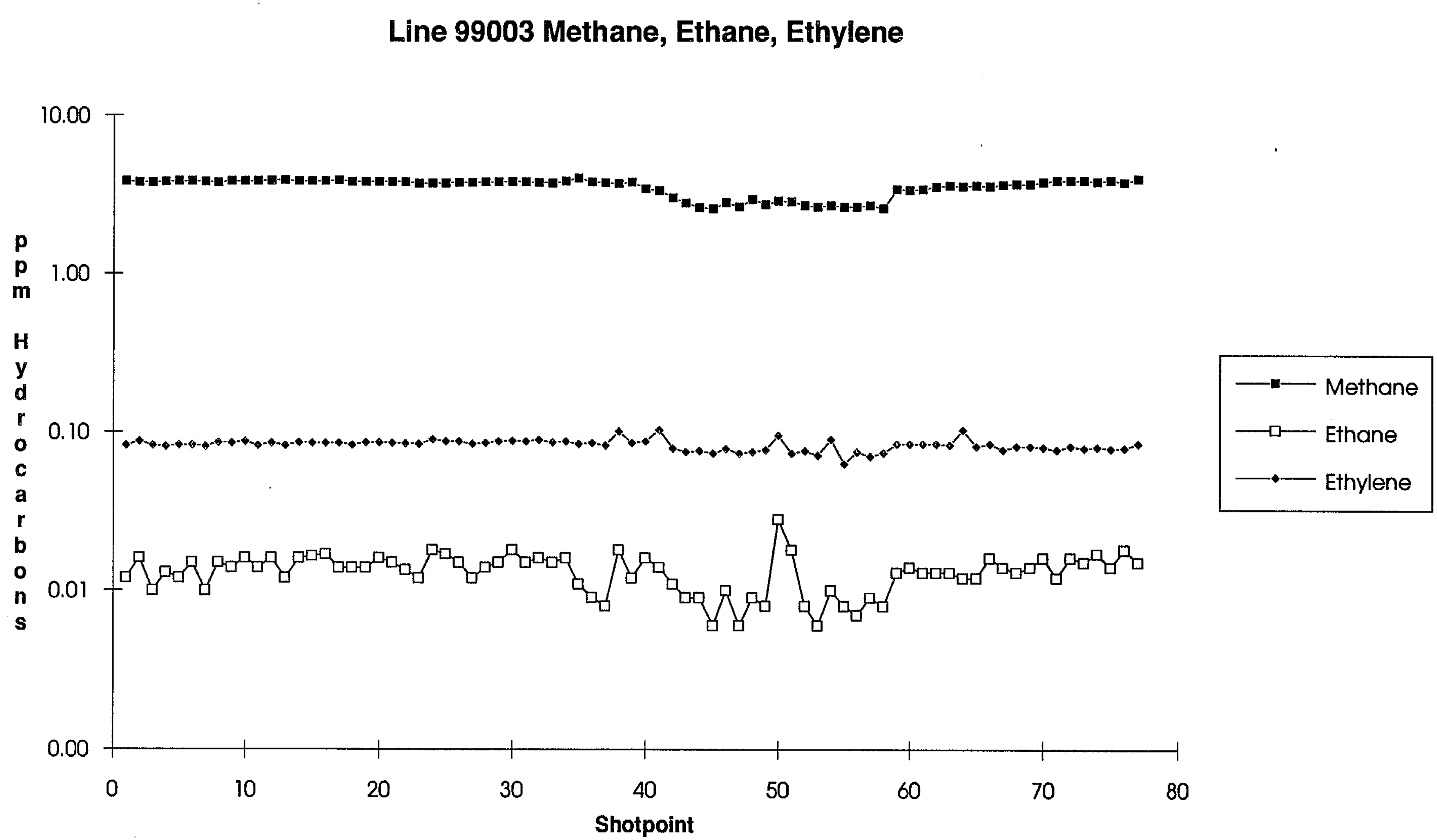
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.305	27.051	53.936	73.694	20.068
Std. Dev.	0.634	0.409	9.128	12.730	12.520
Minimum	59.560	26.560	36.500	51.600	10.800
Maximum	61.570	27.850	66.400	118.100	66.600

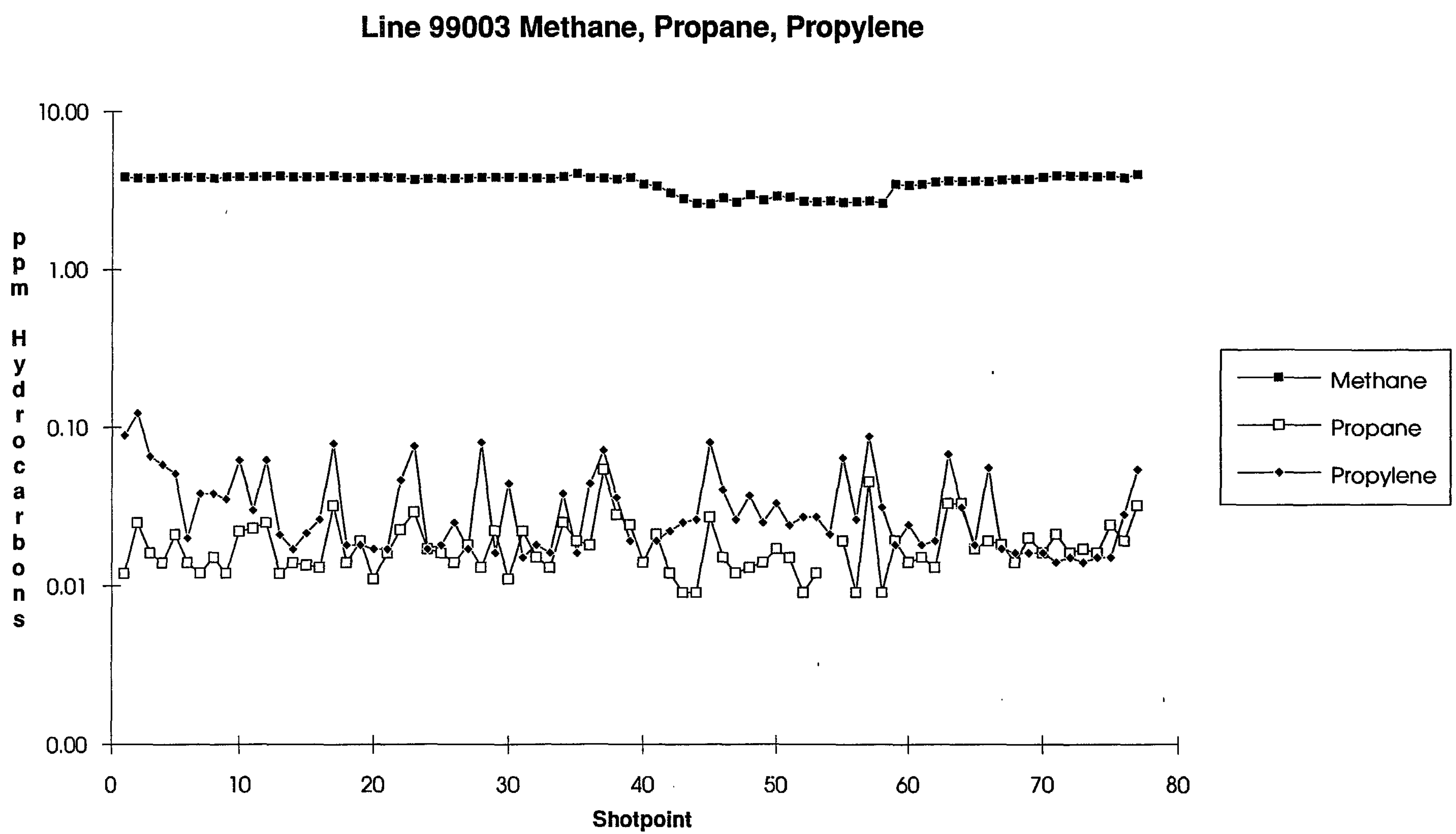
Notes

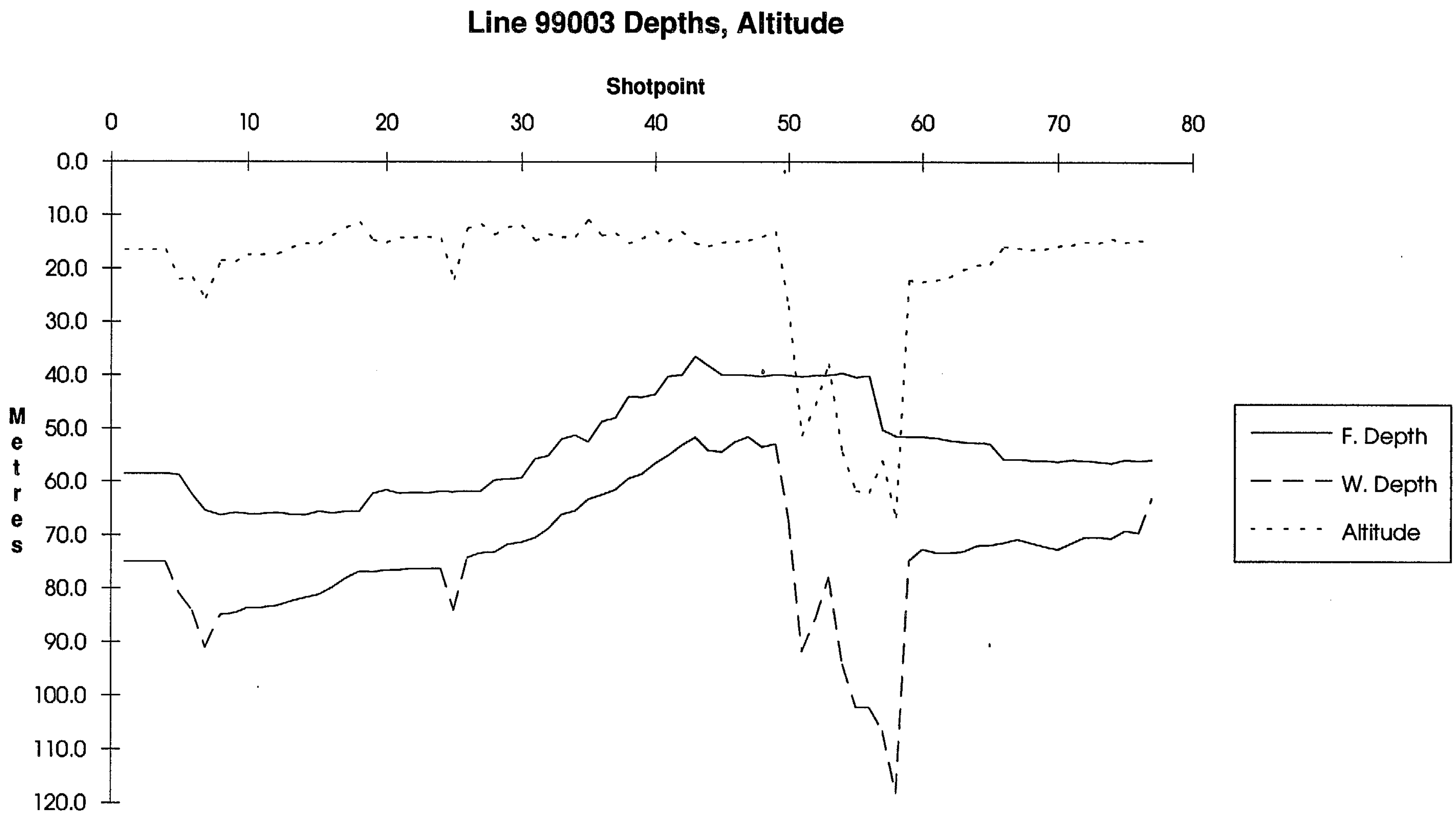
Weak THC anomaly at the start of ine



Line 99003 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
Shotpoint
THC
Methane


Line 99003 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
10
20
30
40
50
60
70
80
Shotpoint
Methane
Ethane
Ethylene


Line 99003 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
10
20
30
40
50
60
70
80
Shotpoint
Methane
Propane
Propylene


Line 99003 Depths, Altitude
Shotpoint
0
10
20
30
40
50
60
70
80
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

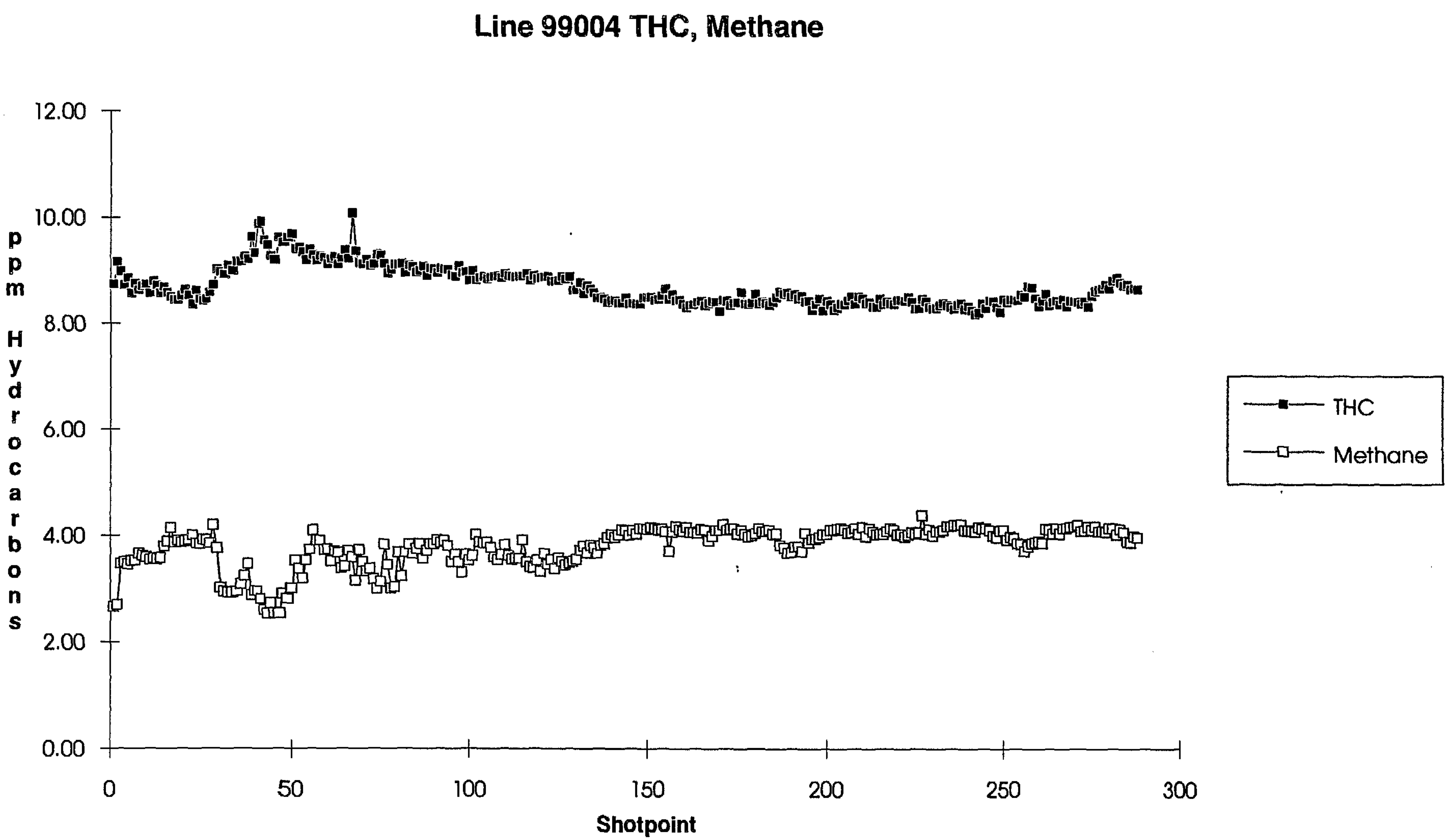
Line Number	99004
No. of Shotpoints	288

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	12-Feb-91	14:01:19	12	01.925	126	18.337
End	289	12-Feb-91	23:41:51	11	19.834	125	54.204

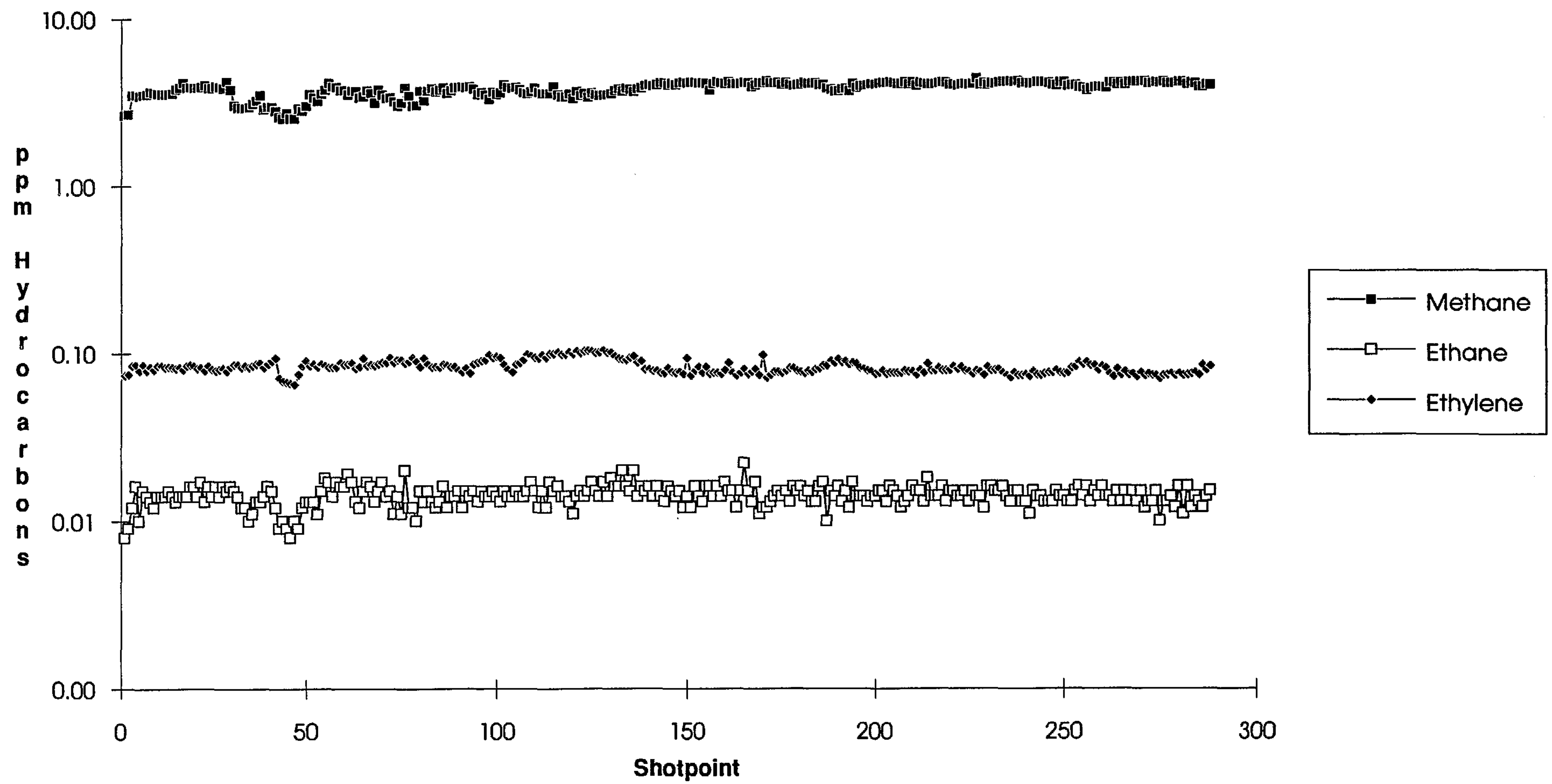
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.685	3.788	0.014	0.082	0.020	0.031	0.000	0.000	0.000	0.070	0.036	0.046	0.913
Std. Dev.	0.365	0.373	0.002	0.008	0.013	0.025	0.002	0.004	0.001	0.032	0.033	0.021	0.405
Minimum	8.171	2.538	0.008	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.244
Maximum	10.069	4.368	0.022	0.104	0.107	0.141	0.022	0.072	0.005	0.207	0.114	0.087	4.226

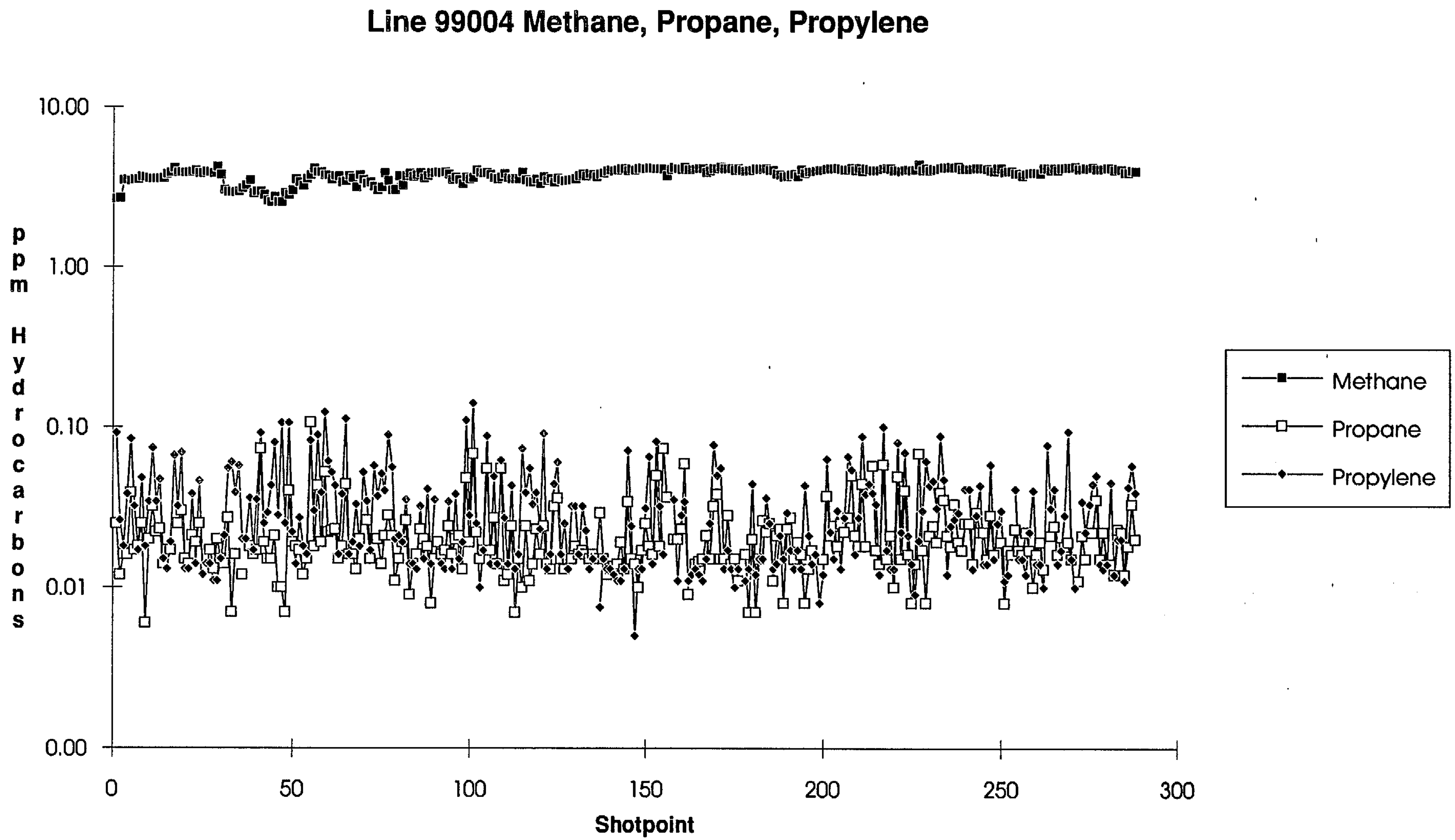
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.385	26.412	64.016	77.927	14.239
Std. Dev.	0.691	0.500	13.089	14.835	6.031
Minimum	58.590	25.820	32.000	43.100	7.800
Maximum	61.300	27.770	80.900	115.200	56.700

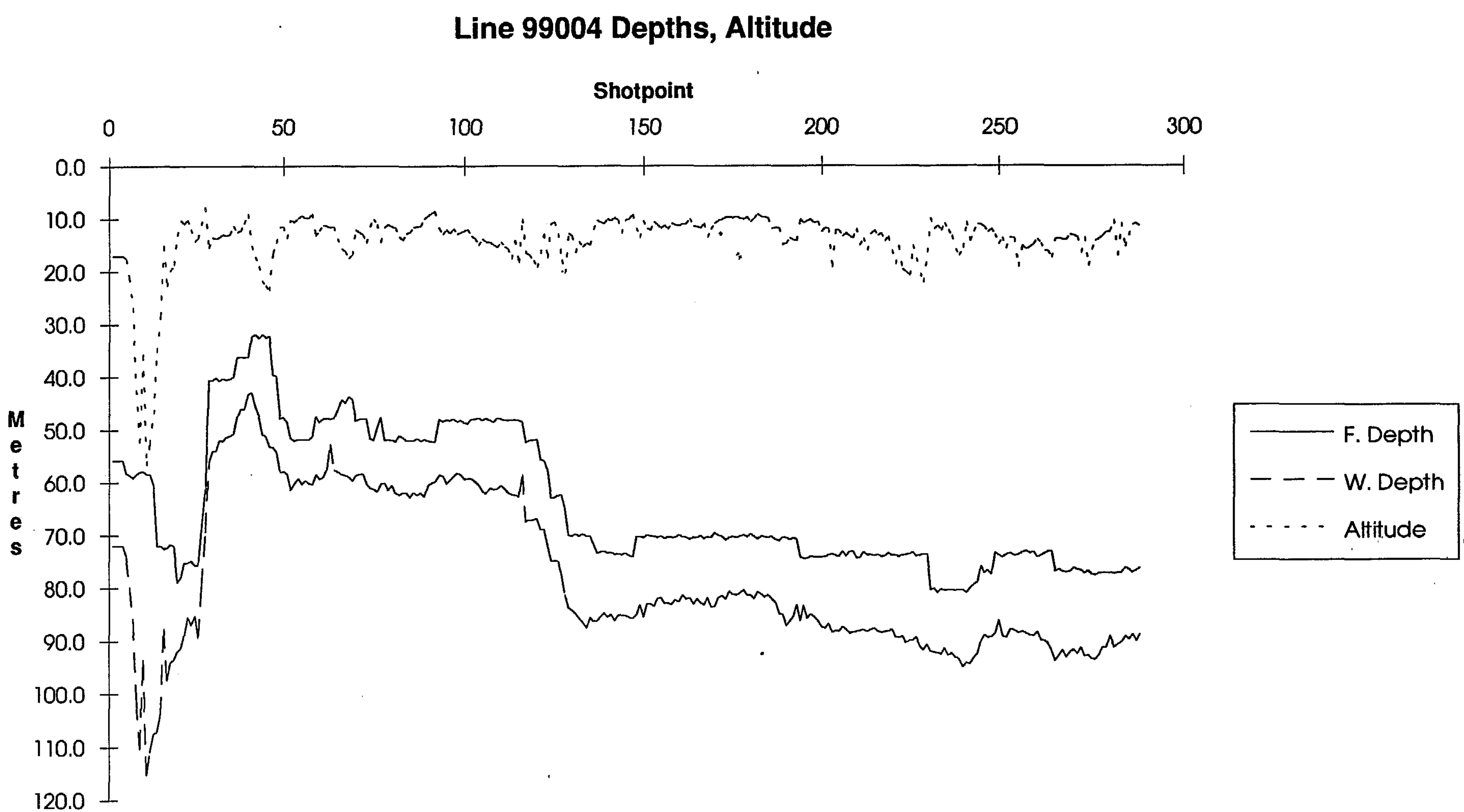
Notes
No hydrocarbon anomalies detected


Line 99004 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Shotpoint
THC
Methane

Line 99004 Methane, Ethane, Ethylene




Line 99004 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
Shotpoint
Methane
Propane
Propylene



Line 99004 Depths, Altitude
Shotpoint
0
50
100
150
200
250
300
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

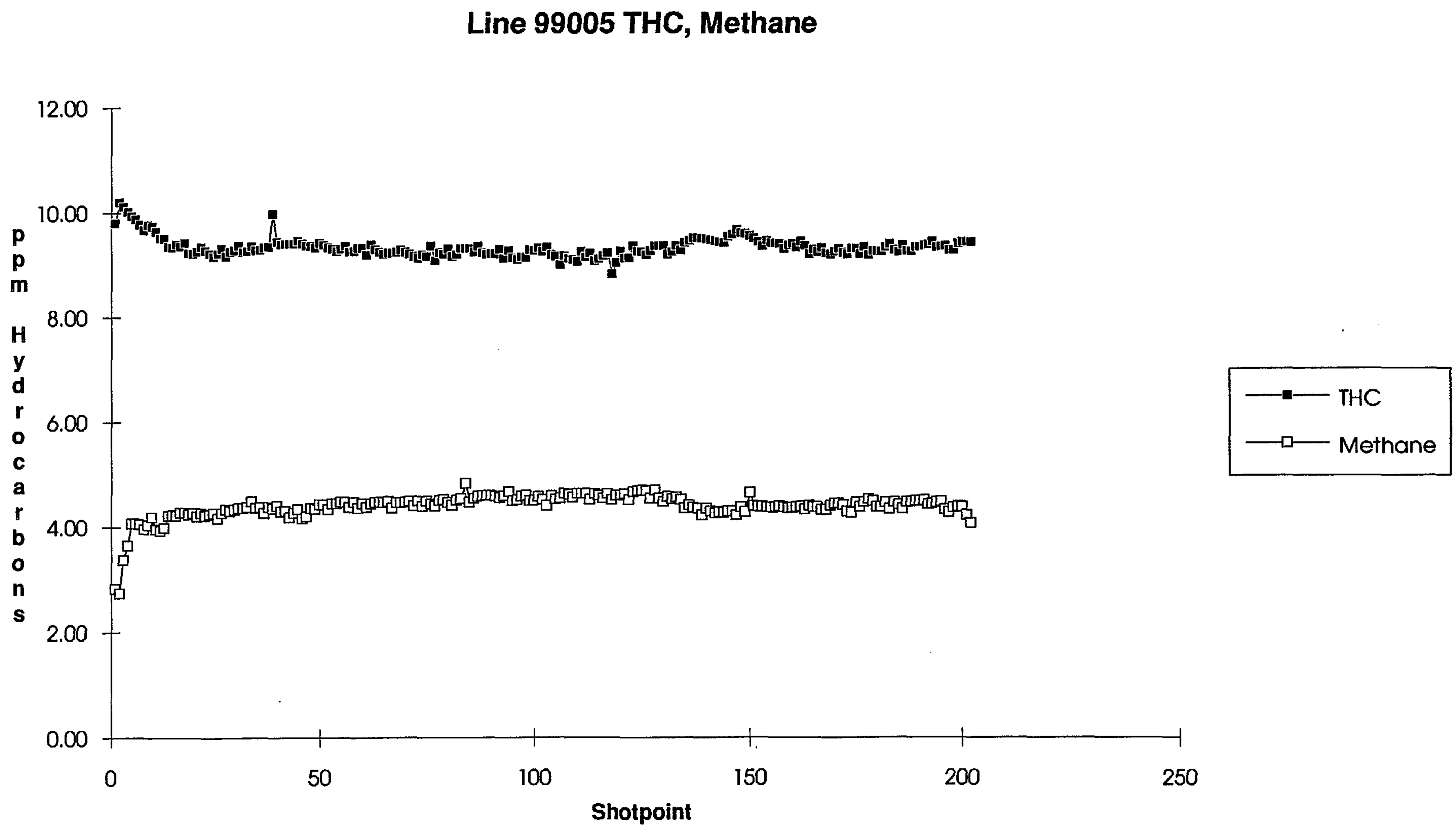
Line Number	99005
No. of Shotpoints	202

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	13-Feb-91	01:27:29	11	22.422	125	53.161
End	202	13-Feb-91	08:11:20	11	05.221	126	22.600

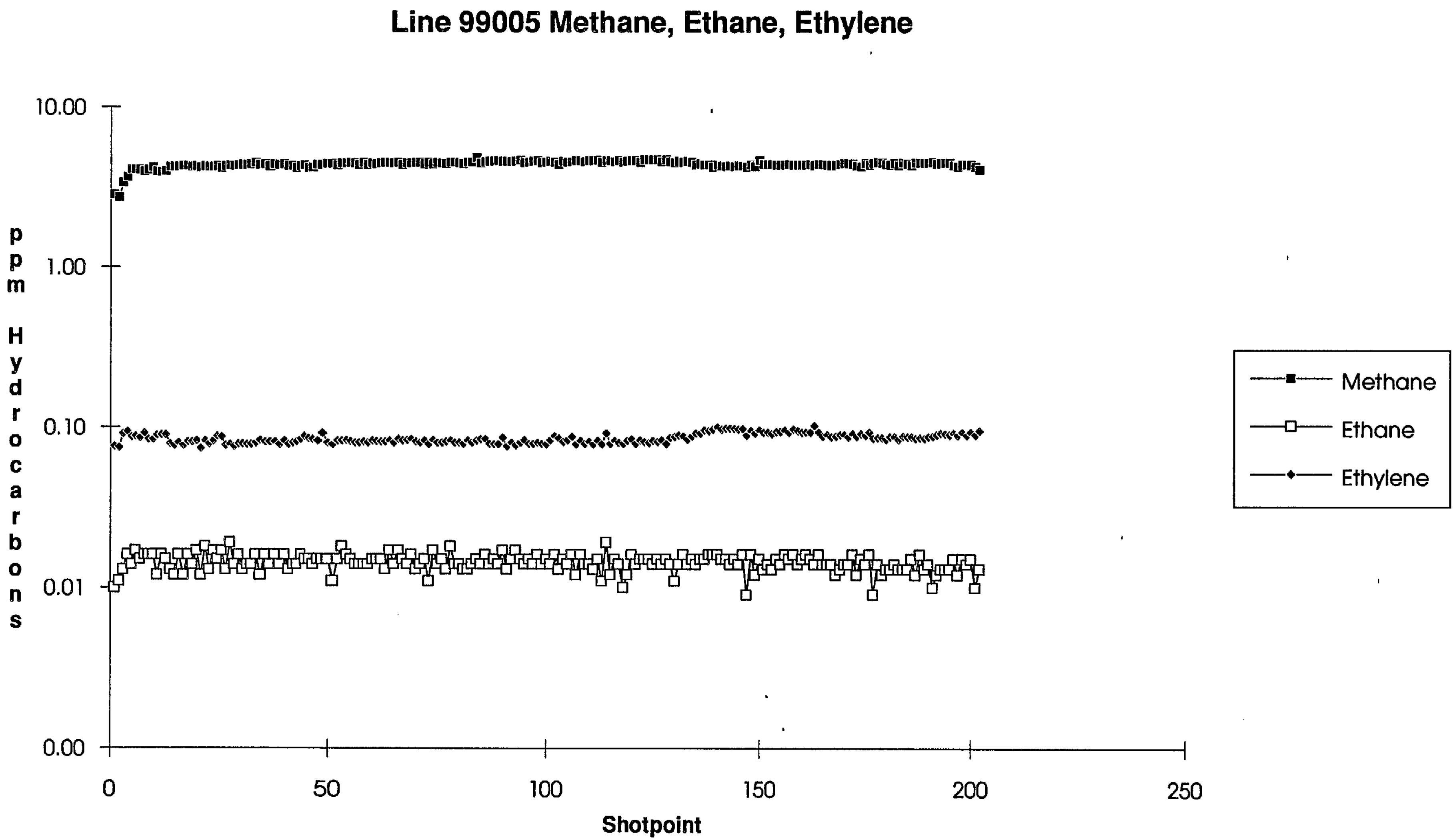
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.328	4.383	0.014	0.085	0.023	0.029	0.000	0.001	0.000	0.062	0.035	0.063	0.865
Std. Dev.	0.185	0.237	0.002	0.006	0.011	0.023	0.002	0.003	0.000	0.026	0.046	0.033	0.254
Minimum	8.814	2.742	0.009	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.302
Maximum	10.199	4.826	0.019	0.102	0.059	0.152	0.017	0.036	0.005	0.159	0.155	0.123	1.600

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.146	27.787	76.289	91.847	14.467
Std. Dev.	0.422	0.305	2.825	3.856	2.940
Minimum	60.420	27.280	61.900	77.800	8.800
Maximum	63.120	29.360	84.700	108.100	31.800

Notes
No hydrocarbon anomalies detected

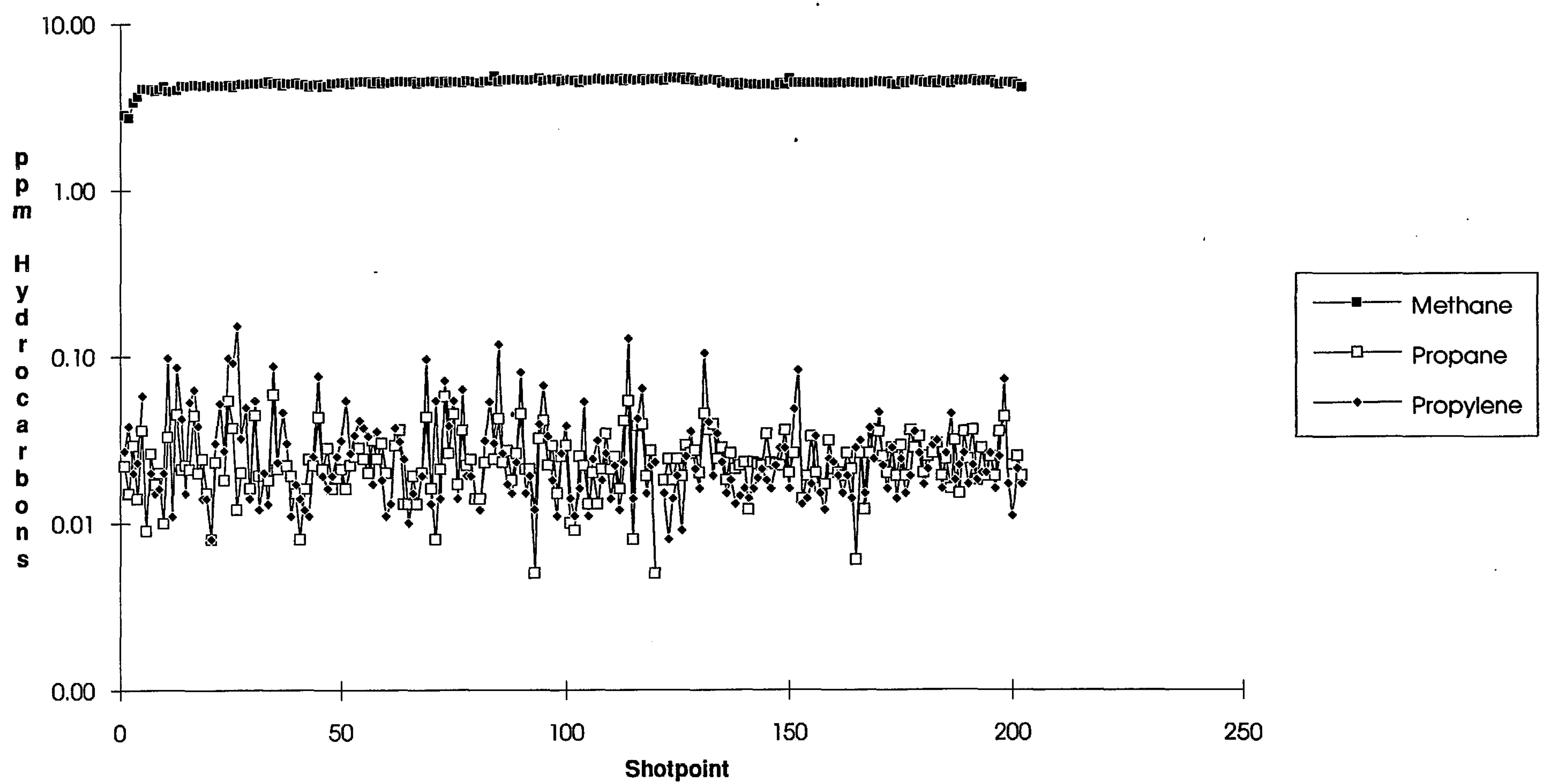


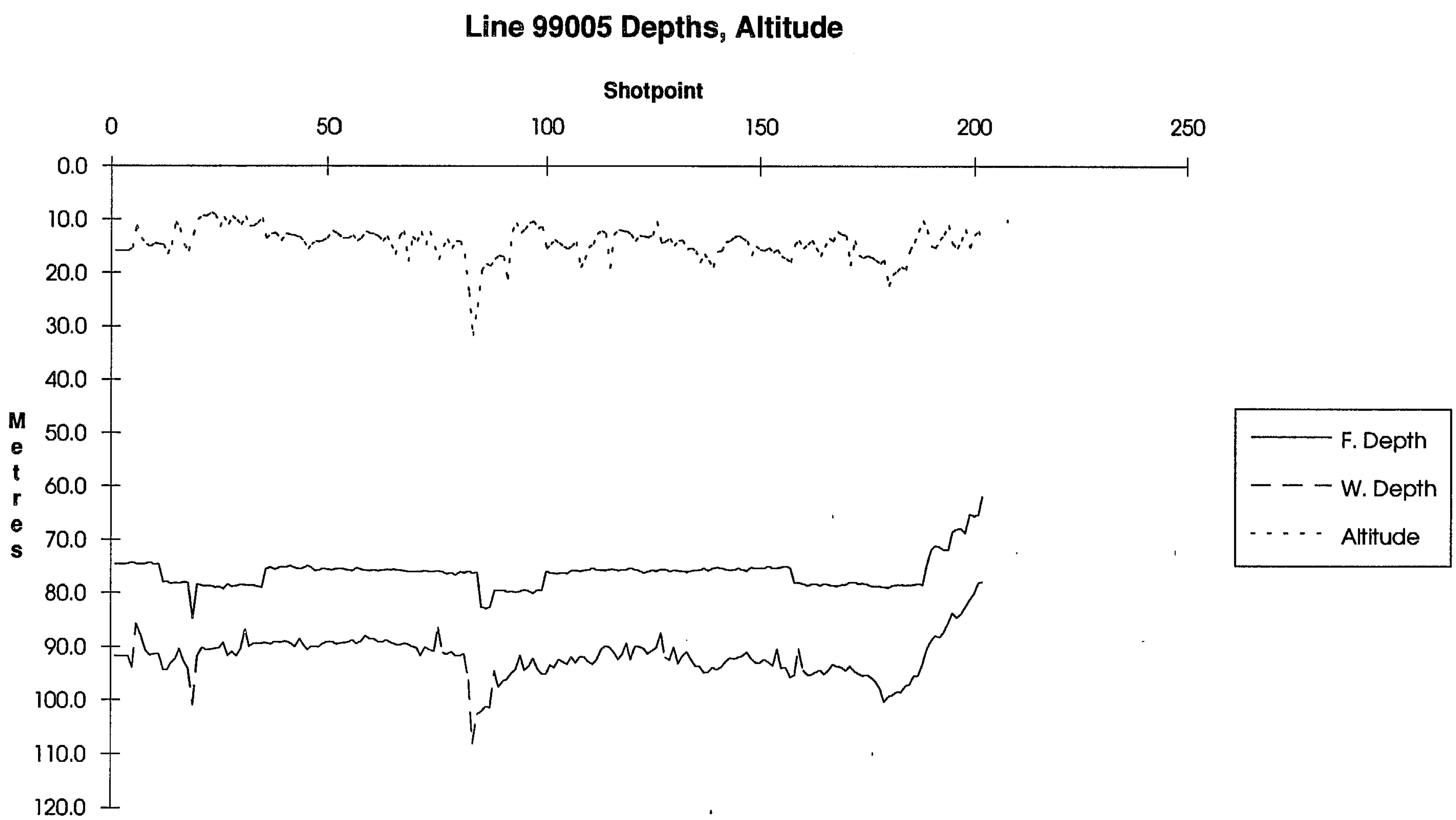
Line 99005 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Shotpoint
THC
Methane



Line 99005 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
Shotpoint
Methane
Ethane
Ethylene

Line 99005 Methane, Propane, Propylene





Line 99005 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

Line Summary

Line Number	99006
No. of Shotpoints	170

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	13-Feb-91	11:06:02	11	08.435	126	24.200
End	170	13-Feb-91	16:50:51	10	44.451	126	08.454

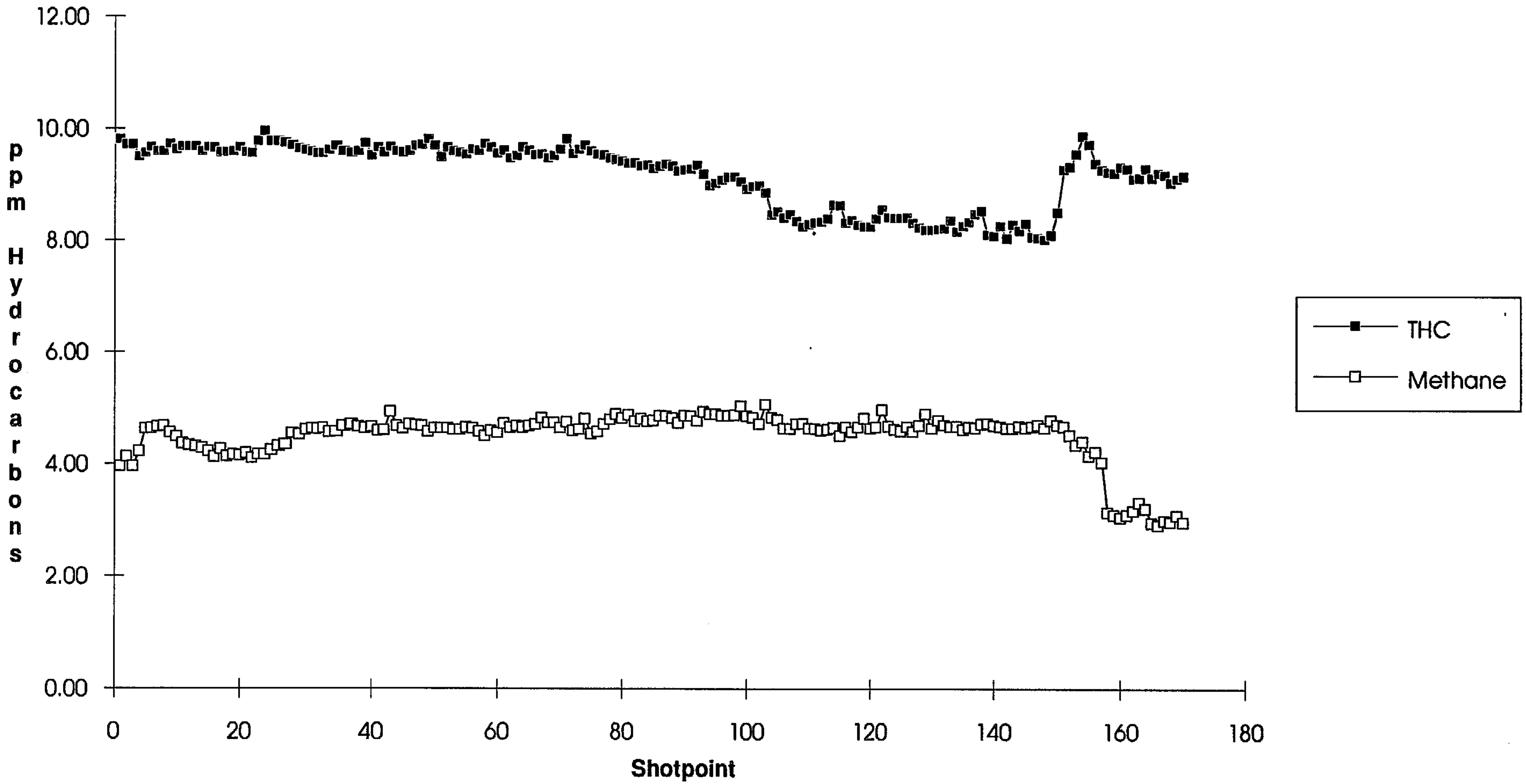
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.160	4.498	0.014	0.092	0.024	0.036	0.000	0.000	0.000	0.064	0.005	0.053	0.855
Std. Dev.	0.571	0.461	0.002	0.016	0.010	0.026	0.001	0.002	0.000	0.034	0.022	0.029	0.263
Minimum	8.022	2.917	0.007	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260
Maximum	9.948	5.058	0.017	0.117	0.063	0.153	0.012	0.020	0.000	0.203	0.137	0.123	2.071

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.644	26.481	76.899	112.448	34.067
Std. Dev.	1.262	0.961	11.105	44.672	48.077
Minimum	57.550	24.860	54.900	75.300	10.100
Maximum	61.350	27.770	99.000	232.800	177.500

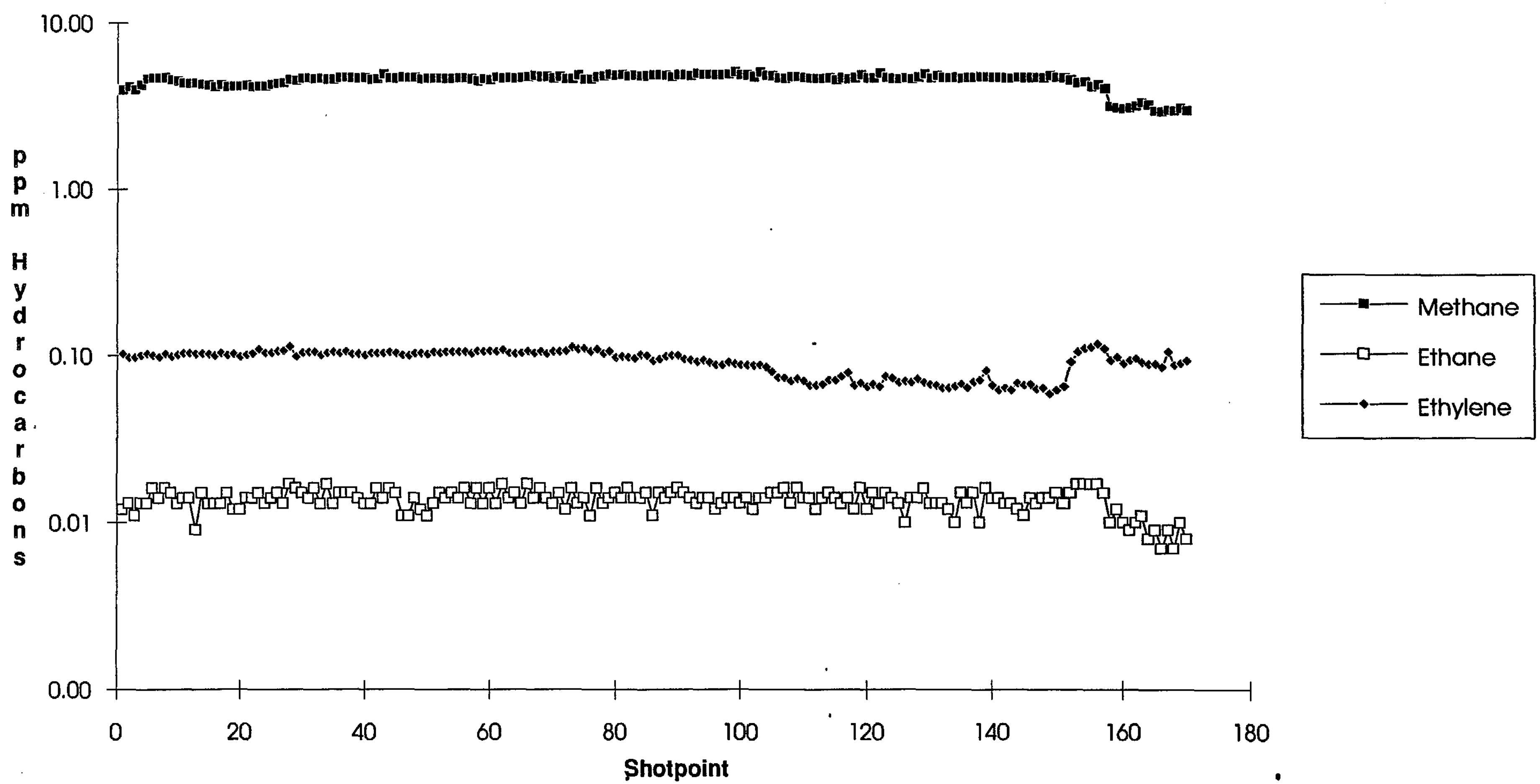
Notes

Variations in hydrocarbon values towards end of line are due to variations in fish depths and water depths

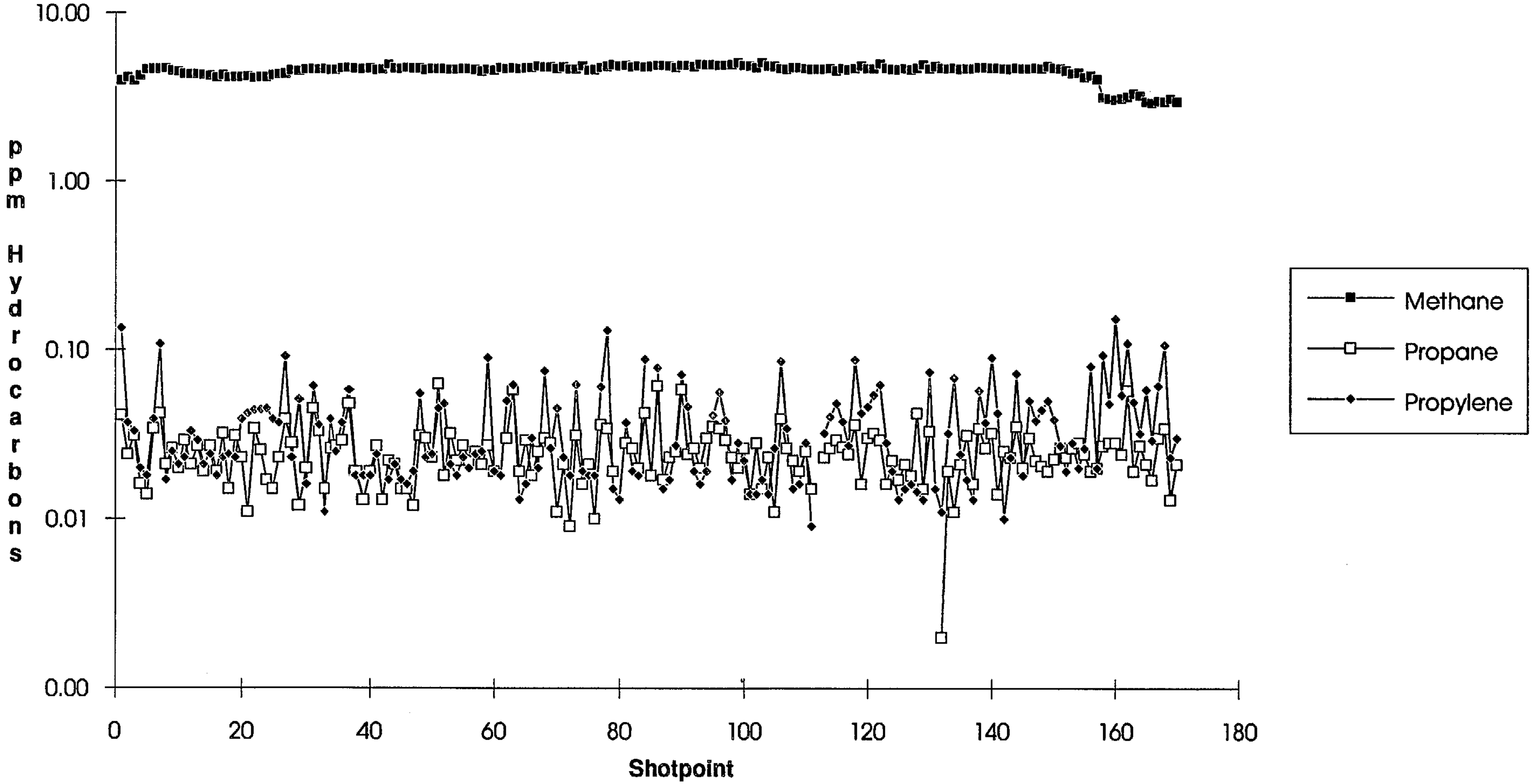
Line 99006 THC, Methane



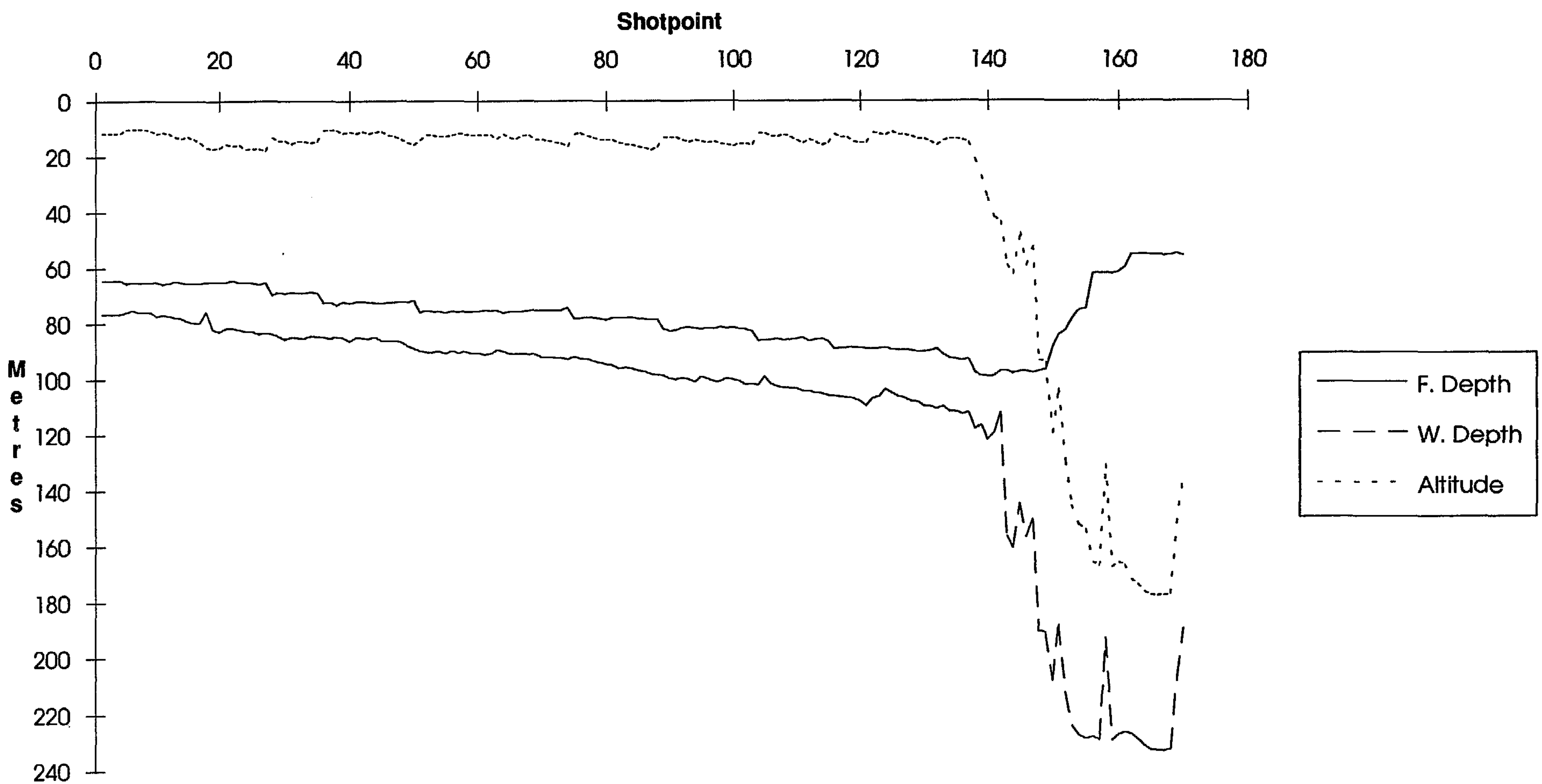
Line 99006 Methane, Ethane, Ethylene



Line 99006 Methane, Propane, Propylene



Line 99006 Depths, Altitude



Line Summary

Line Number	99007
No. of Shotpoints	327

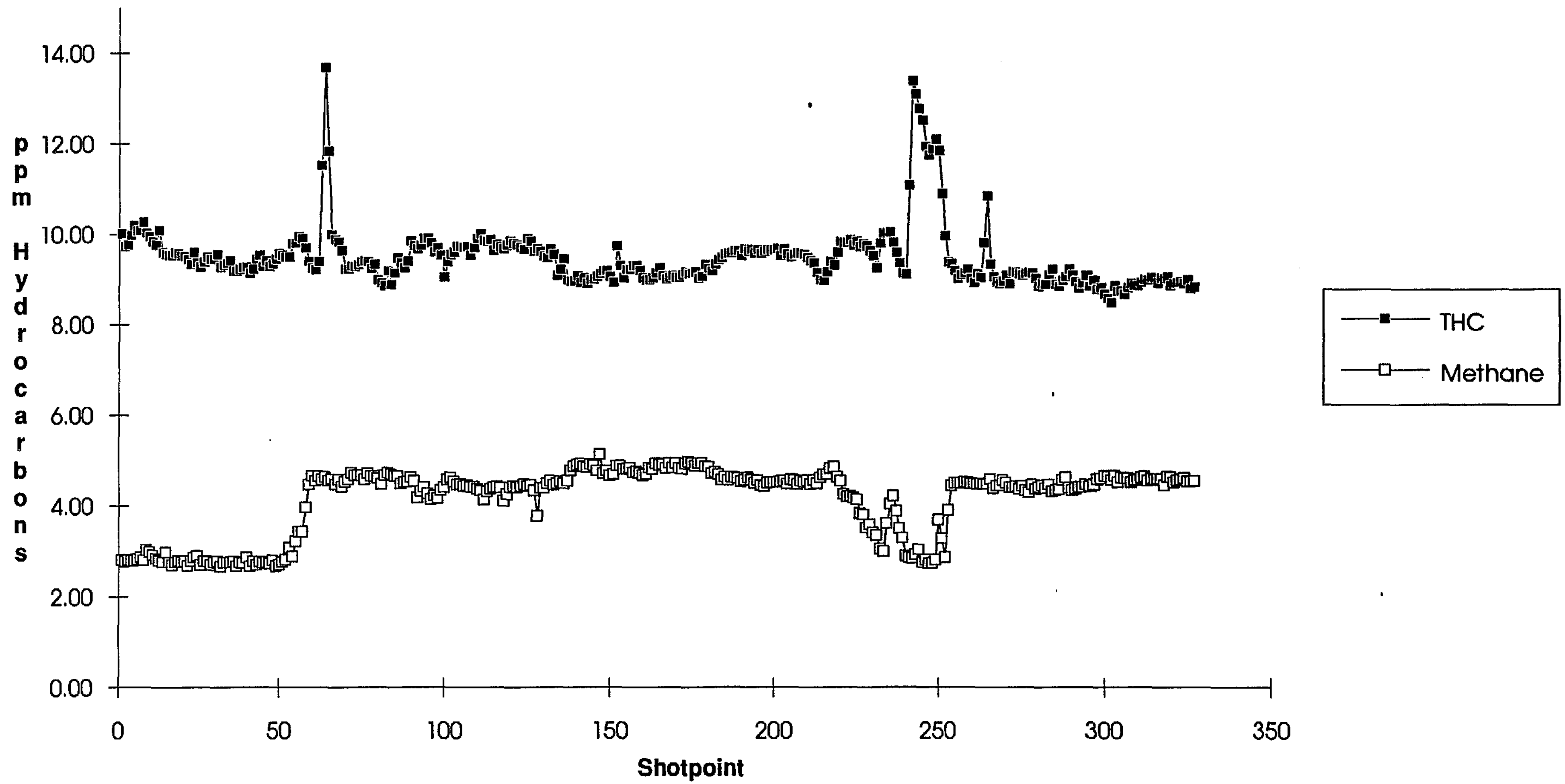
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	13-Feb-91	18:49:39	10	44.259	126	12.691
End	328	14-Feb-91	08:28:01	11	06.488	125	51.395

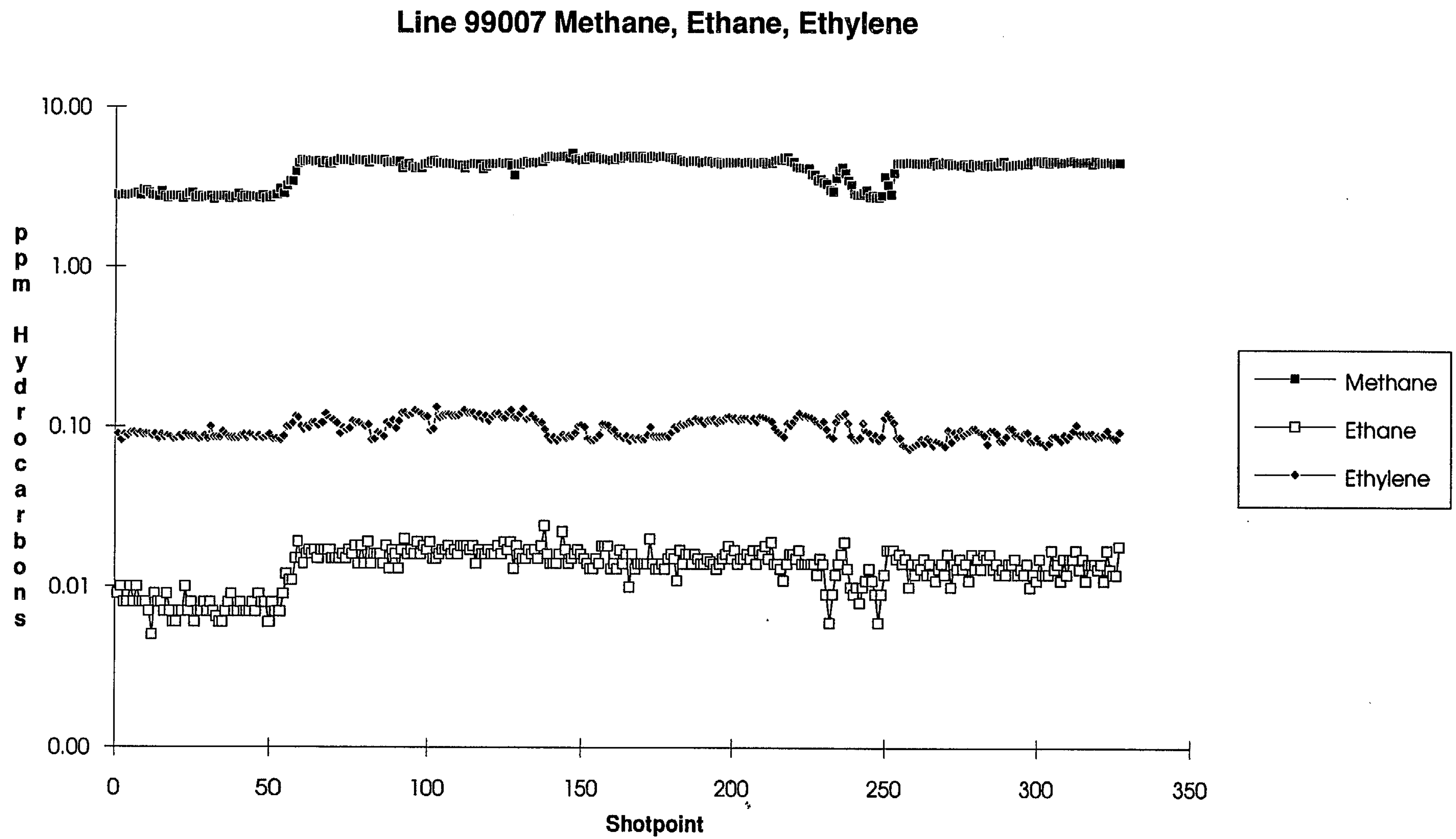
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.475	4.139	0.014	0.098	0.023	0.040	0.000	0.001	0.000	0.074	0.002	0.051	0.887
Std. Dev.	0.689	0.736	0.004	0.013	0.012	0.029	0.001	0.003	0.001	0.038	0.011	0.030	0.312
Minimum	8.478	2.660	0.005	0.073	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.217
Maximum	13.670	5.138	0.024	0.133	0.077	0.161	0.012	0.028	0.009	0.237	0.091	0.120	2.231

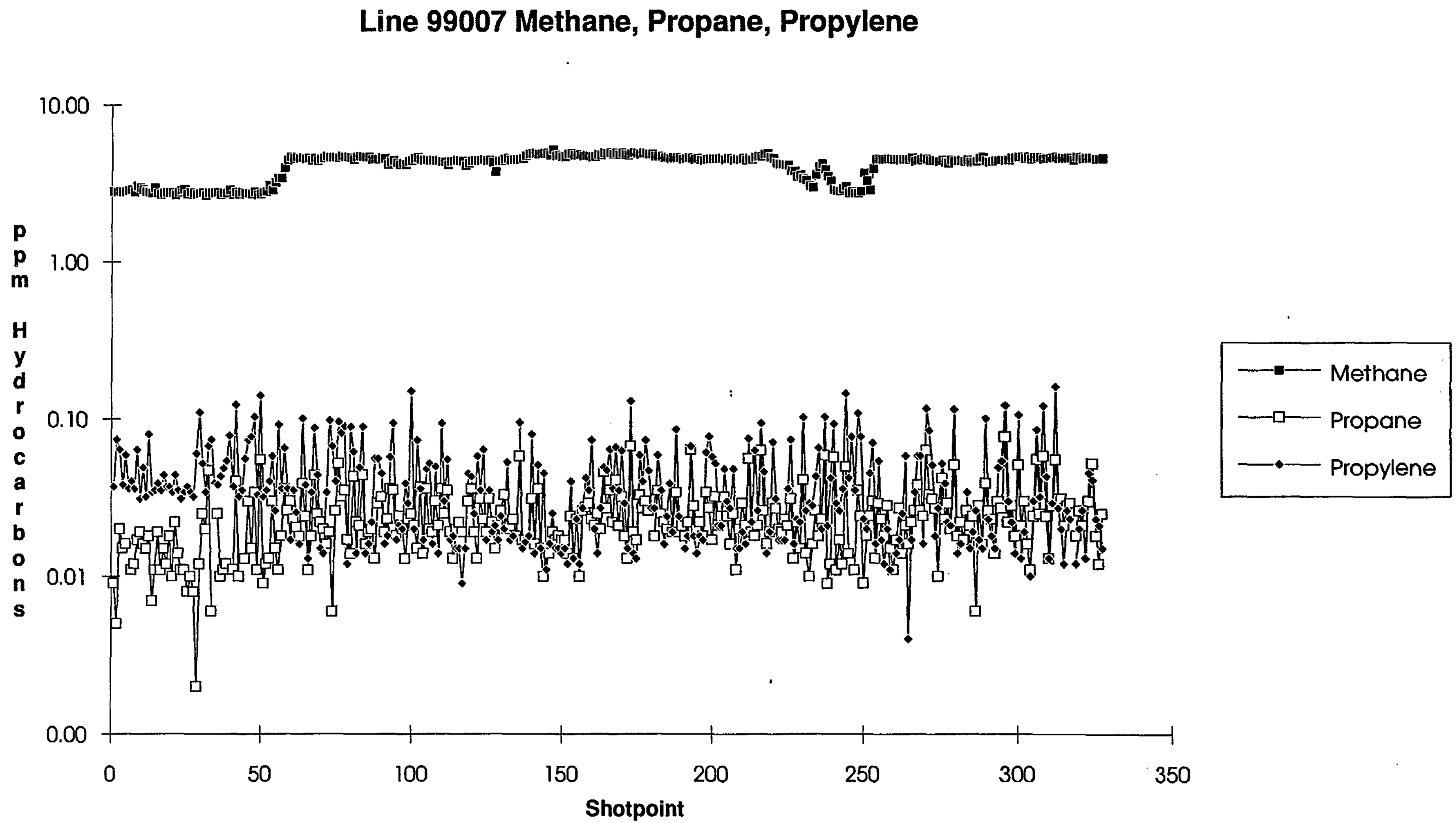
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.508	27.210	71.956	120.376	48.417
Std. Dev.	1.132	0.856	26.207	39.624	58.666
Minimum	58.580	25.720	11.100	20.700	4.800
Maximum	63.240	29.230	95.100	259.200	247.660

Notes
Variations in hydrocarbon values due to variations in fish depths and water depths

Line 99007 THC, Methane

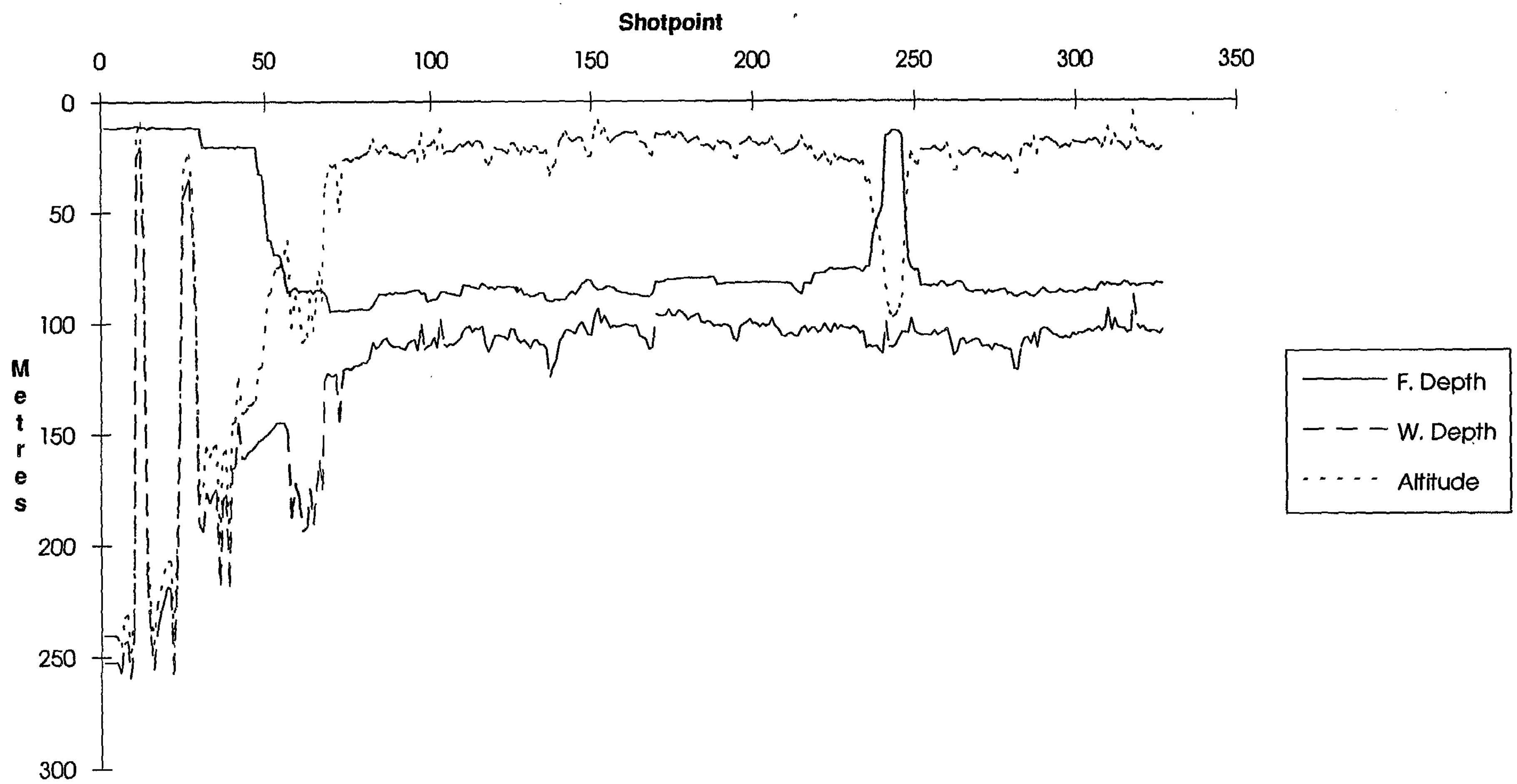



Line 99007 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
350
Shotpoint
Methane
Ethane
Ethylene



Line 99007 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
350
Shotpoint
Methane
Propane
Propylene

Line 99007 Depths, Altitude



Line Summary

Line Number	99008
No. of Shotpoints	652

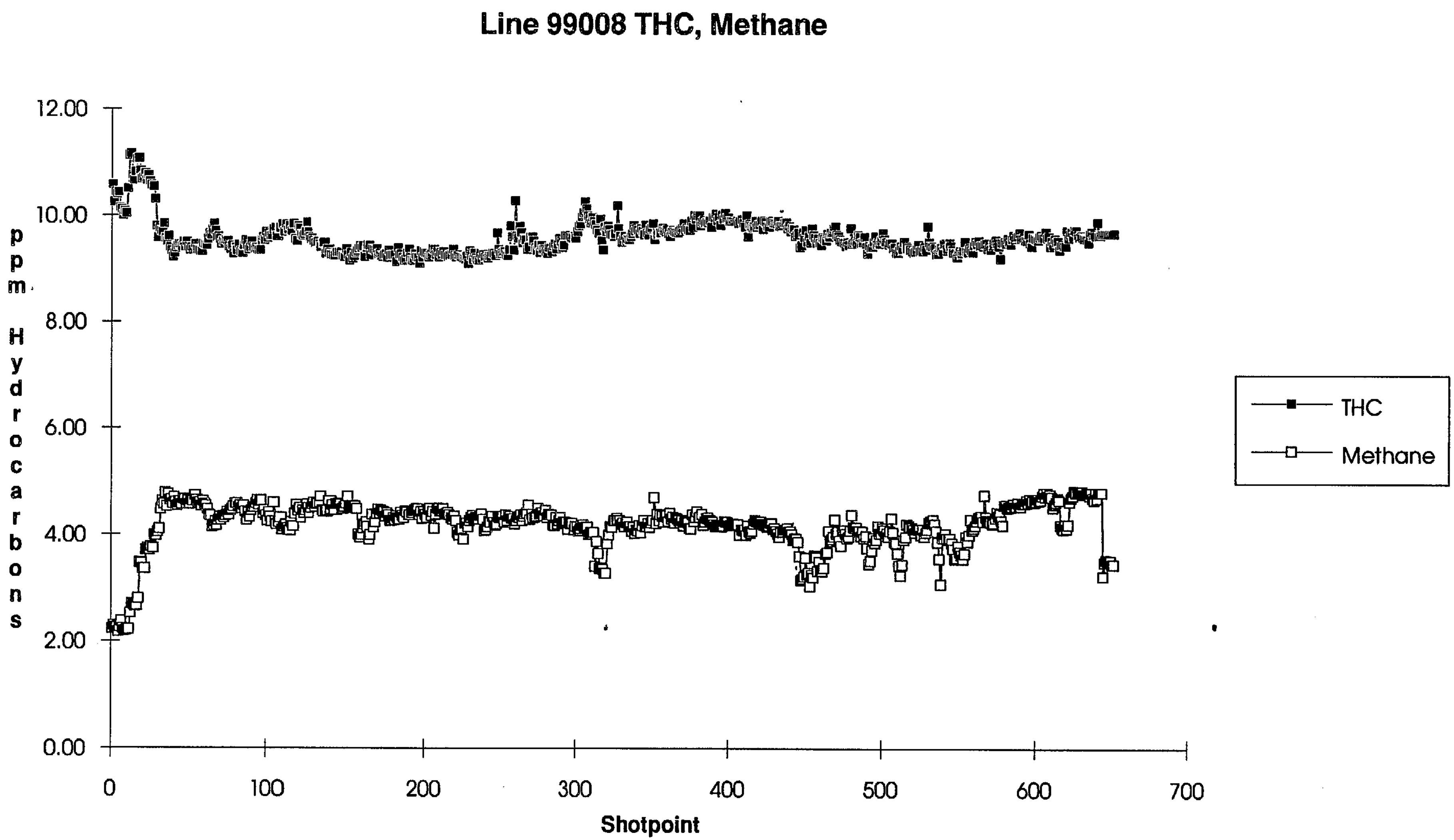
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	14-Feb-91	15:45:06	10	56.934	125	54.198
End	652	15-Feb-91	14:00:30	12	34.180	126	49.034

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.577	4.175	0.013	0.092	0.024	0.034	0.000	0.000	0.000	0.077	0.031	0.052	0.891
Std. Dev.	0.306	0.446	0.003	0.011	0.014	0.021	0.001	0.003	0.002	0.046	0.058	0.032	0.352
Minimum	9.093	2.179	0.004	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.161
Maximum	11.159	4.830	0.023	0.116	0.116	0.120	0.019	0.037	0.019	0.251	0.361	0.165	2.935

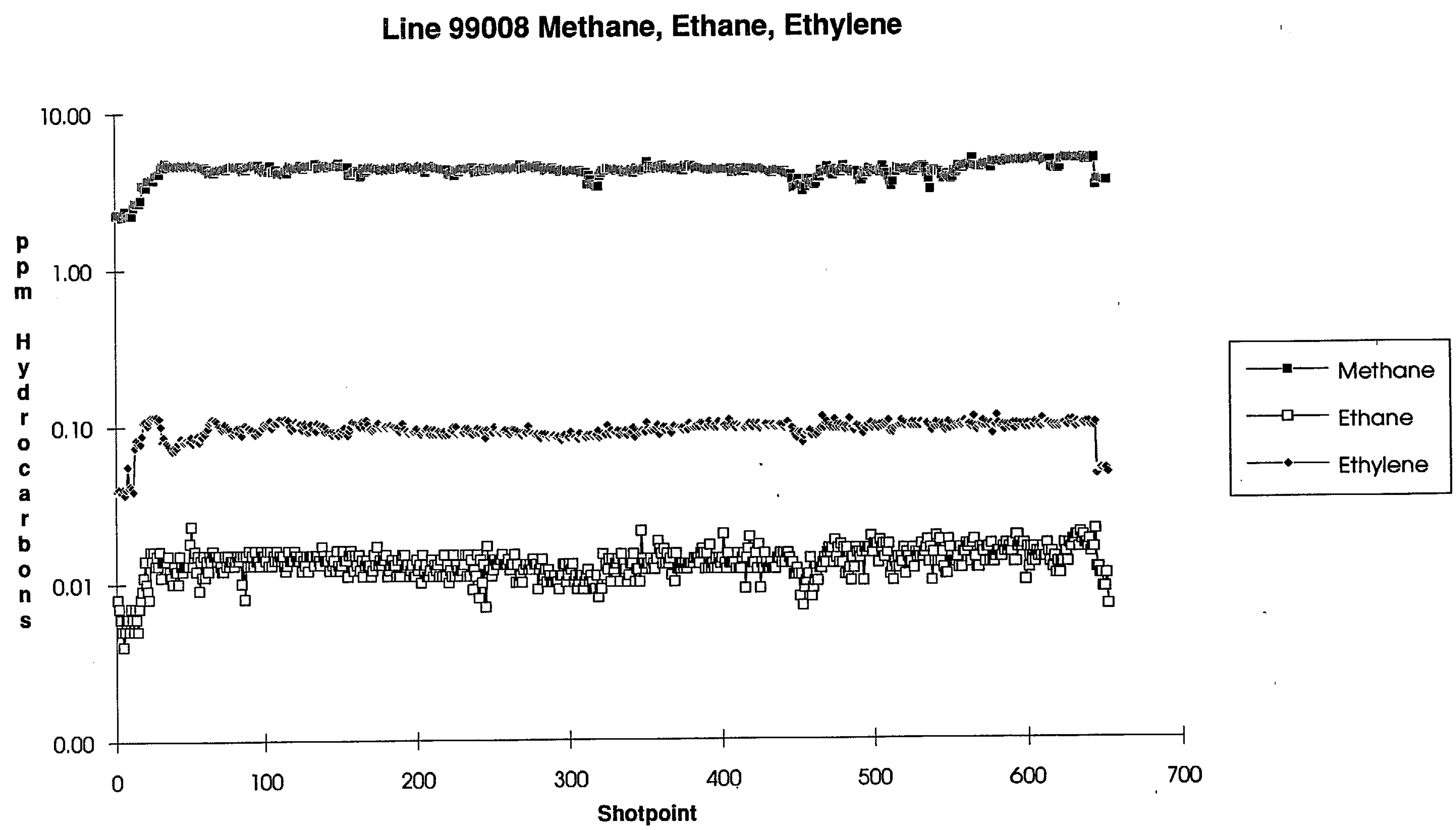
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.901	27.456	67.117	87.260	19.283
Std. Dev.	1.157	0.898	12.342	16.532	21.411
Minimum	58.680	25.770	10.900	53.900	8.500
Maximum	63.480	29.490	88.100	195.860	184.560

Notes

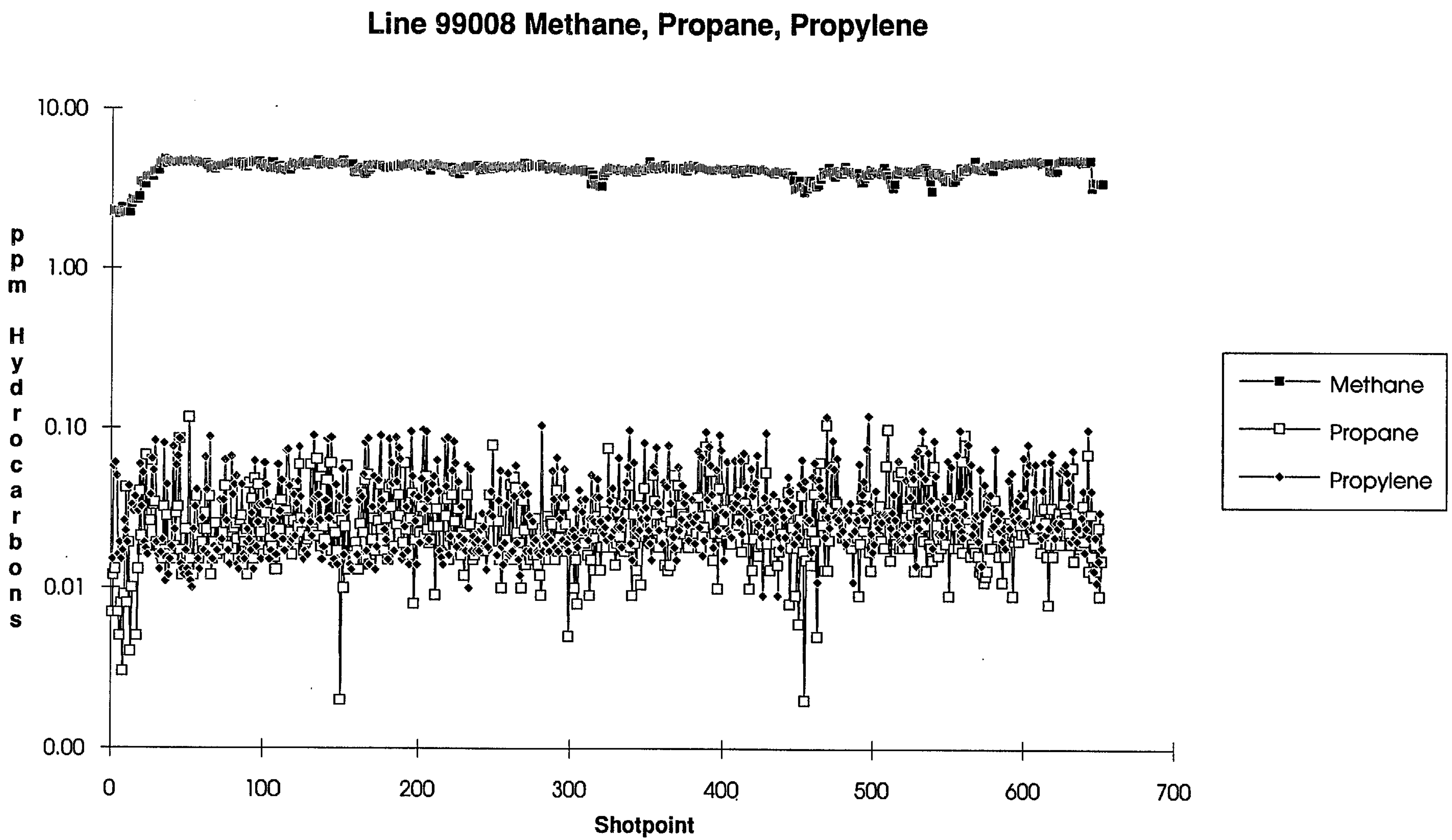
Variations in hydrocarbon values are due to variations in fish depths and water depths

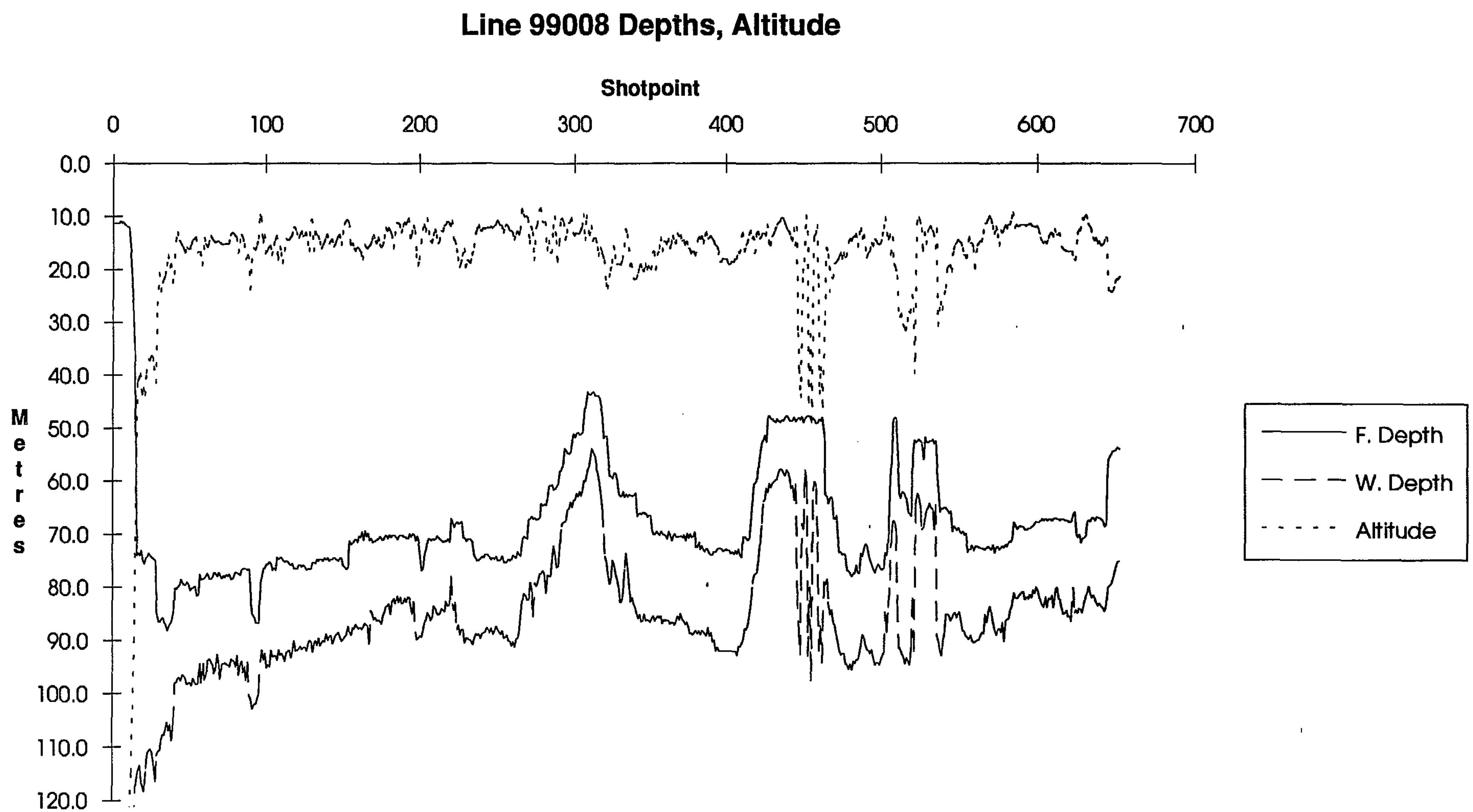


Line 99008 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane



Line 99008 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
Shotpoint
Methane
Ethane
Ethylene


Line 99008 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
Shotpoint
Methane
Propane
Propylene


Line 99008 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
700
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	99009
No. of Shotpoints	289

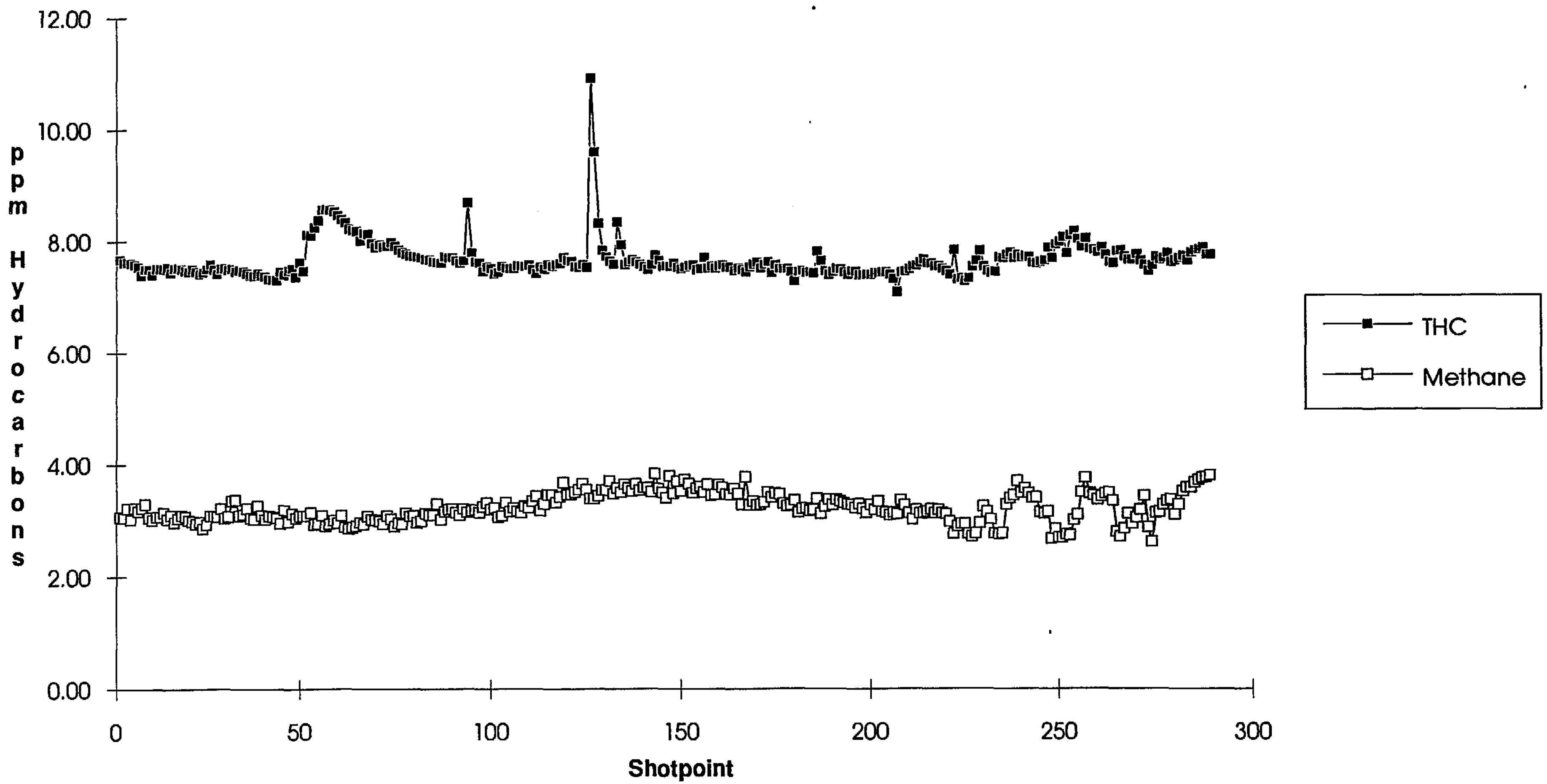
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	15-Feb-91	19:03:10	12	36.258	126	33.488
End	507	16-Feb-91	13:33:39	11	50.757	126	51.650

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.653	3.223	0.010	0.058	0.021	0.029	0.001	0.000	0.005	0.056	0.065	0.039	0.981
Std. Dev.	0.336	0.251	0.002	0.003	0.016	0.023	0.004	0.002	0.004	0.027	0.041	0.022	0.552
Minimum	7.079	2.615	0.006	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.279
Maximum	10.911	3.831	0.014	0.067	0.095	0.116	0.062	0.020	0.013	0.140	0.435	0.129	3.488

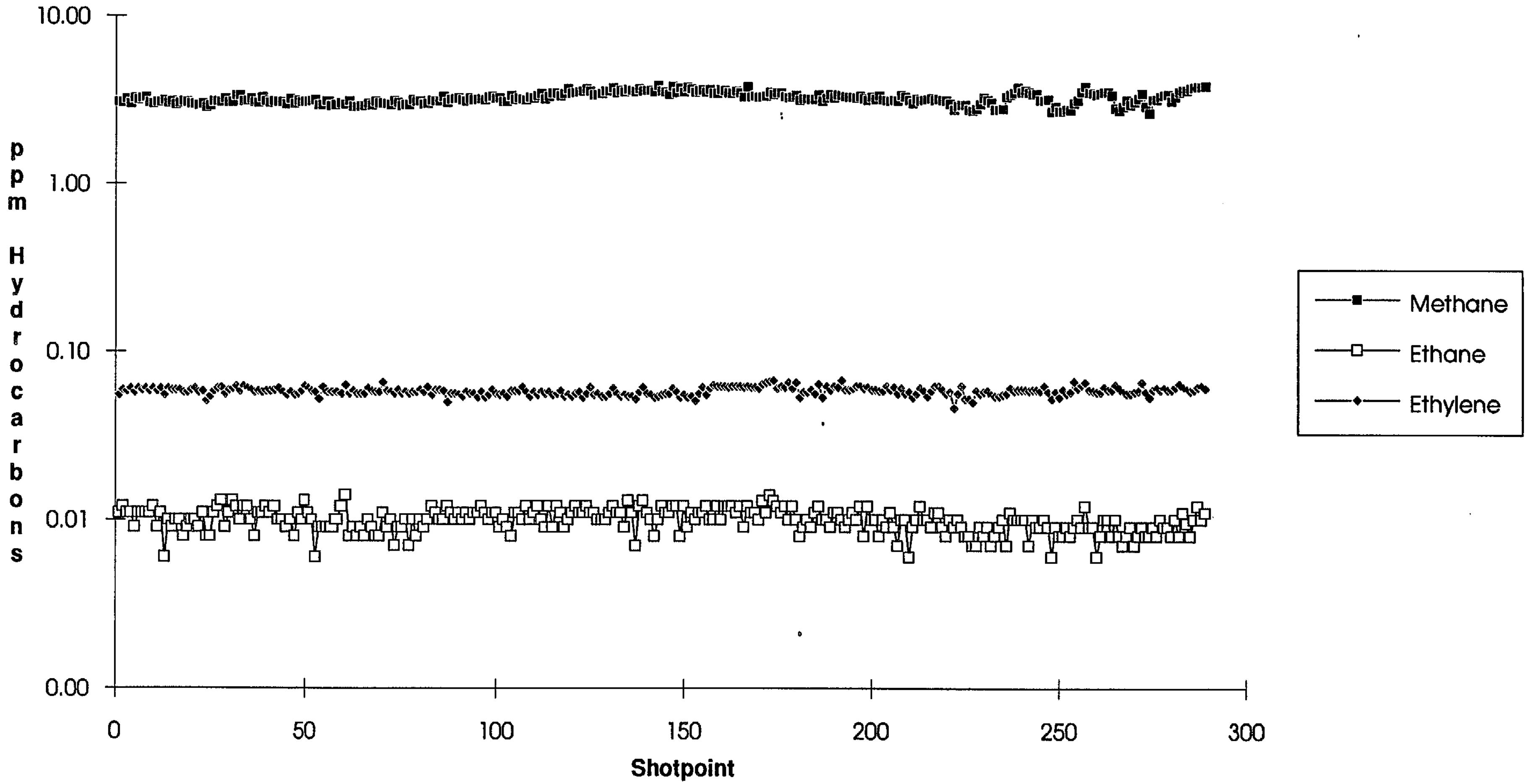
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.648	26.357	65.796	82.258	15.630
Std. Dev.	0.517	0.405	8.983	10.492	5.049
Minimum	58.720	25.660	53.000	60.900	5.900
Maximum	60.680	27.200	81.000	102.200	38.200

Notes
THC amonaly at shotpoints 228 to 231

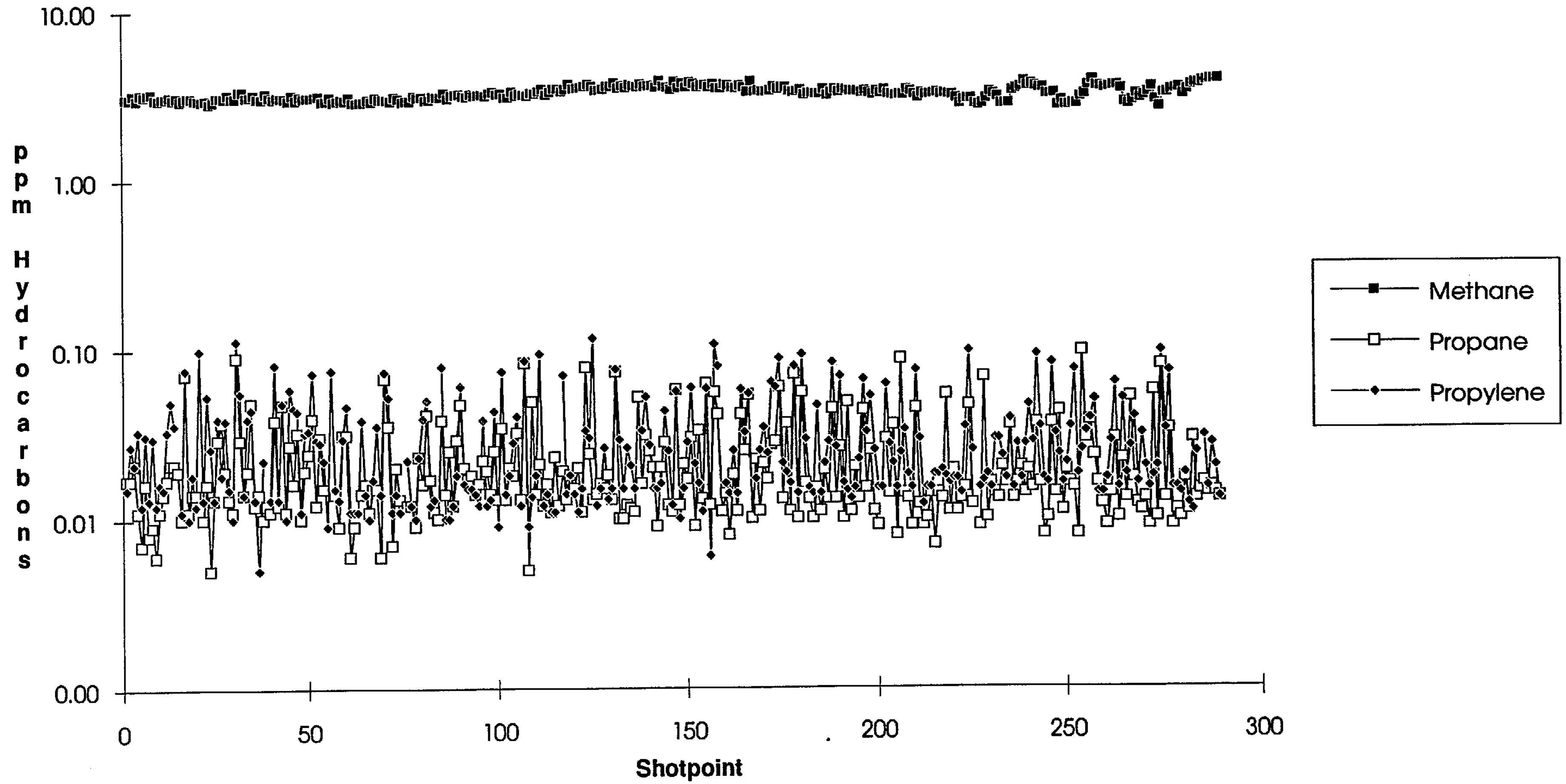
Line 99009 THC, Methane



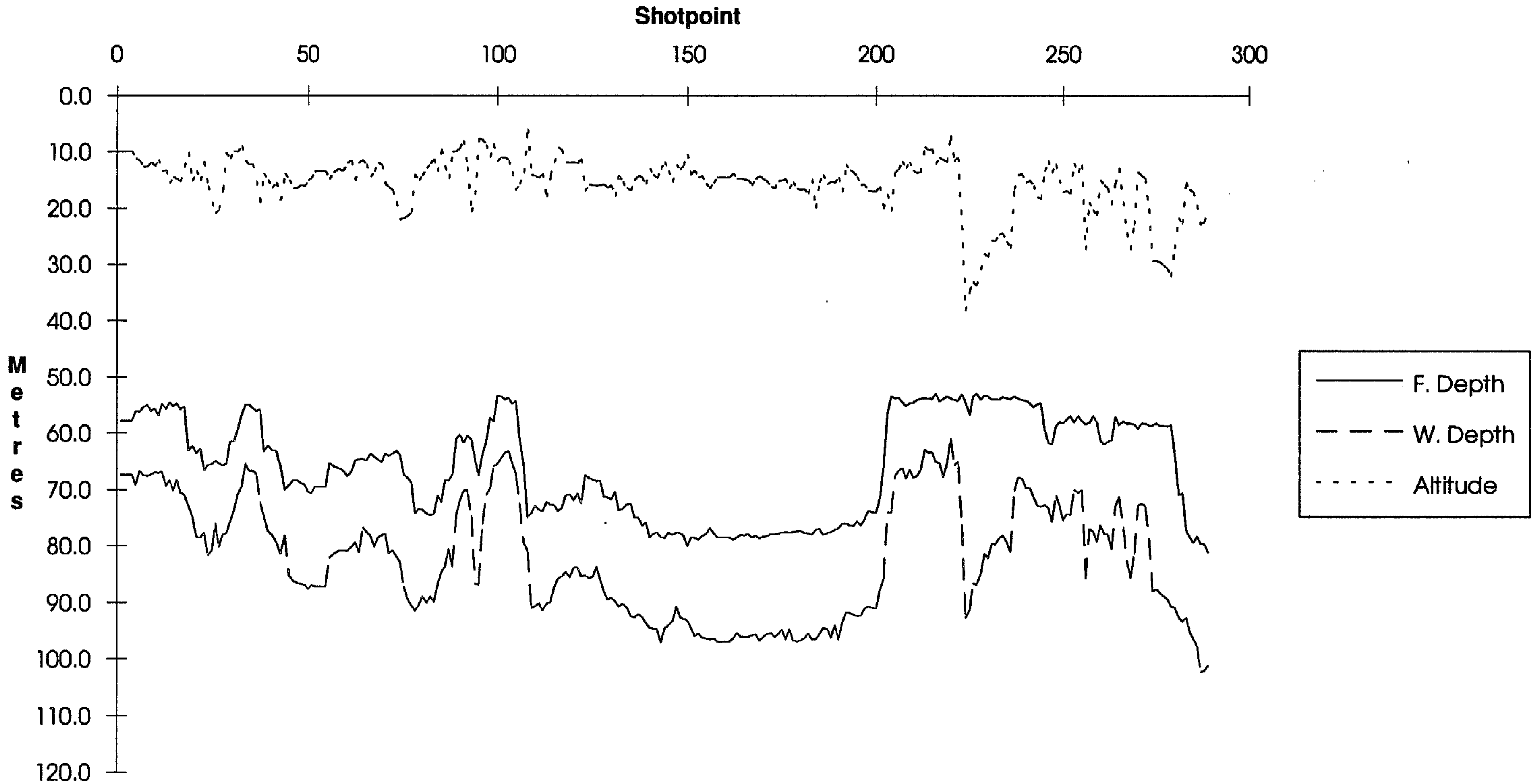
Line 99009 Methane, Ethane, Ethylene



Line 99009 Methane, Propane, Propylene



Line 99009 Depths, Altitude



Line Summary

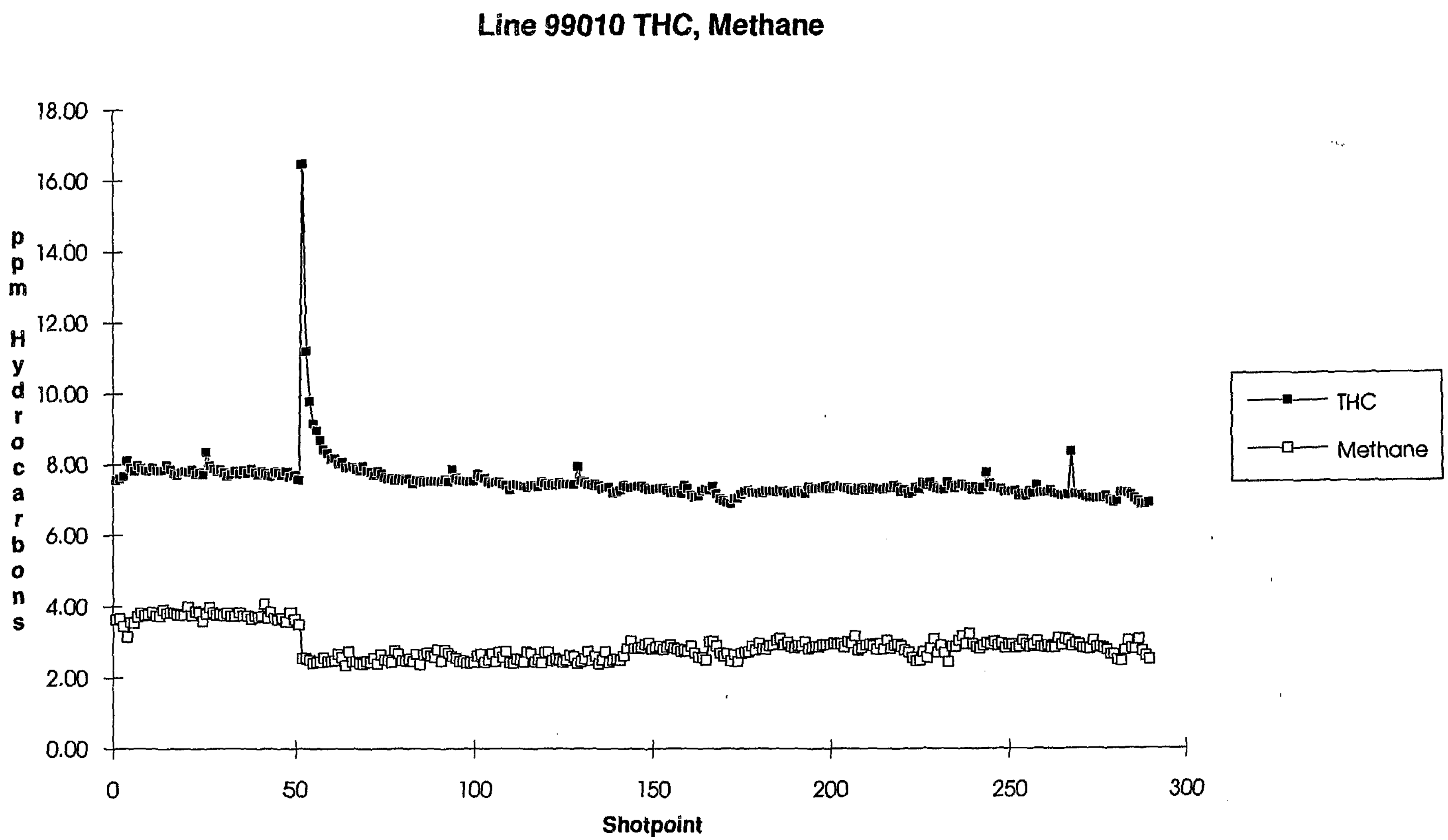
Line Number	99010
No. of Shotpoints	290

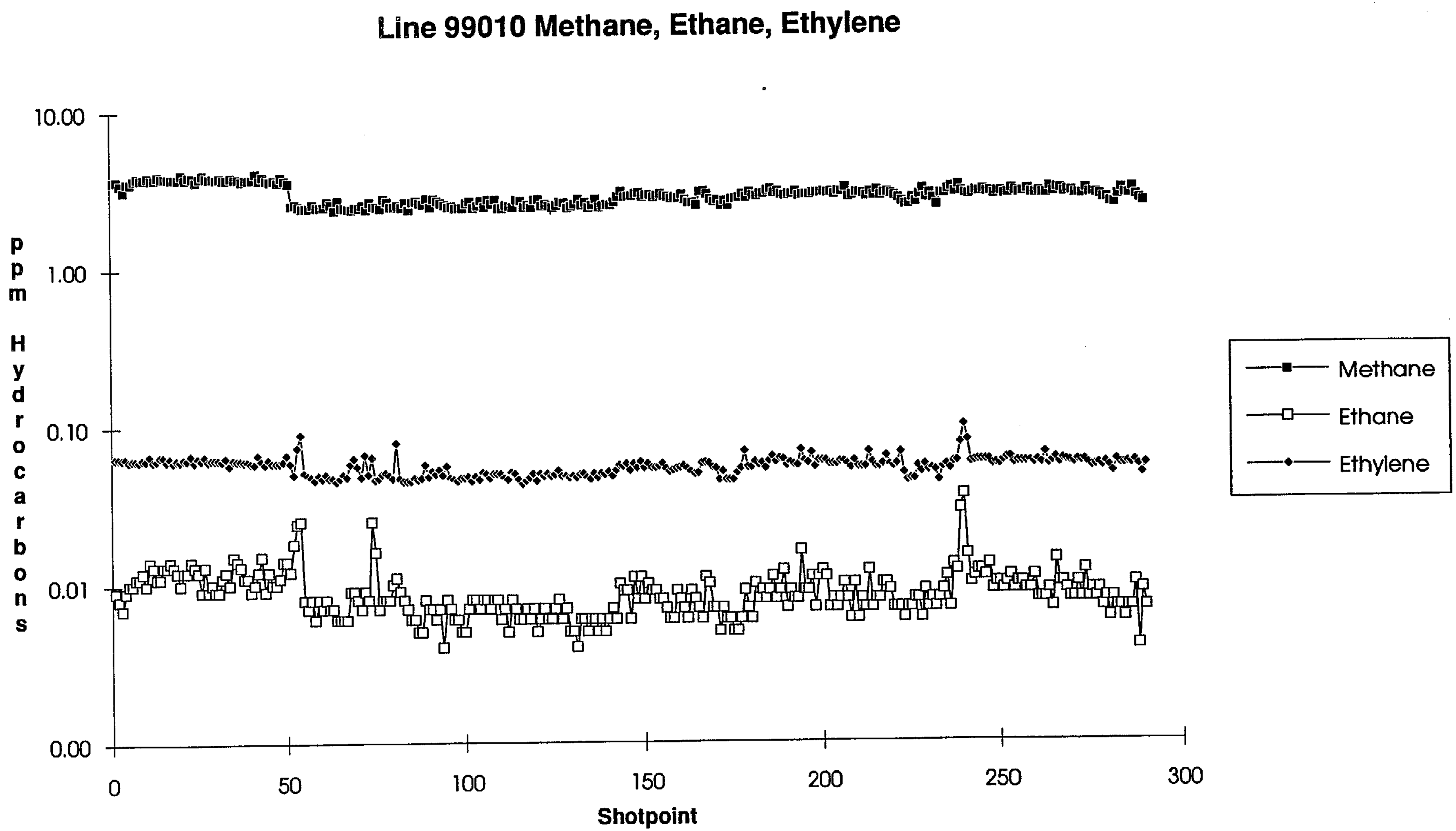
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	16-Feb-91	17:22:45	33.32	11.000	56.56	127.000
End	311	16-Feb-91	03:57:01	24.54	12.000	12.119	126.000

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.503	2.895	0.009	0.055	0.018	0.035	0.002	0.001	0.007	0.080	0.048	0.038	1.031
Std. Dev.	0.674	0.432	0.004	0.007	0.016	0.032	0.008	0.004	0.005	0.045	0.034	0.022	0.672
Minimum	6.853	2.344	0.004	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.247
Maximum	16.493	4.061	0.036	0.099	0.154	0.234	0.086	0.036	0.038	0.198	0.169	0.117	5.287

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.460	26.930	47.206	76.226	28.867
Std. Dev.	0.876	0.682	26.841	15.264	20.813
Minimum	58.490	25.440	2.100	49.500	7.870
Maximum	62.620	28.570	85.120	144.500	109.070

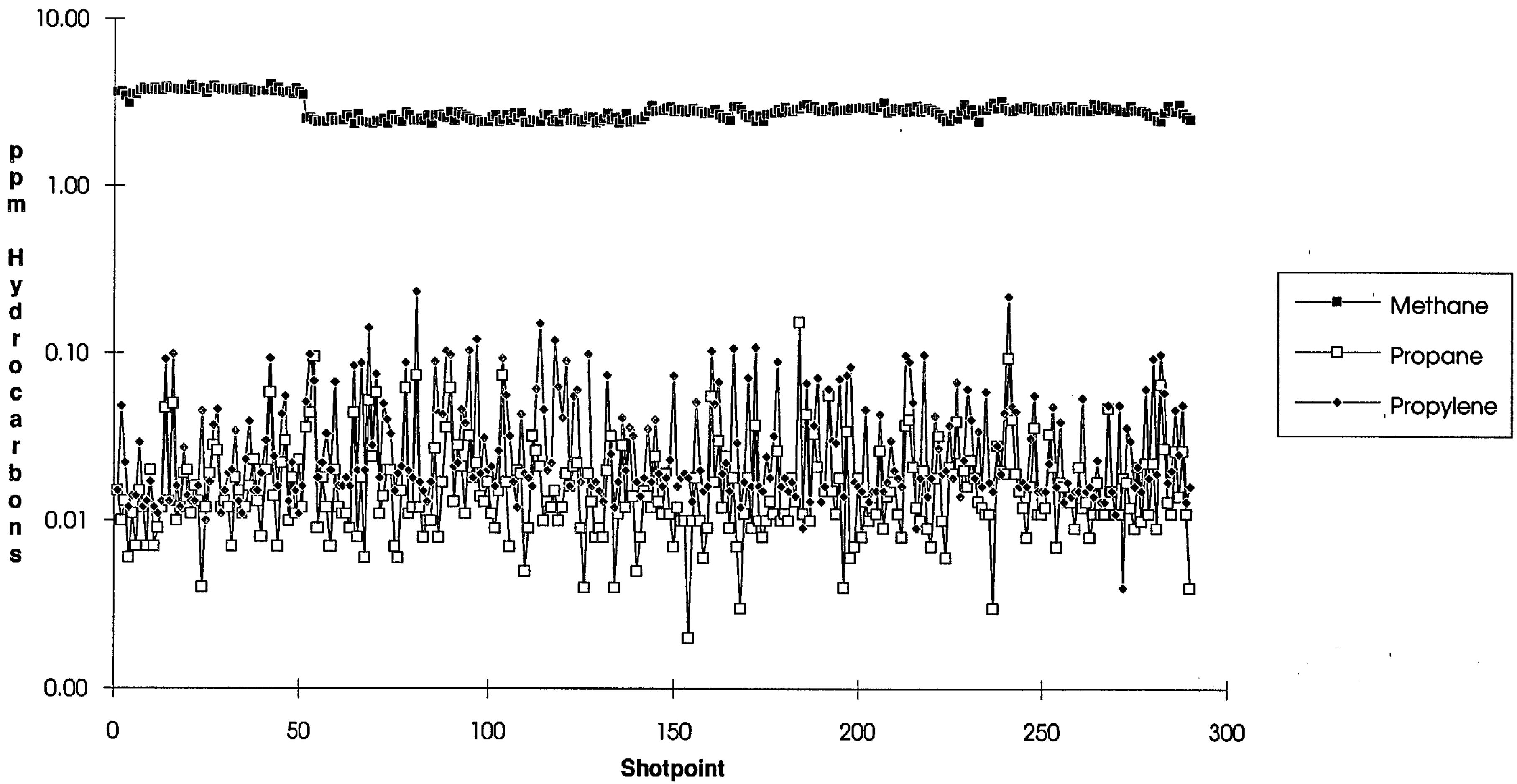
Notes
Variations in hydrocarbon values due to variations in fish depths and water depths
Fish 3 metres below surface from SP73 to SP 133


Line 99010 THC, Methane
ppm Hydrocarbons
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Shotpoint
THC
Methane

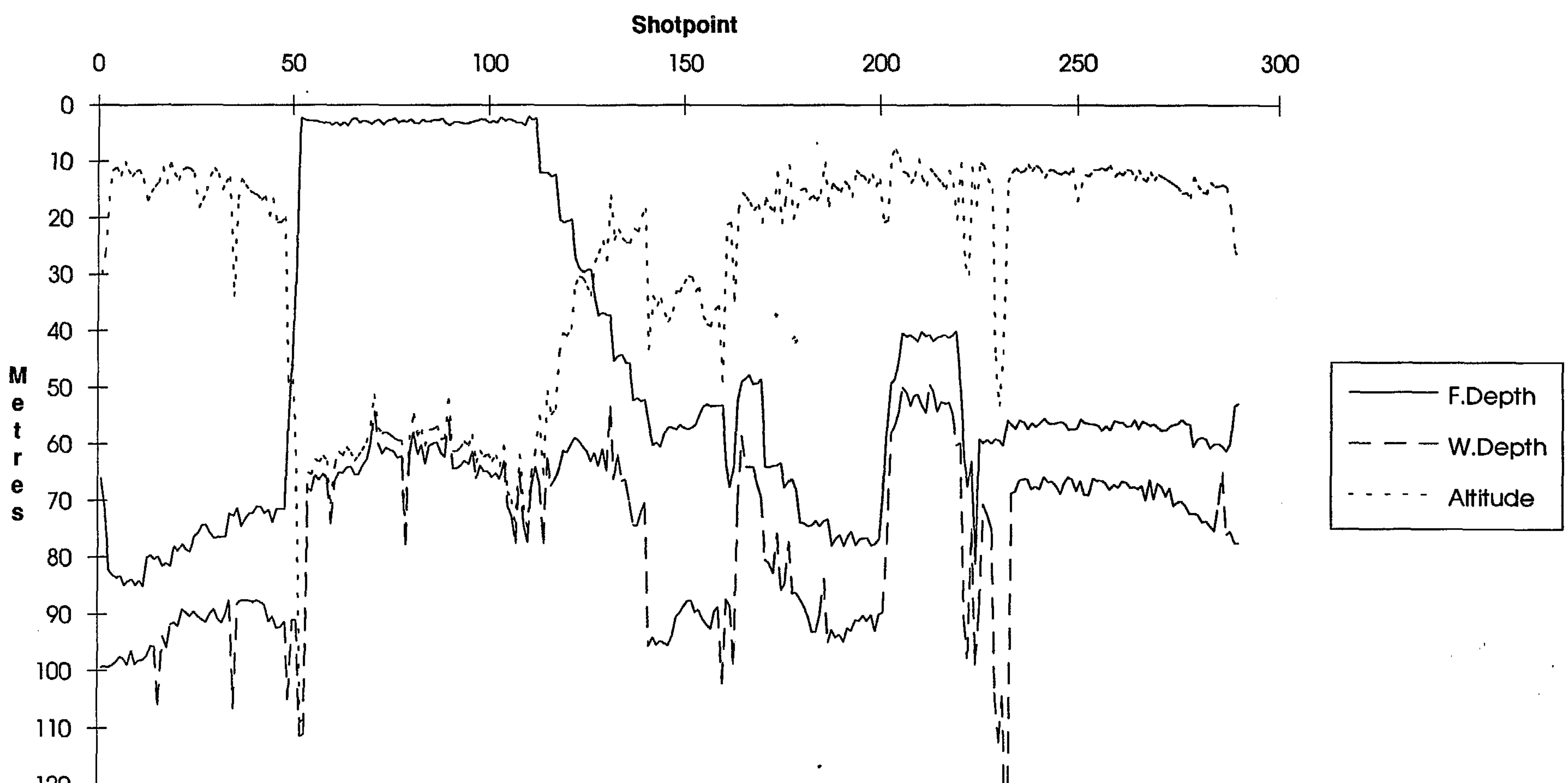


Line 99010 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
Shotpoint
Methane
Ethane
Ethylene

Line 99010 Methane, Propane, Propylene



Line 99010 Depths, Altitude



Line Summary

Line Number	99011
No. of Shotpoints	303

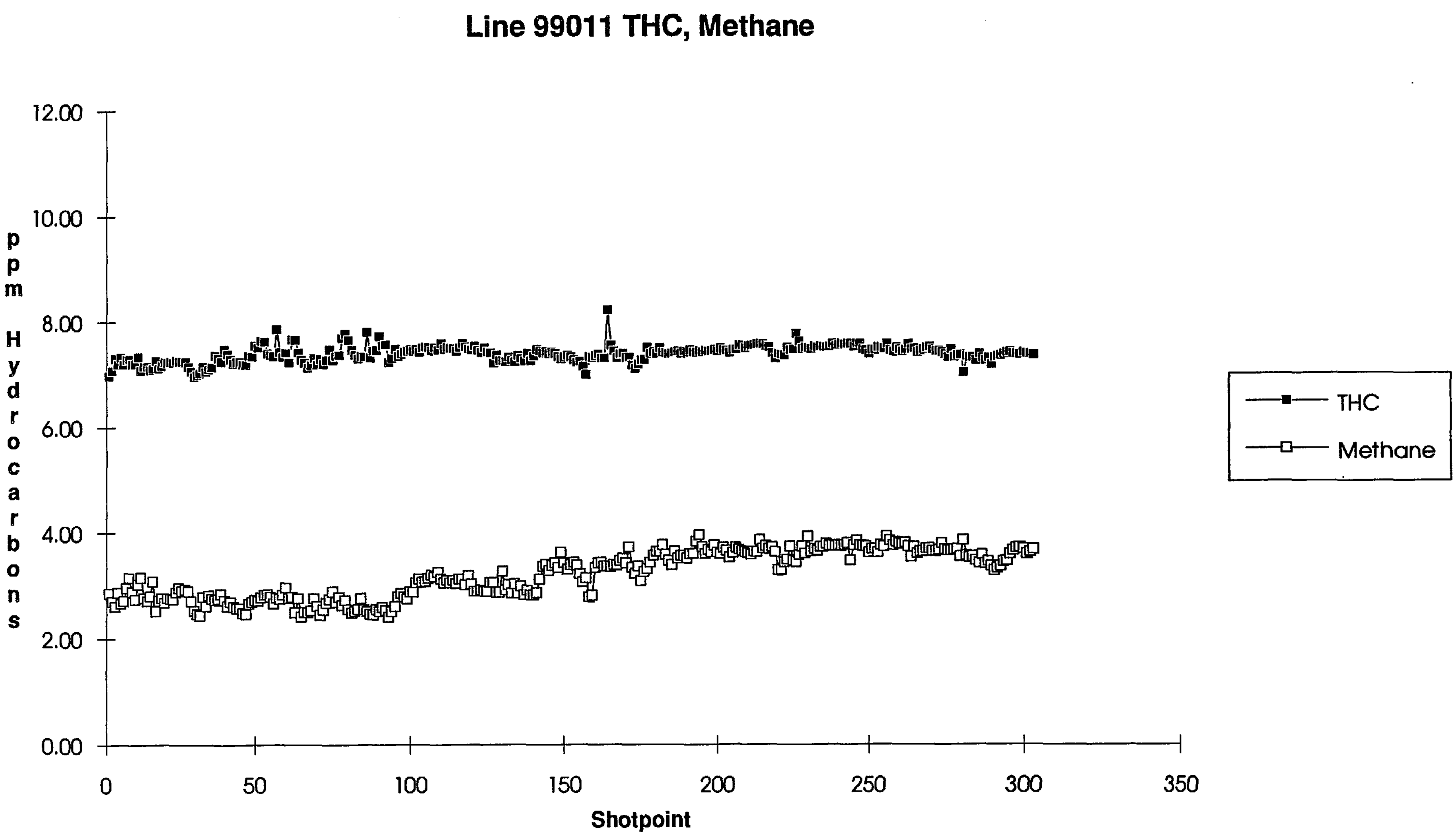
	Shotpoint	Date	Time	Latitude		Longitude	
Start	3	17-Feb-91	09:22:47	12	04.602	126	24.527
End	371	17-Feb-91	22:09:48	11	47.871	127	12.906

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.388	3.210	0.009	0.057	0.019	0.028	0.002	0.000	0.003	0.052	0.036	0.029	0.952
Std. Dev.	0.153	0.438	0.002	0.006	0.013	0.018	0.008	0.002	0.003	0.029	0.039	0.025	0.519
Minimum	6.955	2.415	0.004	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.192
Maximum	8.216	3.956	0.017	0.071	0.078	0.106	0.066	0.021	0.020	0.178	0.142	0.101	3.464

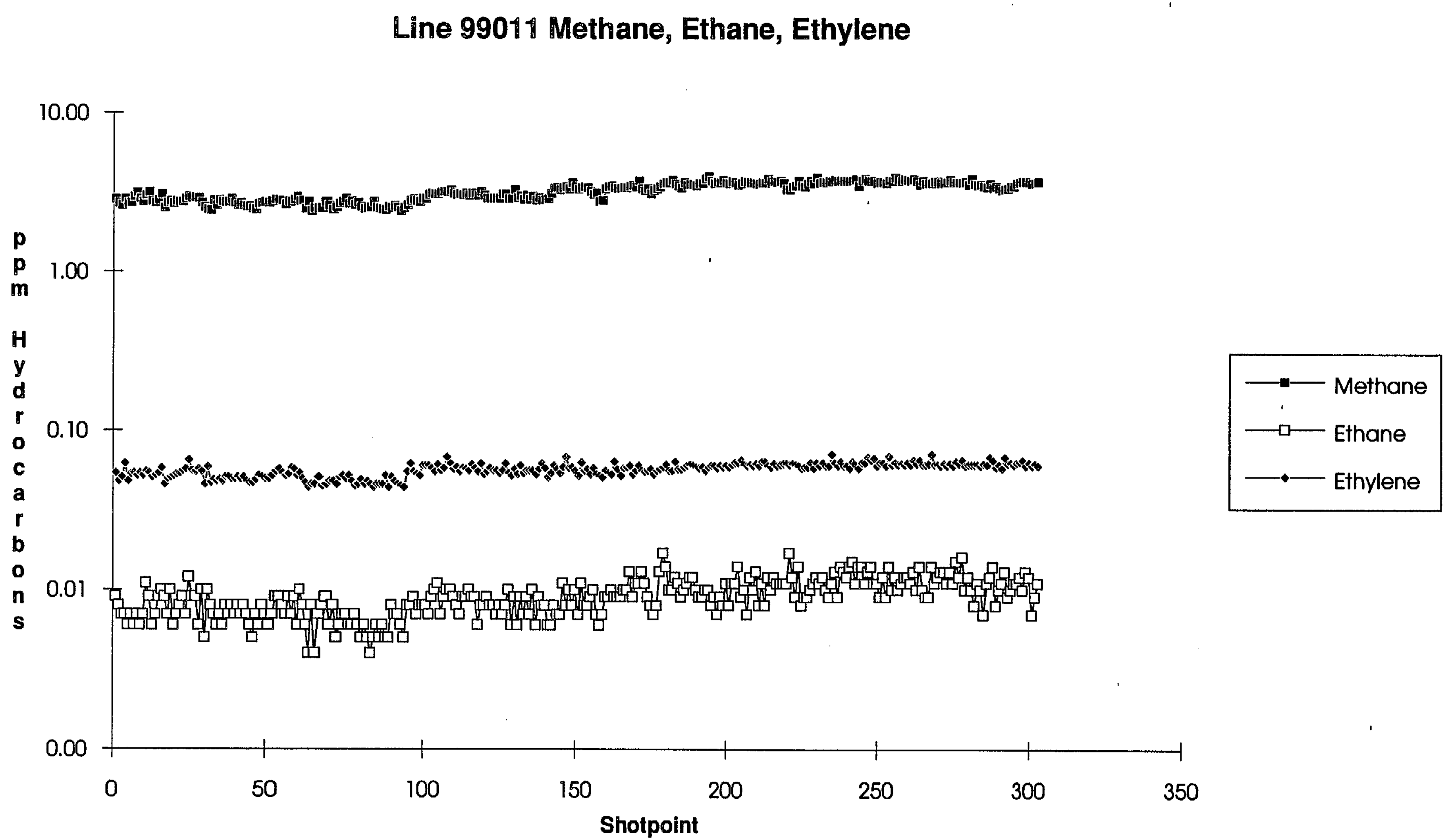
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.675	26.288	64.729	86.057	21.362
Std. Dev.	1.091	0.871	21.908	21.300	10.660
Minimum	58.040	25.030	33.000	47.600	8.800
Maximum	61.260	27.450	102.400	120.200	65.600

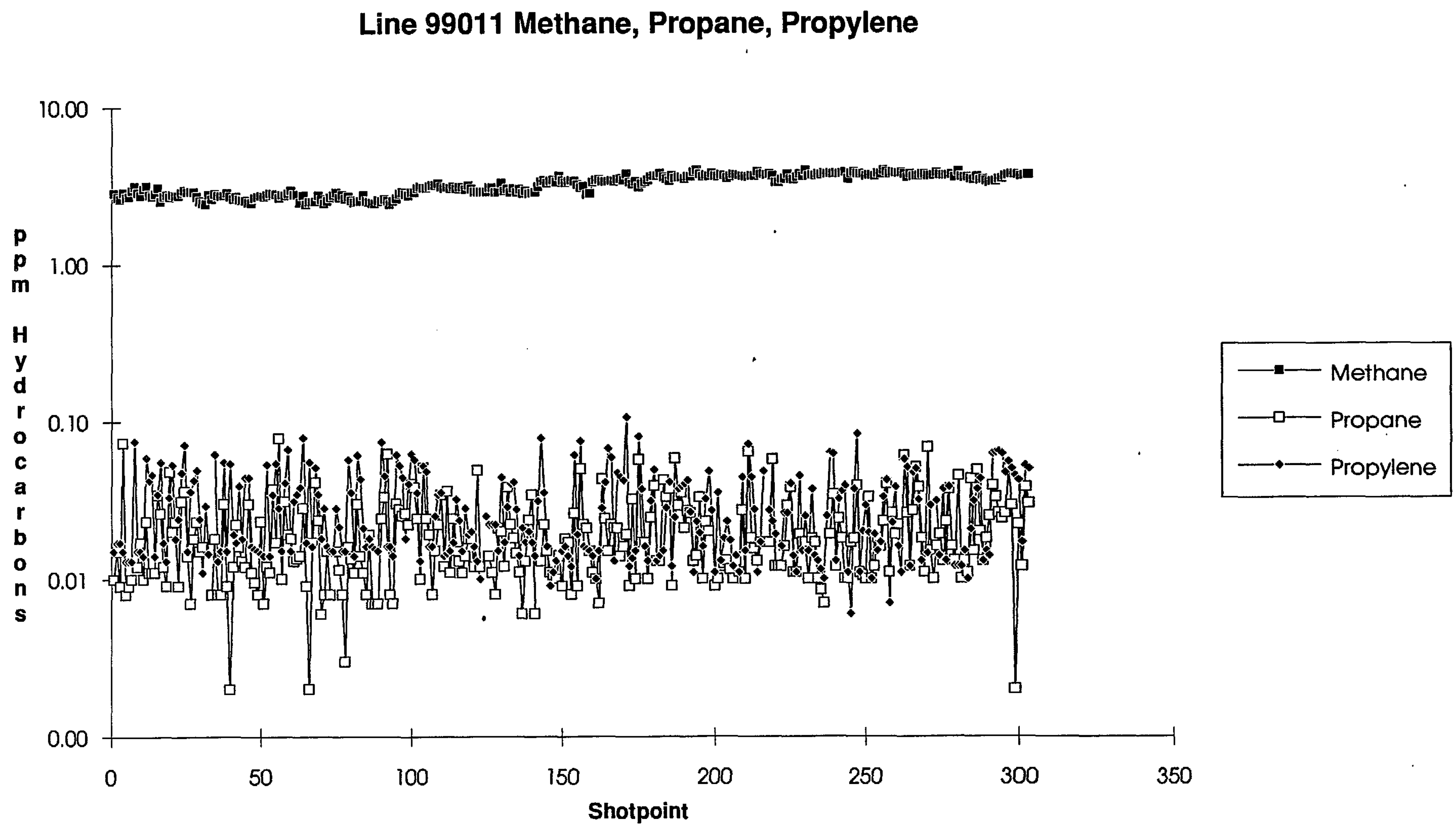
Notes

No hydrocarbon anomalies detected

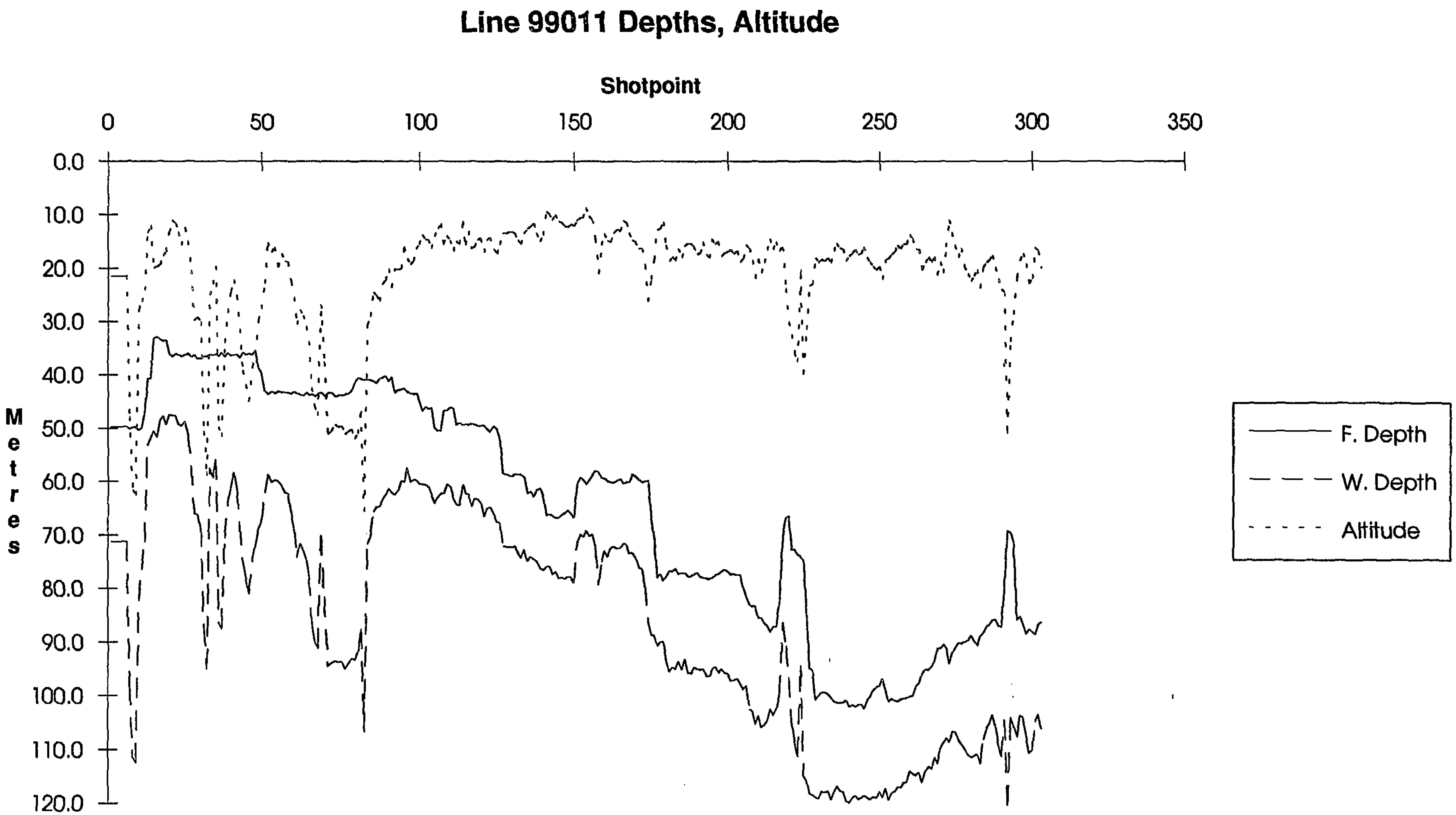


Line 99011 THC, Methane
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
350
Shotpoint
THC
Methane


Line 99011 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
350
Shotpoint
Methane
Ethane
Ethylene



Line 99011 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
350
Shotpoint
Methane
Propane
Propylene


Line 99011 Depths, Altitude
Shotpoint
0
50
100
150
200
250
300
350
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

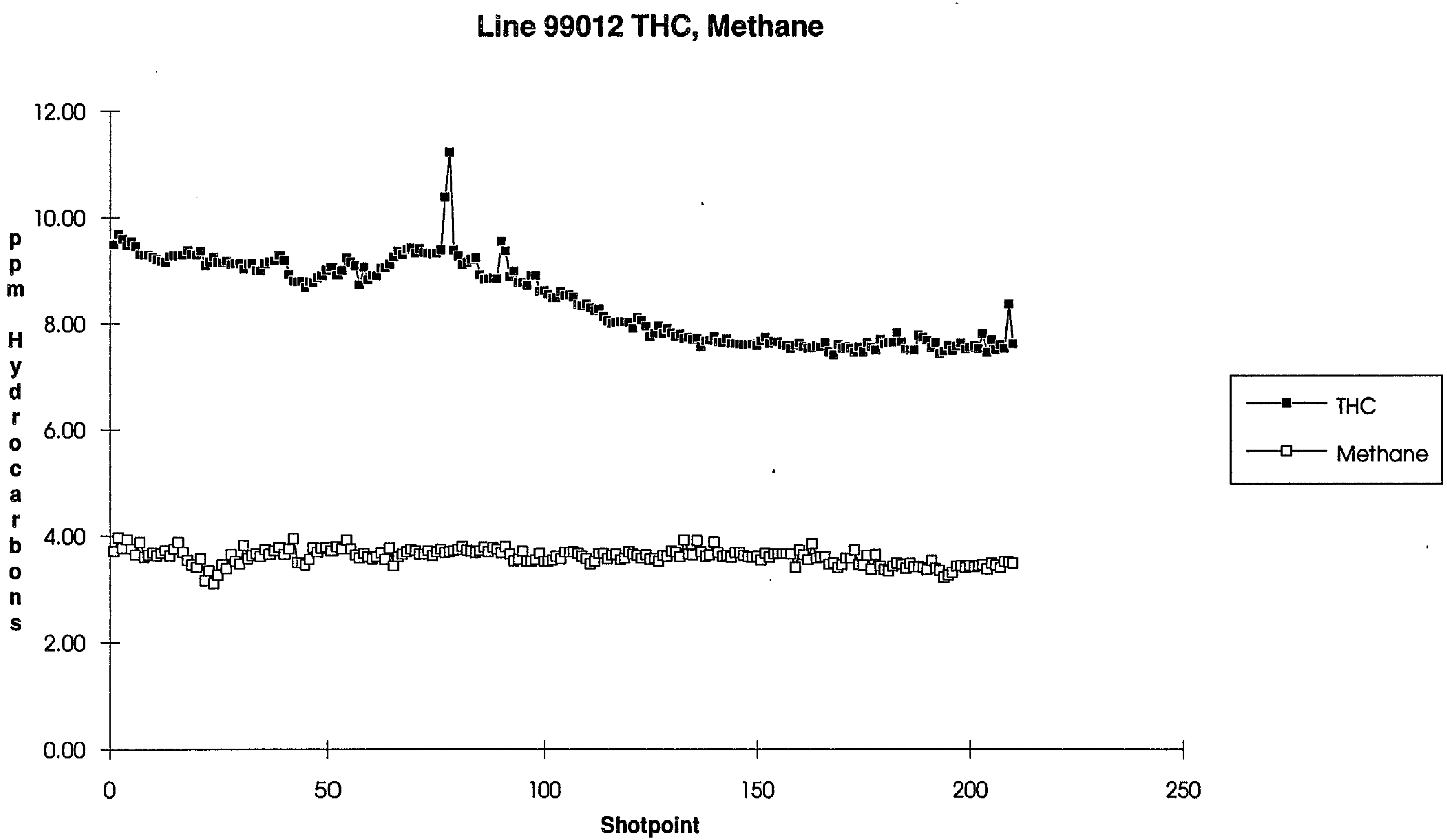
Line Number 99012
No. of Shotpoints 210

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	18-Feb-91	04:59:26	11	58.957	127	21.570
End	211	18-Feb-91	12:06:17	12	08.782	126	49.064

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.425	3.602	0.012	0.065	0.020	0.026	0.001	0.001	0.003	0.039	0.023	0.026	0.900
Std. Dev.	0.767	0.146	0.003	0.005	0.013	0.018	0.003	0.004	0.003	0.015	0.029	0.017	0.406
Minimum	7.402	3.107	0.007	0.057	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.231
Maximum	11.222	3.962	0.035	0.085	0.086	0.084	0.024	0.058	0.012	0.102	0.104	0.063	2.528

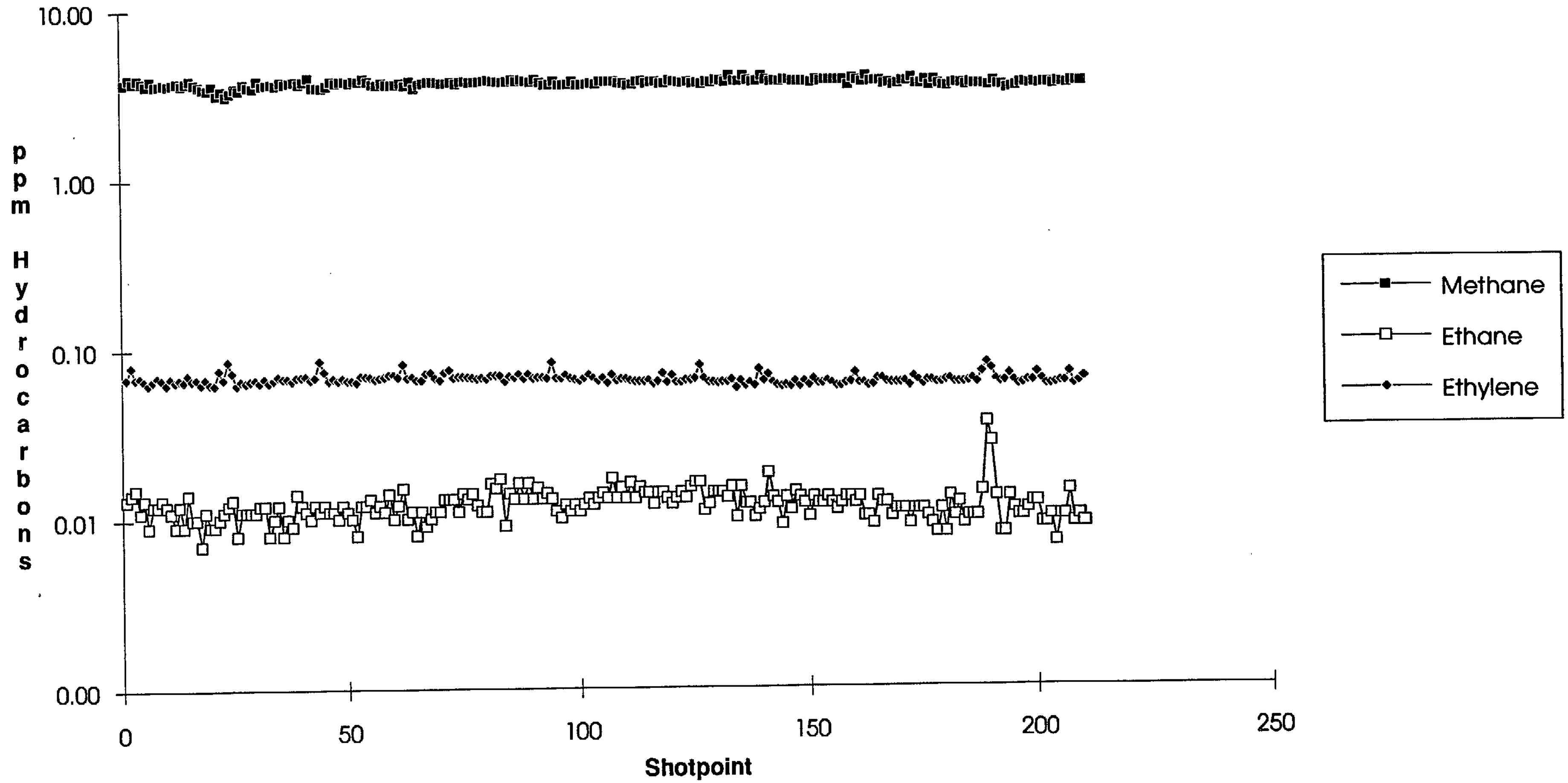
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.223	26.620	76.825	95.345	17.118
Std. Dev.	1.141	0.815	4.756	7.573	3.908
Minimum	58.560	25.360	60.500	73.200	10.500
Maximum	61.640	27.630	84.300	110.700	28.100

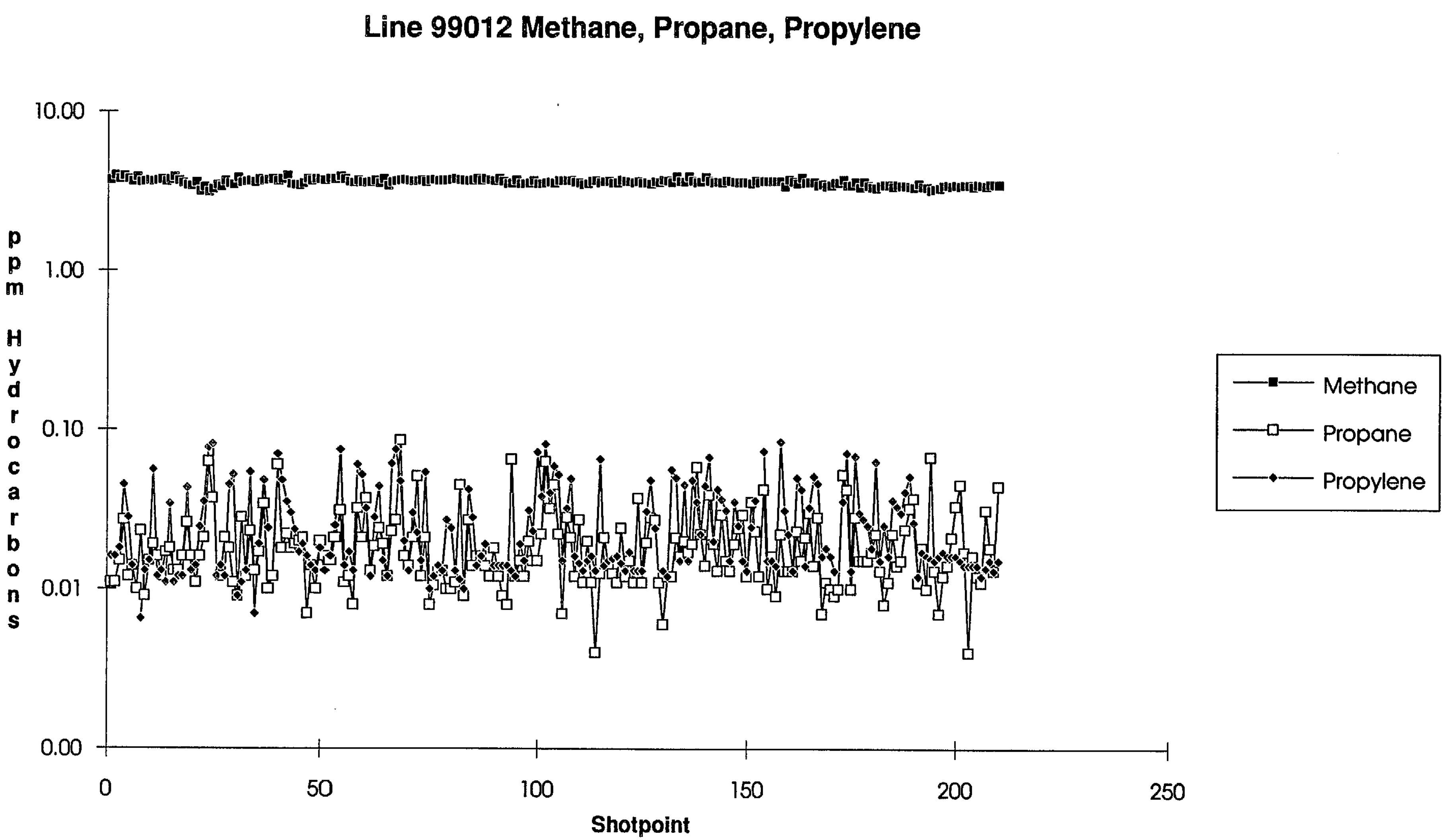
Notes
No hydrocarbon anomalies

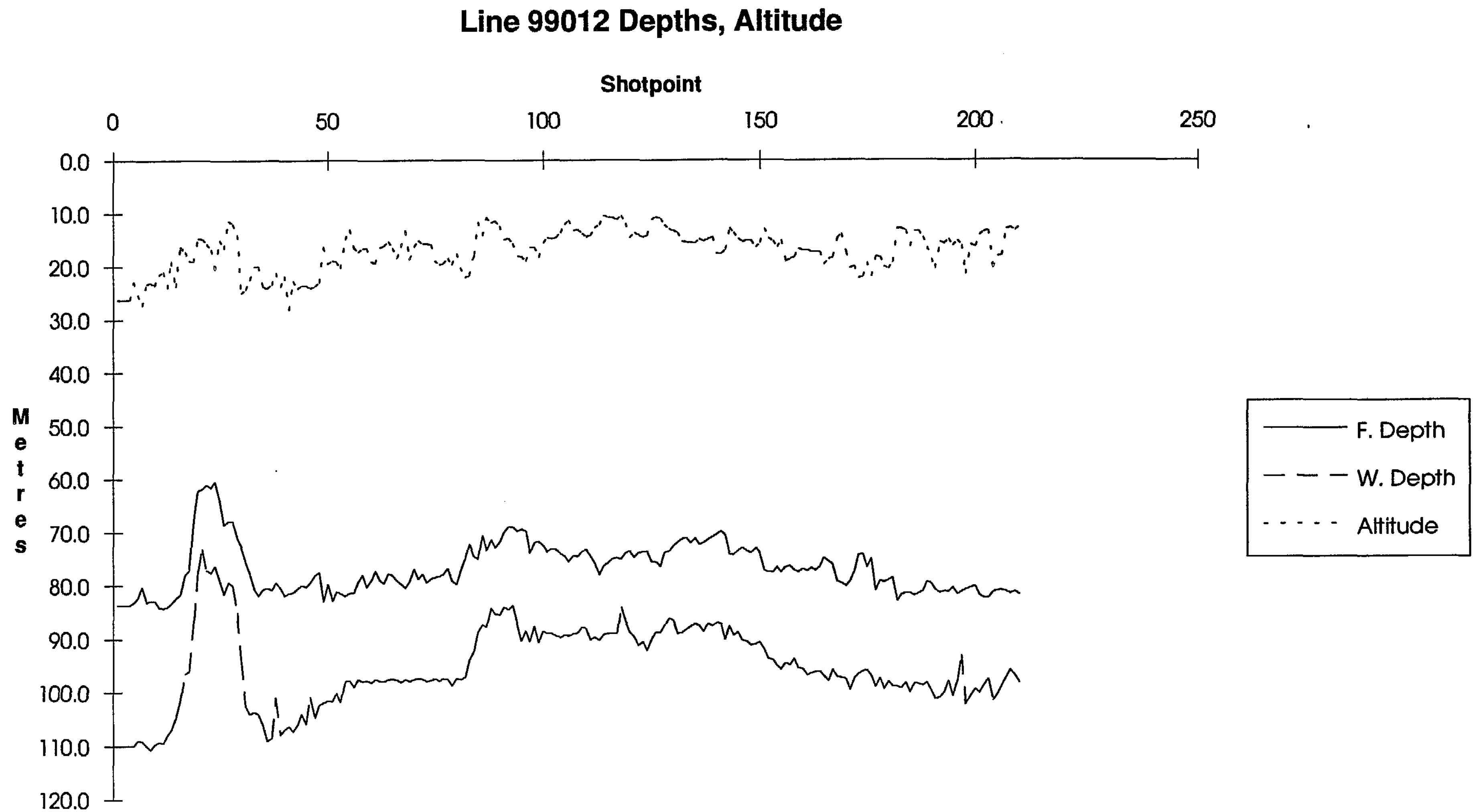


Line 99012 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Shotpoint
THC
Methane

Line 99012 Methane, Ethane, Ethylene




Line 99012 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 99012 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

Line Summary

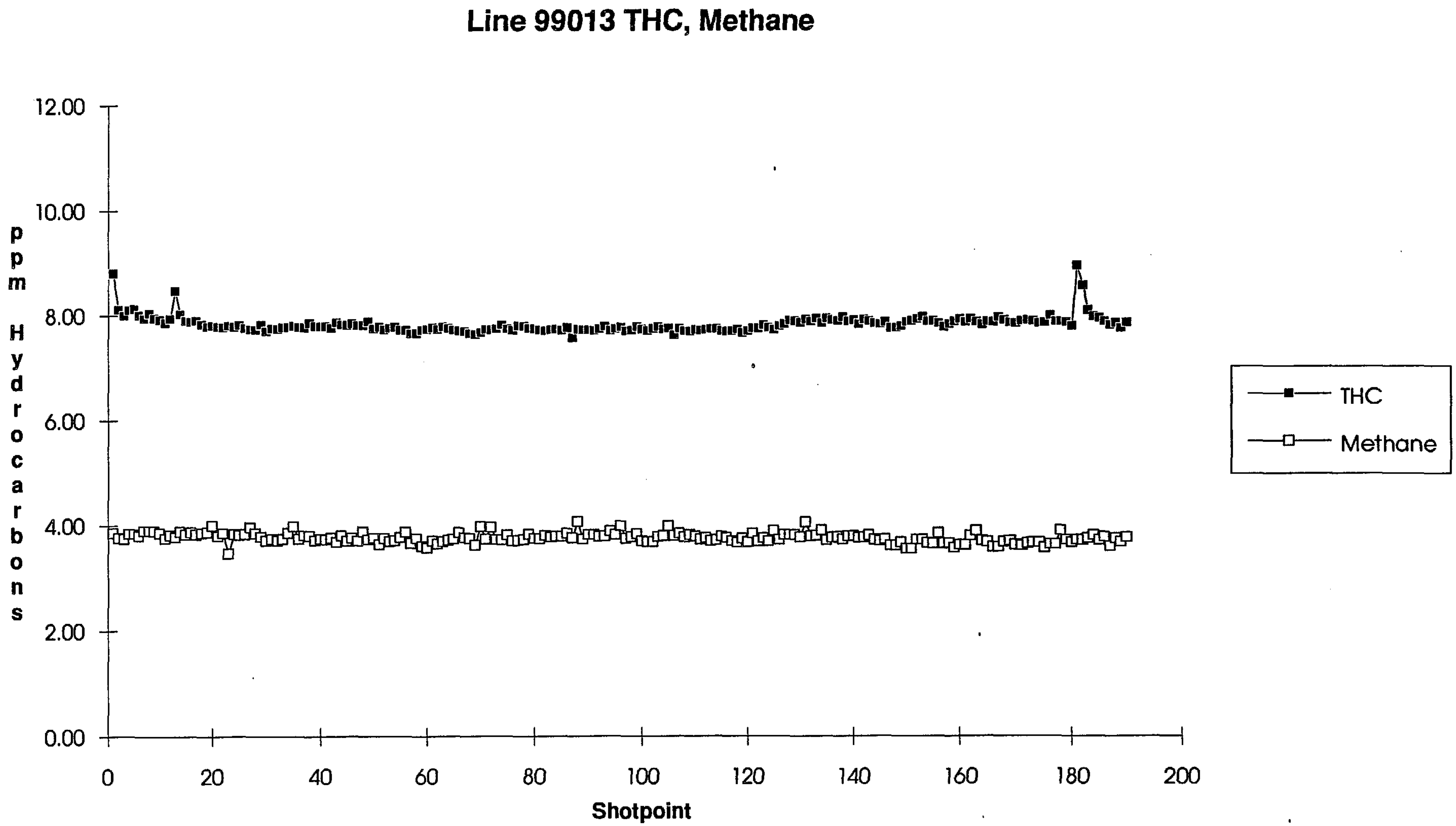
Line Number	99013
No. of Shotpoints	190

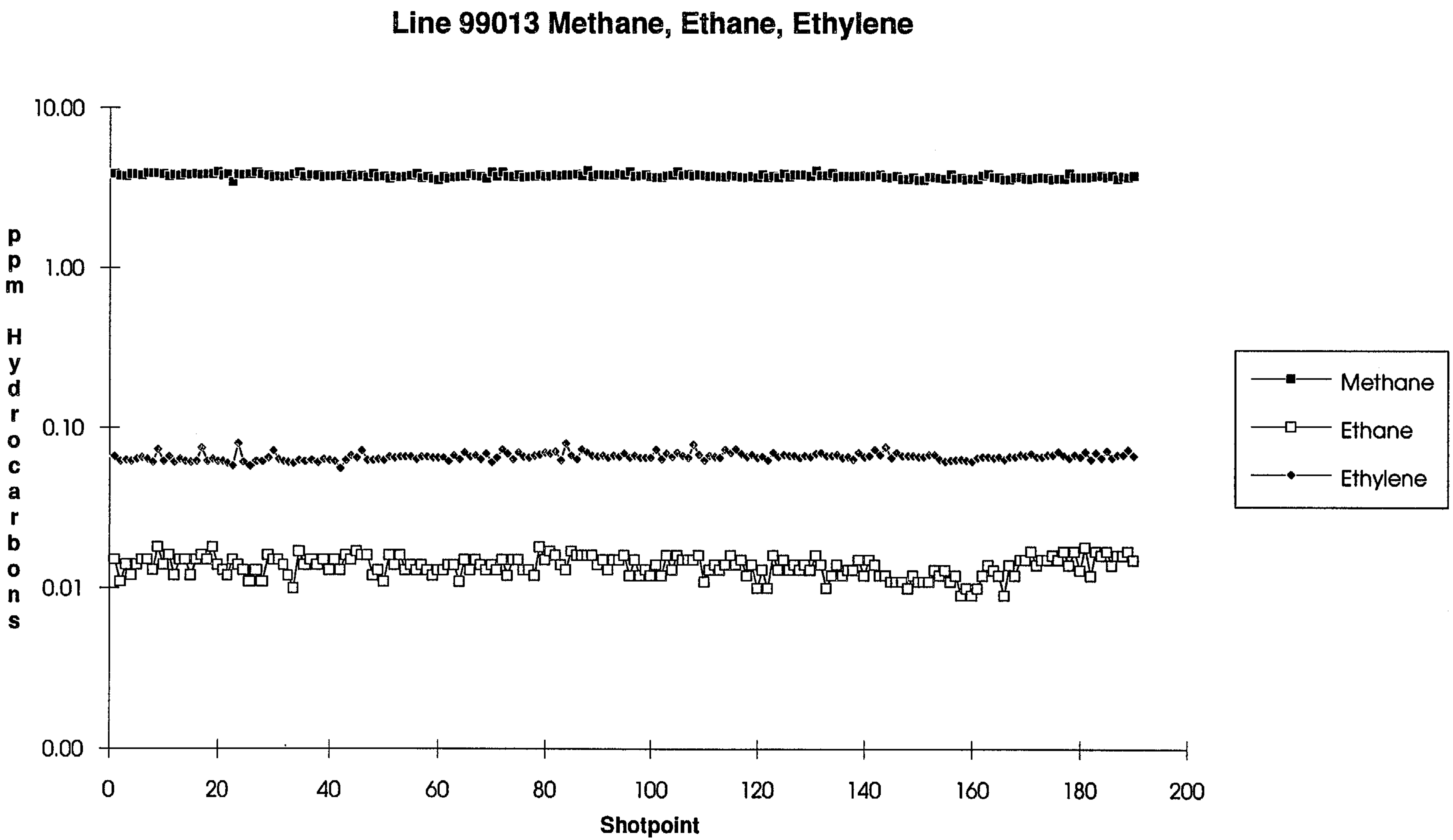
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	18-Feb-91	14:13:02	12	16.341	126	52.923
End	190	18-Feb-91	20:32:21	12	06.106	127	23.571

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.820	3.756	0.014	0.066	0.019	0.027	0.000	0.001	0.004	0.044	0.020	0.033	0.892
Std. Dev.	0.162	0.097	0.002	0.004	0.015	0.017	0.002	0.004	0.003	0.031	0.039	0.025	0.398
Minimum	7.564	3.462	0.009	0.056	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.270
Maximum	8.931	4.064	0.018	0.080	0.079	0.091	0.026	0.034	0.010	0.289	0.243	0.151	2.383

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.211	26.536	78.107	92.035	12.564
Std. Dev.	0.424	0.263	4.187	4.744	2.174
Minimum	59.350	25.960	68.300	81.500	7.500
Maximum	60.740	26.850	88.200	105.600	18.900

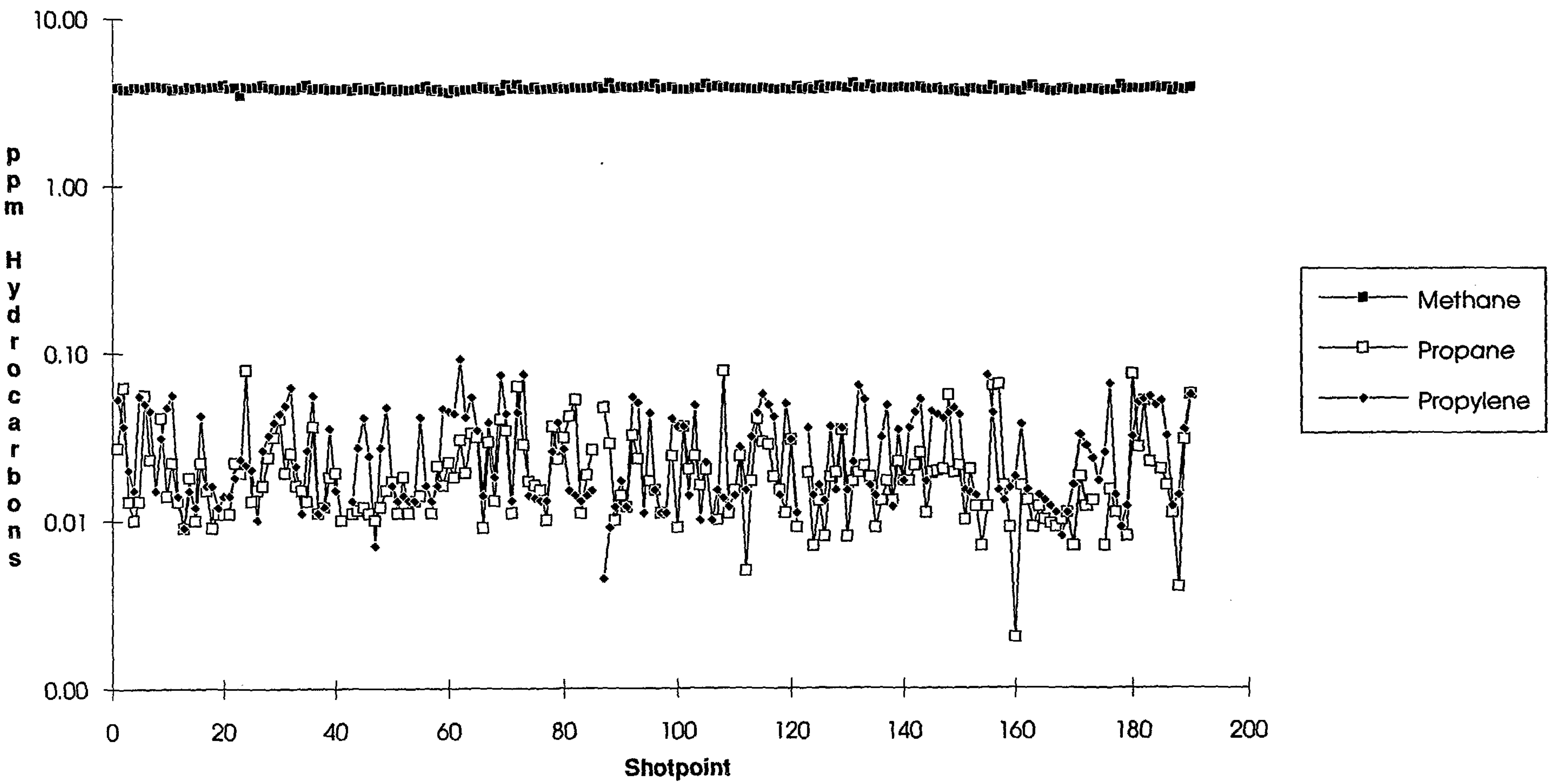
Notes
No hydrocarbon anomalies detected


Line 99013 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

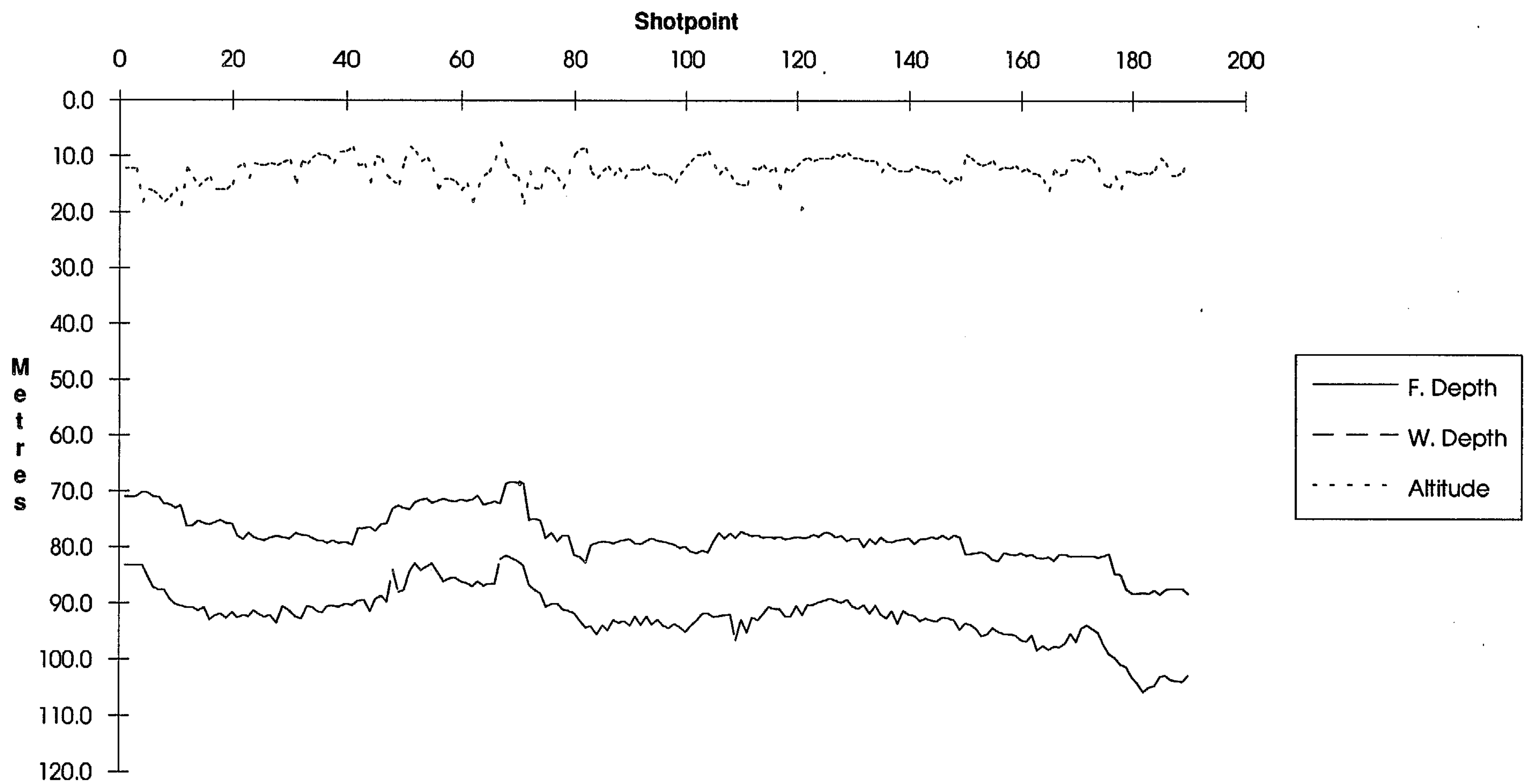


Line 99013 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
140
160
180
200
Shotpoint
Methane
Ethane
Ethylene

Line 99013 Methane, Propane, Propylene



Line 99013 Depths, Altitude



Line Summary

Line Number	99014
No. of Shotpoints	195

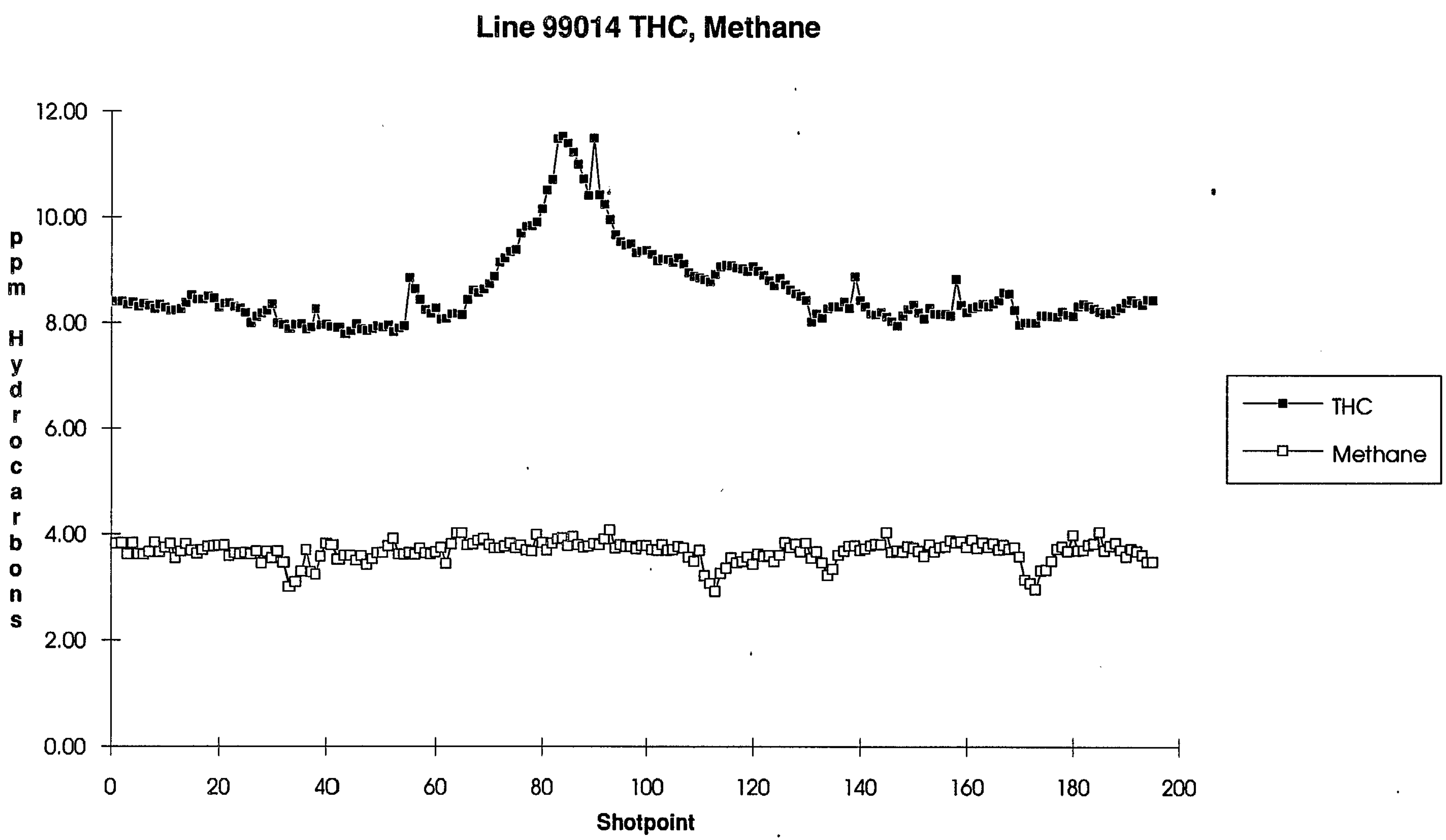
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	19-Feb-91	00:28:39	12	16.140	127	26.346
End	196	19-Feb-91	07:02:09	11	48.078	127	09.025

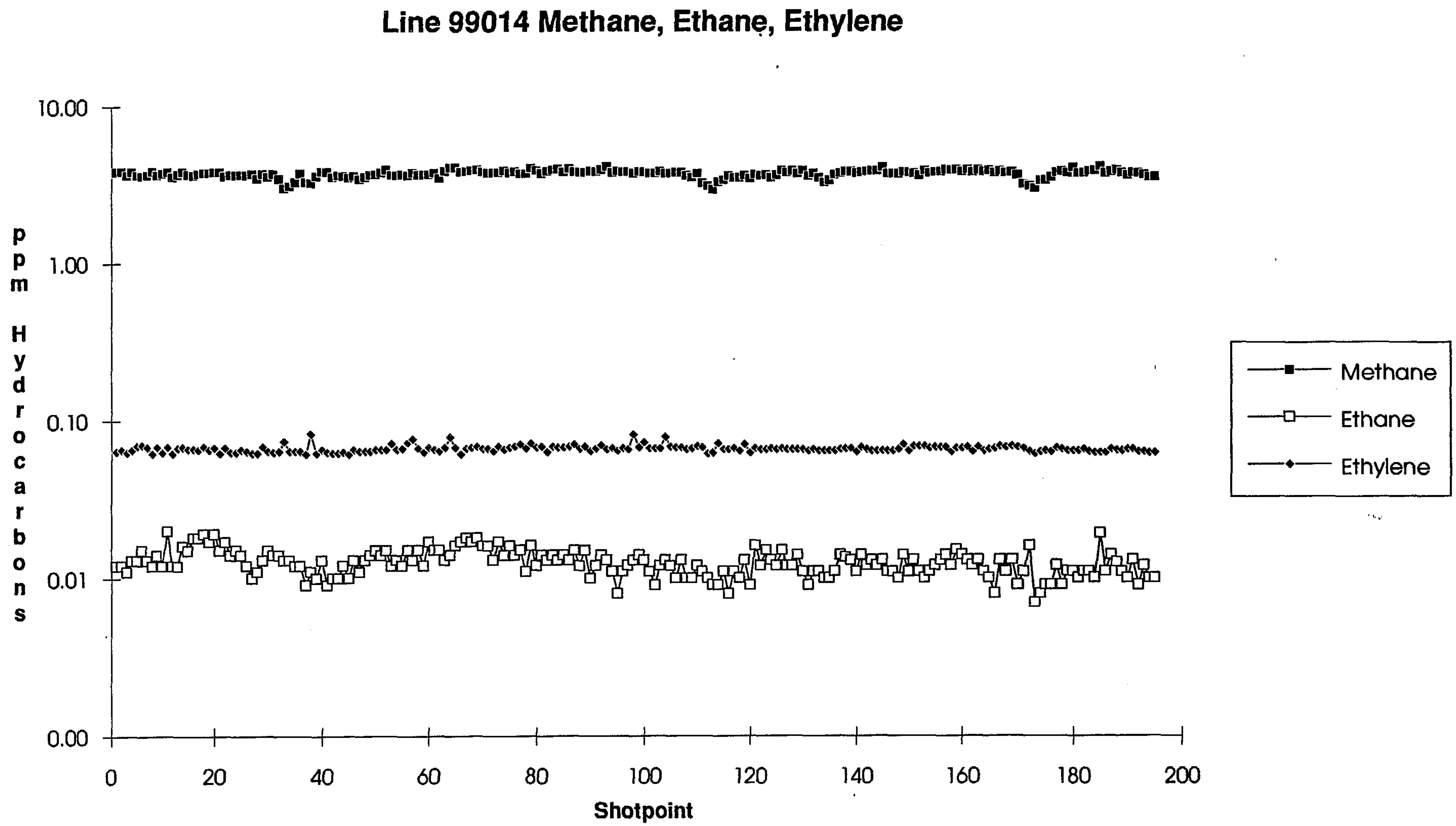
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	8.619	3.671	0.013	0.066	0.017	0.026	0.001	0.001	0.002	0.046	0.022	0.041	0.827
Std. Dev.	0.769	0.199	0.002	0.003	0.012	0.020	0.004	0.003	0.003	0.017	0.037	0.020	0.390
Minimum	7.786	2.926	0.007	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.251
Maximum	11.527	4.074	0.020	0.082	0.084	0.084	0.047	0.024	0.020	0.105	0.124	0.086	3.259

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.012	27.942	78.421	99.024	19.531
Std. Dev.	0.396	0.265	10.869	12.384	8.812
Minimum	60.950	27.280	51.100	65.300	6.500
Maximum	62.650	28.490	93.800	132.500	70.900

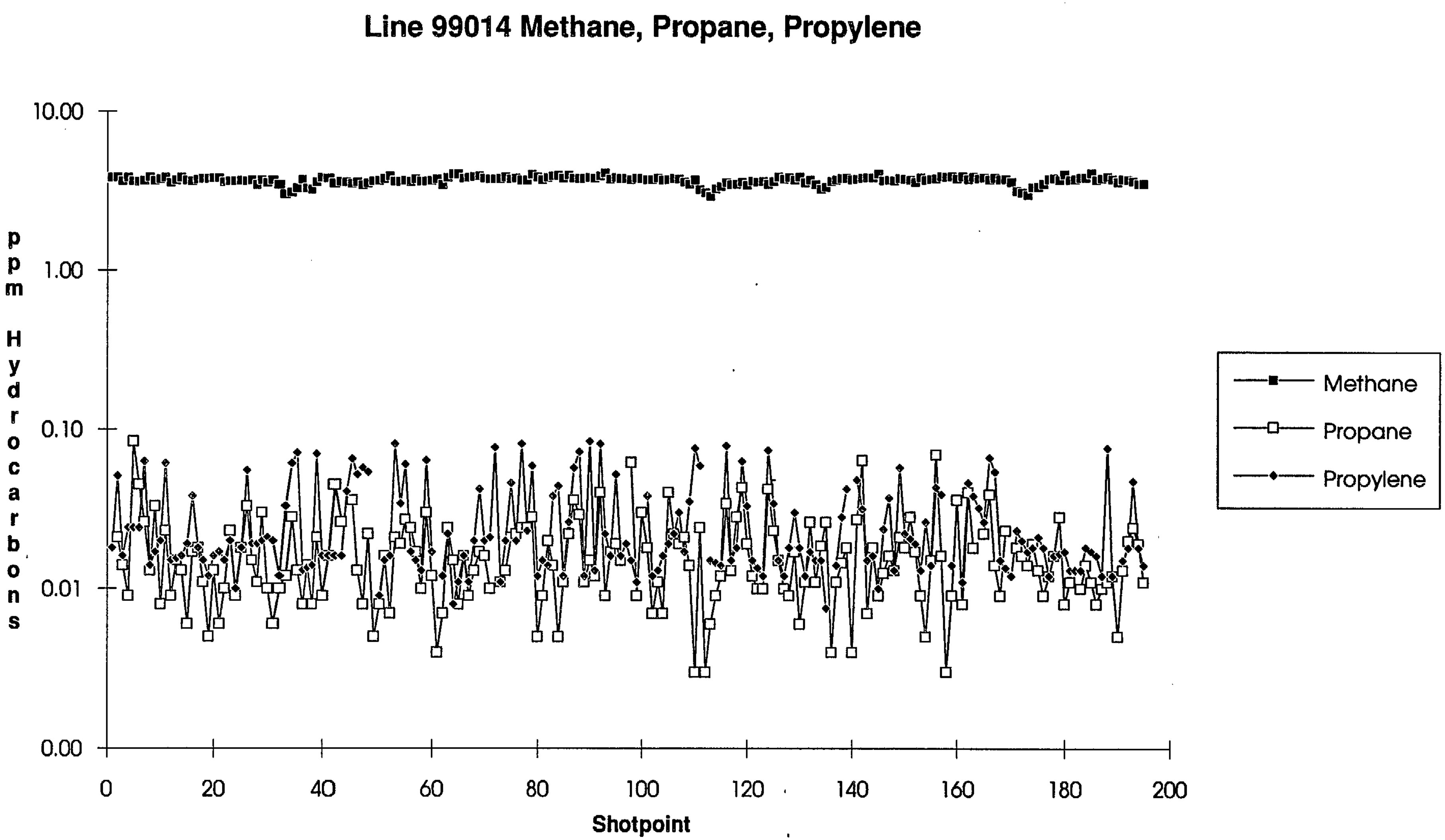
Notes

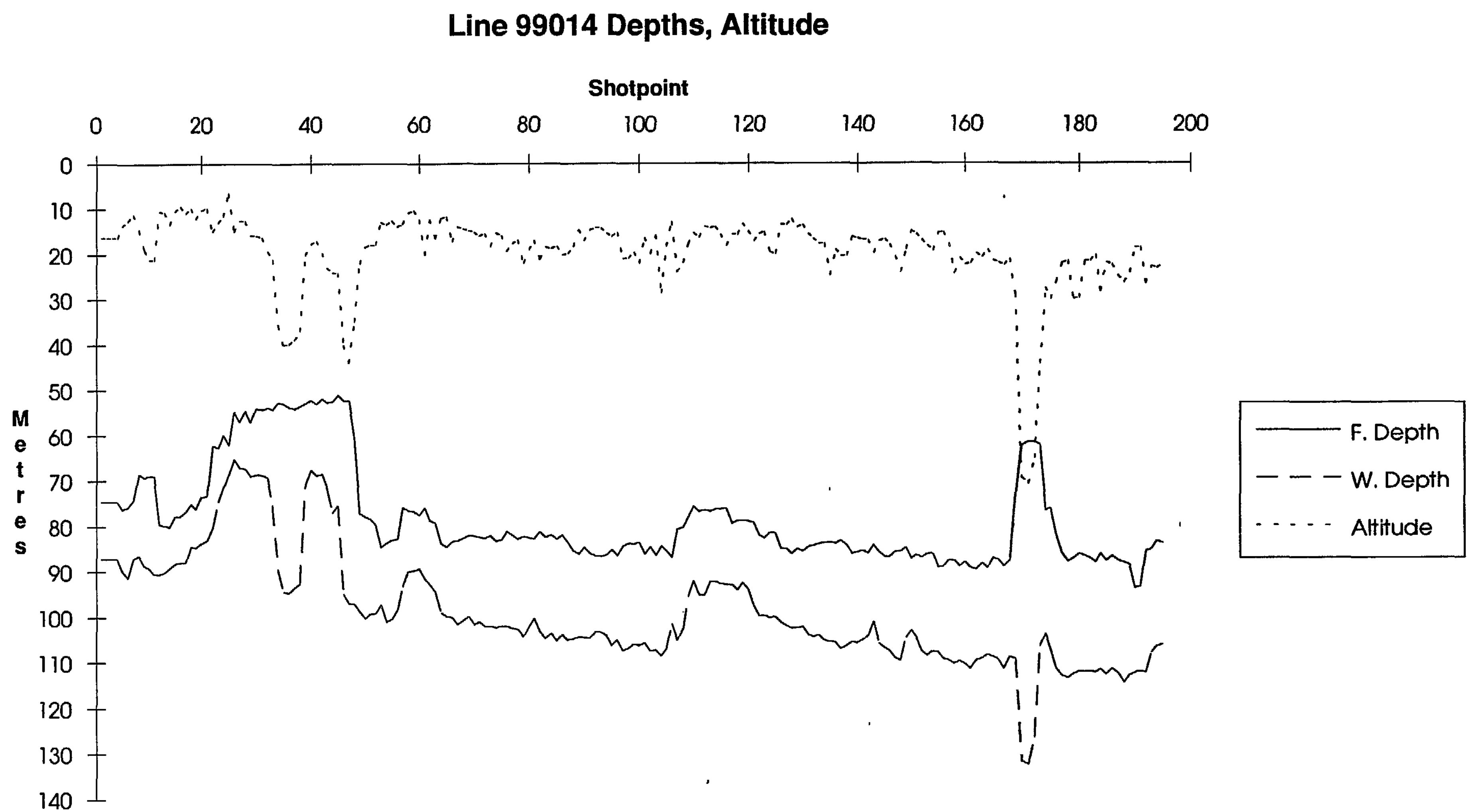
THC amonaly at shotpoints 75 to 100


Line 99014 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 99014 Methane, Ethane, Ethylene
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
Ethane
Ethylene


Line 99014 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 99014 Depths, Altitude
Shotpoint
0
20
40
60
80
100
120
140
160
180
200
Metres
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
F. Depth
W. Depth
Altitude

Line Summary

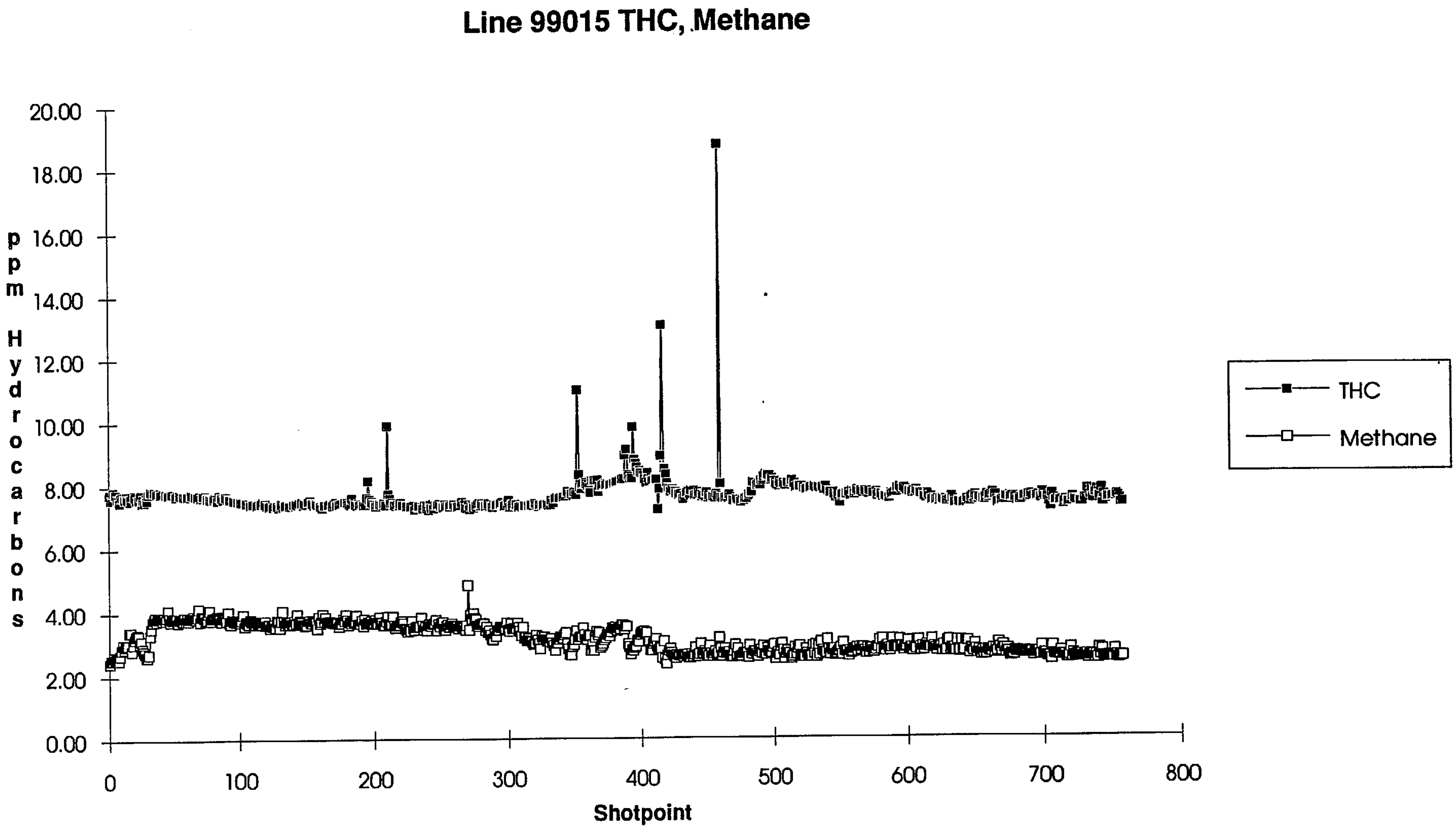
Line Number	99015
No. of Shotpoints	757

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	19-Feb-91	11:16:20	11	48.497	127	11.006
End	760	20-Feb-91	12:59:37	11	00.951	129	12.881

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.641	3.116	0.008	0.056	0.023	0.043	0.002	0.004	0.006	0.072	0.025	0.052	1.170
Std. Dev.	0.547	0.484	0.003	0.009	0.029	0.055	0.009	0.014	0.005	0.050	0.037	0.031	1.124
Minimum	7.203	2.342	0.003	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.144
Maximum	18.755	4.847	0.018	0.107	0.420	0.911	0.083	0.175	0.041	0.511	0.206	0.266	13.174

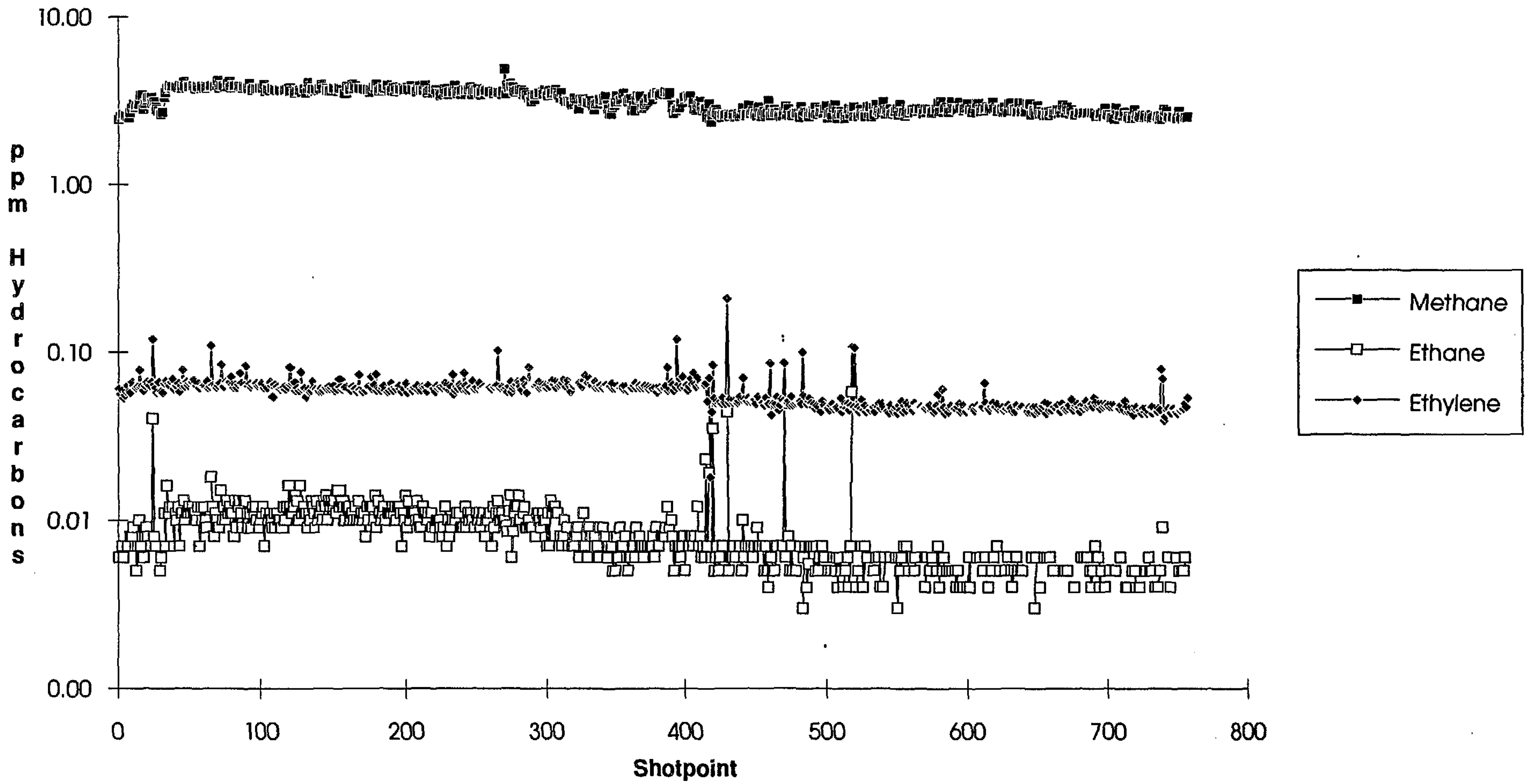
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.624	27.816	58.501	82.305	24.140
Std. Dev.	1.871	1.397	30.104	34.883	15.660
Minimum	59.080	25.980	3.800	27.500	0.400
Maximum	65.120	30.440	100.800	142.600	118.860

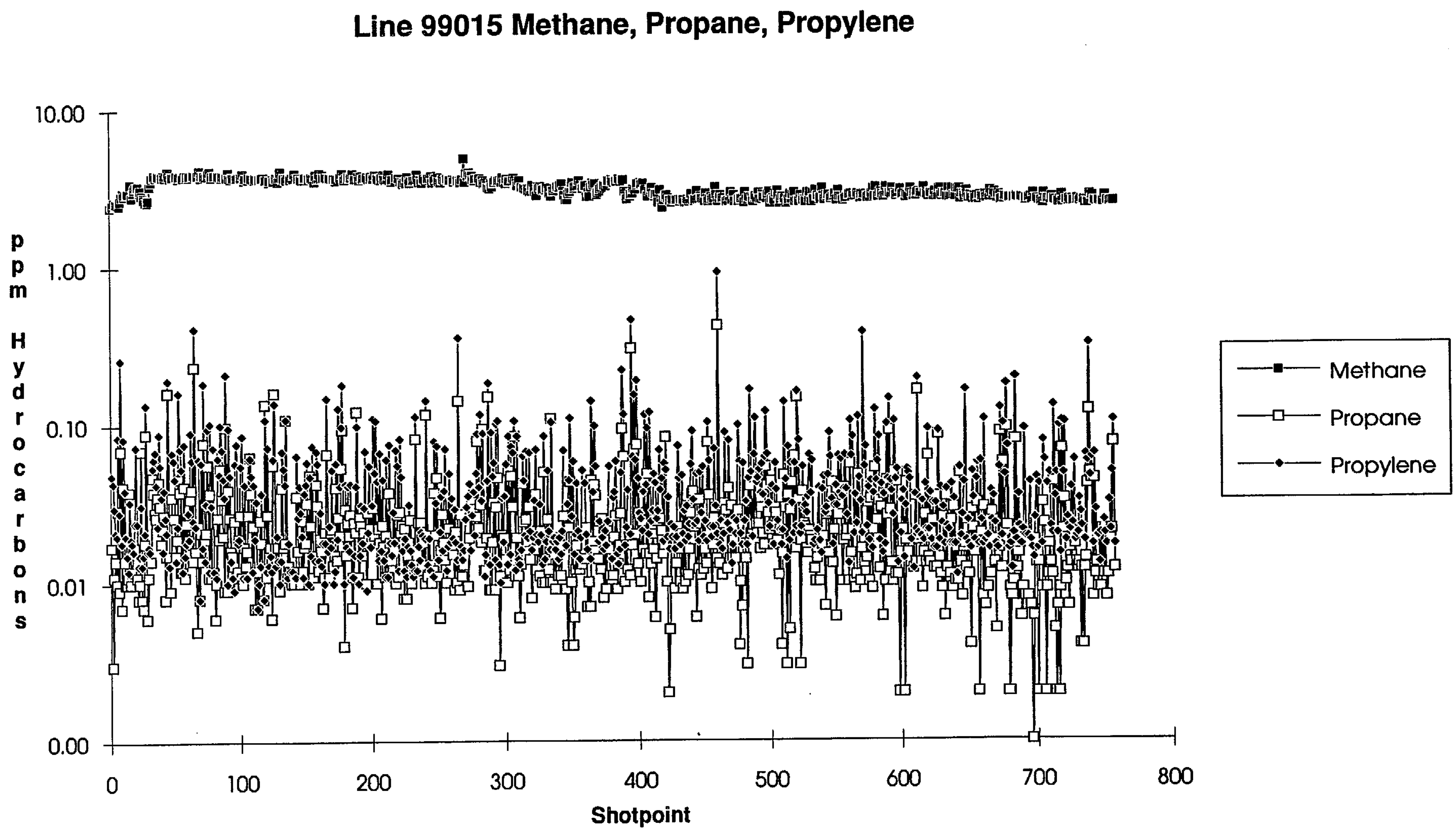
Notes
Butane anomalies at shotpoint 489 to 533 and at 732 to 738
THC anomalies at shotpints 211-213, 391-424, 462-463



Line 99015 THC, Methane
ppm Hydrocarbons
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
700
800
Shotpoint
THC
Methane

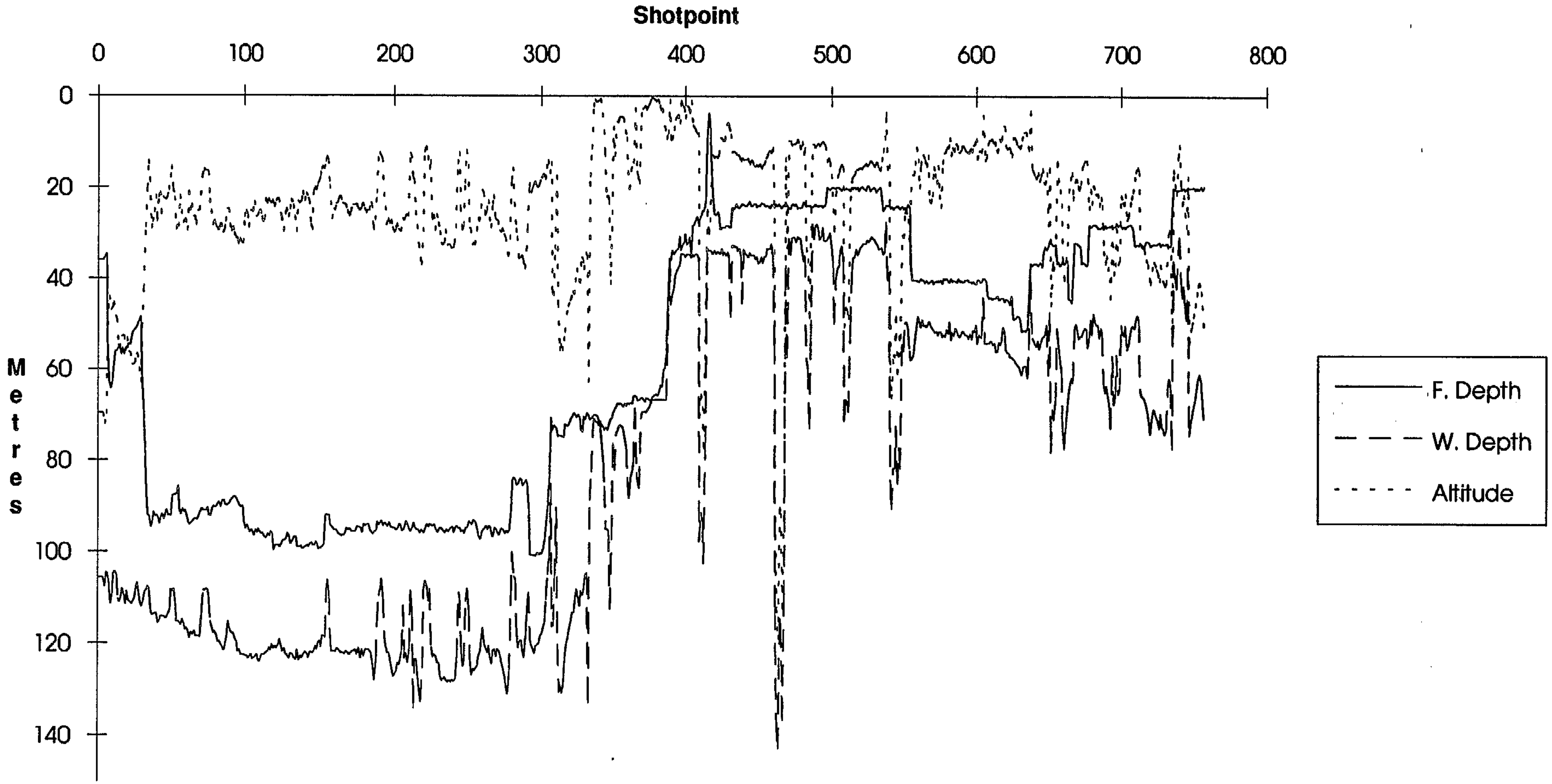
Line 99015 Methane, Ethane, Ethylene



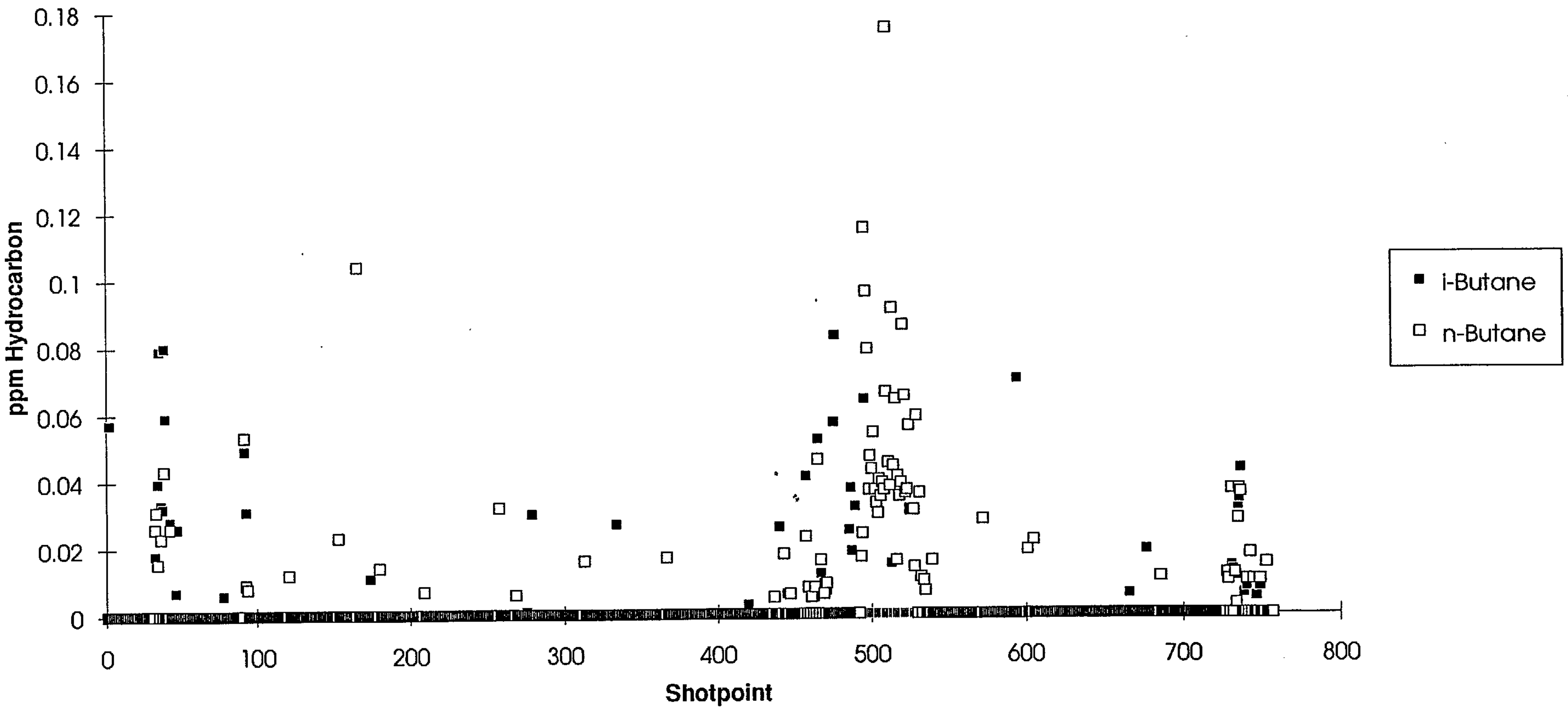


Line 99015 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
700
800
Shotpoint
Methane
Propane
Propylene

Line 99015 Depths, Altitude



Line 99015 v. Butanes



Line Summary

Line Number	99016
No. of Shotpoints	836

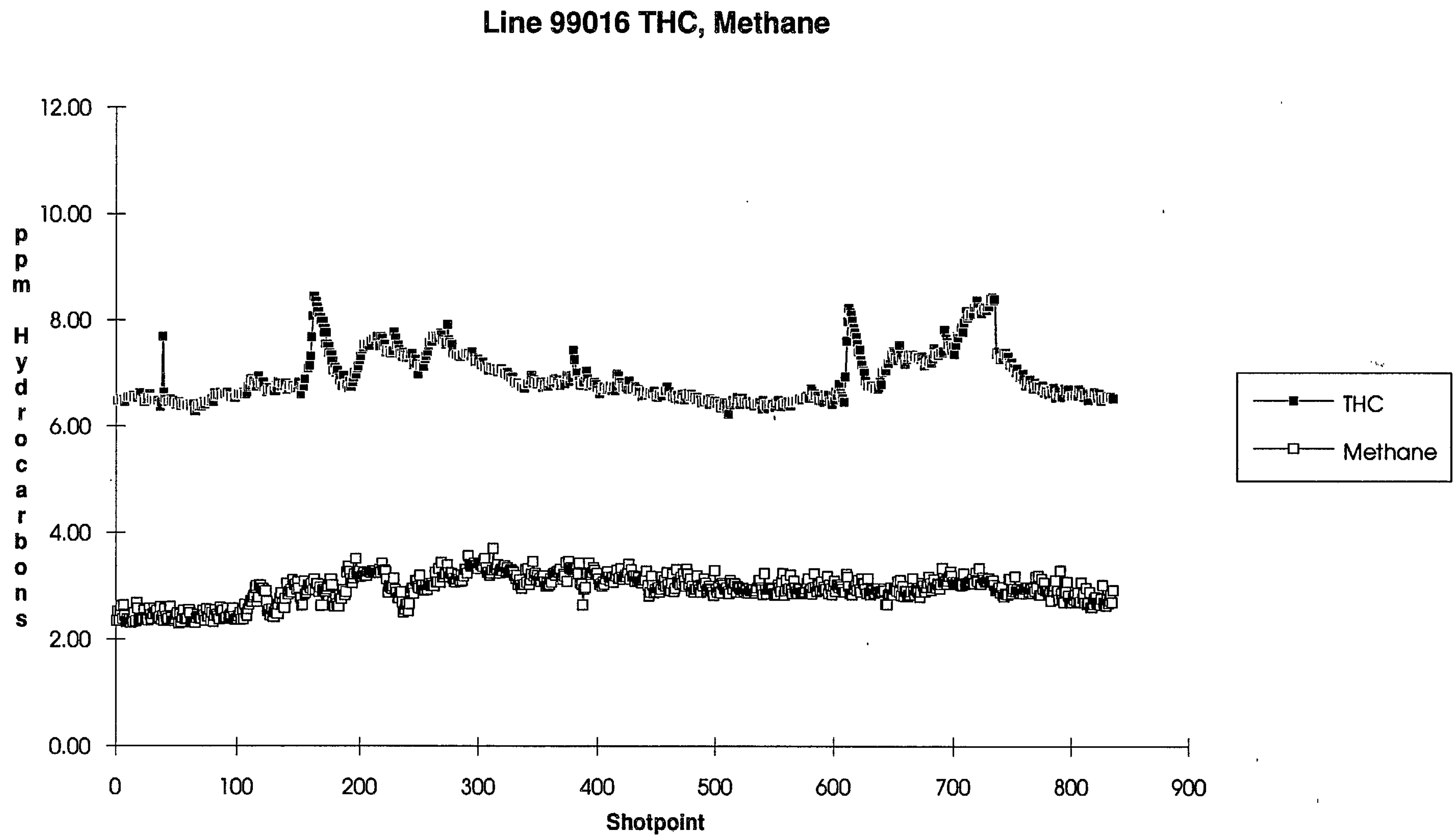
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	20-Feb-91	17:27:57	10	46.735	129	01.170
End	945	22-Feb-91	11:24:20	11	29.896	126	57.582

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	6.913	2.939	0.007	0.046	0.019	0.019	0.001	0.001	0.005	0.045	0.015	0.025	0.913
Std. Dev.	0.470	0.268	0.003	0.006	0.017	0.019	0.005	0.003	0.005	0.024	0.026	0.020	0.624
Minimum	6.230	2.294	0.004	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.154
Maximum	8.447	3.698	0.044	0.093	0.096	0.098	0.078	0.046	0.030	0.157	0.324	0.118	3.478

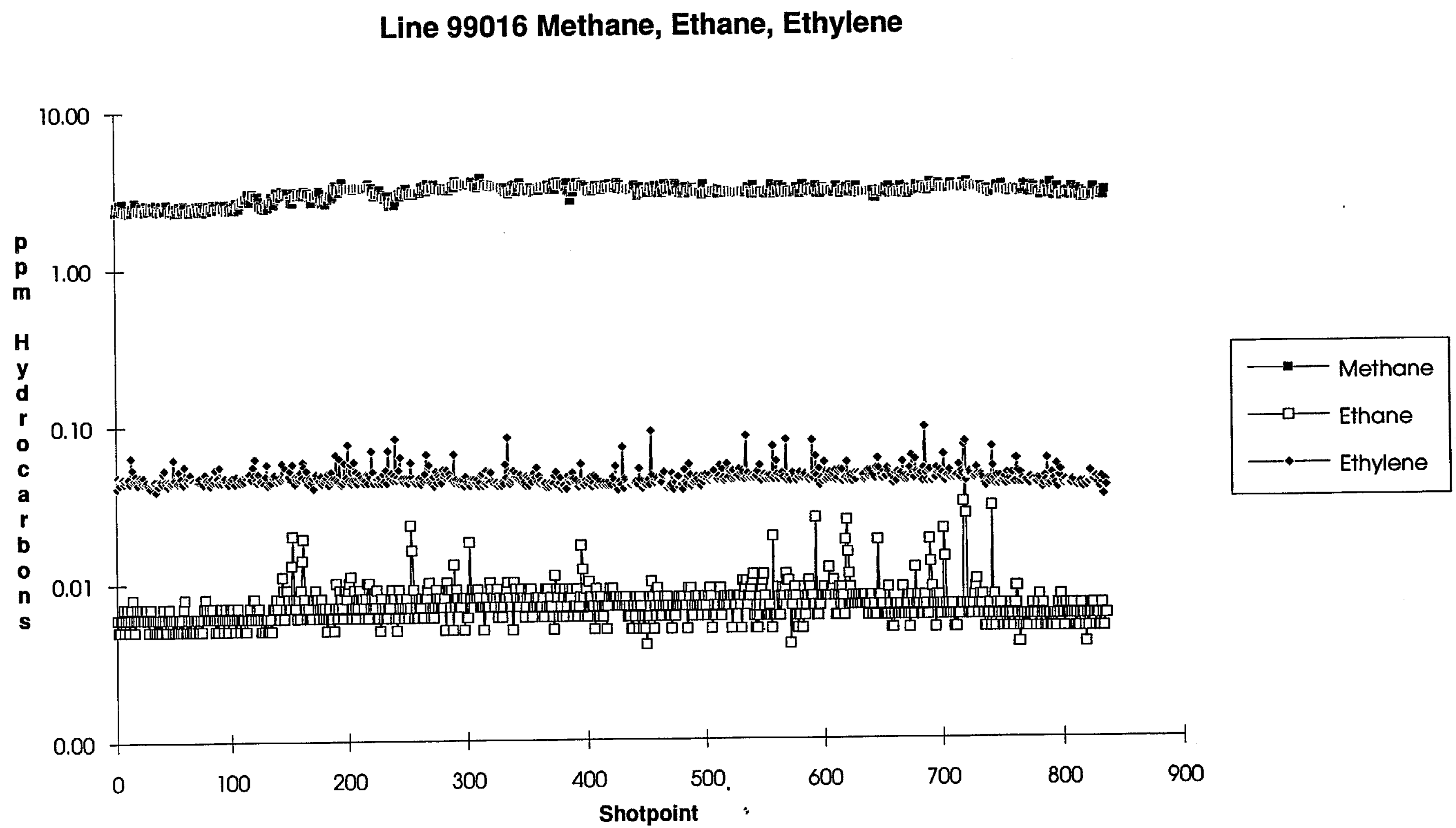
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.212	26.030	66.582	90.267	24.218
Std. Dev.	0.659	0.541	25.313	31.689	11.453
Minimum	57.620	24.700	19.900	25.800	1.100
Maximum	60.830	27.230	95.800	151.000	68.400

Notes

No hydrocarbon anomalies detected

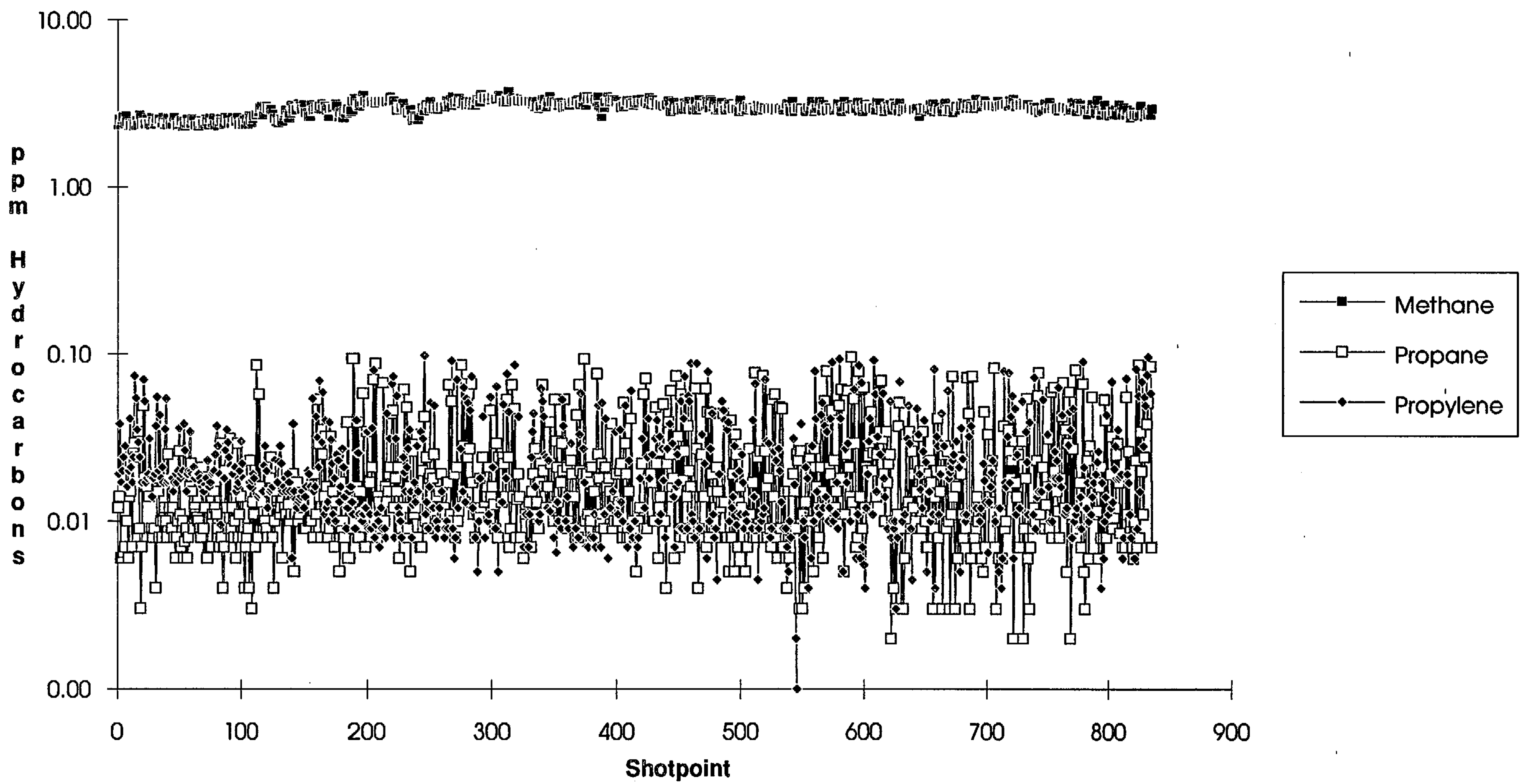


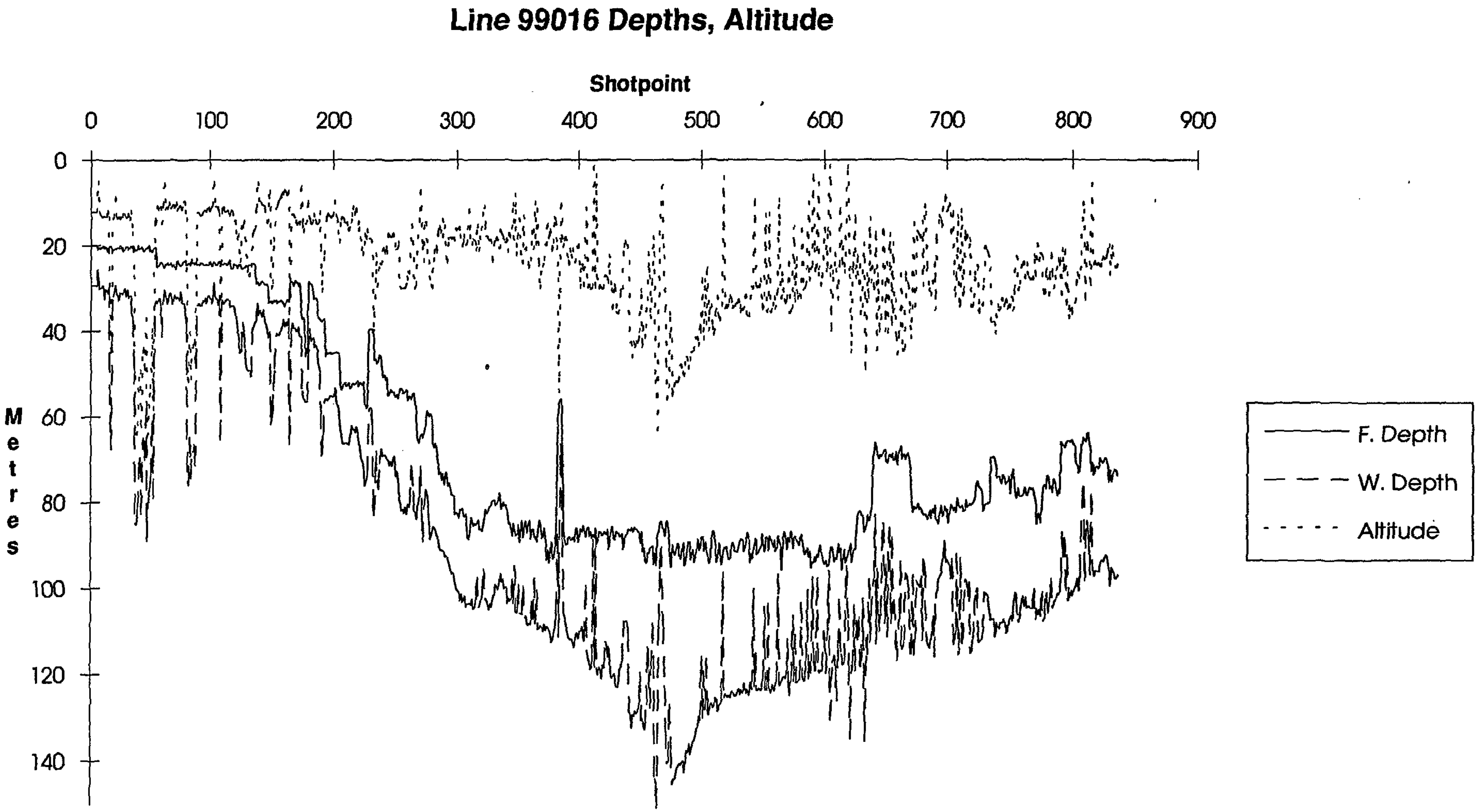
Line 99016 THC, Methane
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
THC
Methane



Line 99016 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
Methane
Ethane
Ethylene

Line 99016 Methane, Propane, Propylene





Line 99016 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
140
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	99017
No. of Shotpoints	849

	Shotpoint	Date	Time	Latitude		Longitude	
Start	16	22-Feb-91	15:41:08	11	18.812	126	55.529
End	1058	24-Feb-91	07:04:16	13	22.356	128	11.549

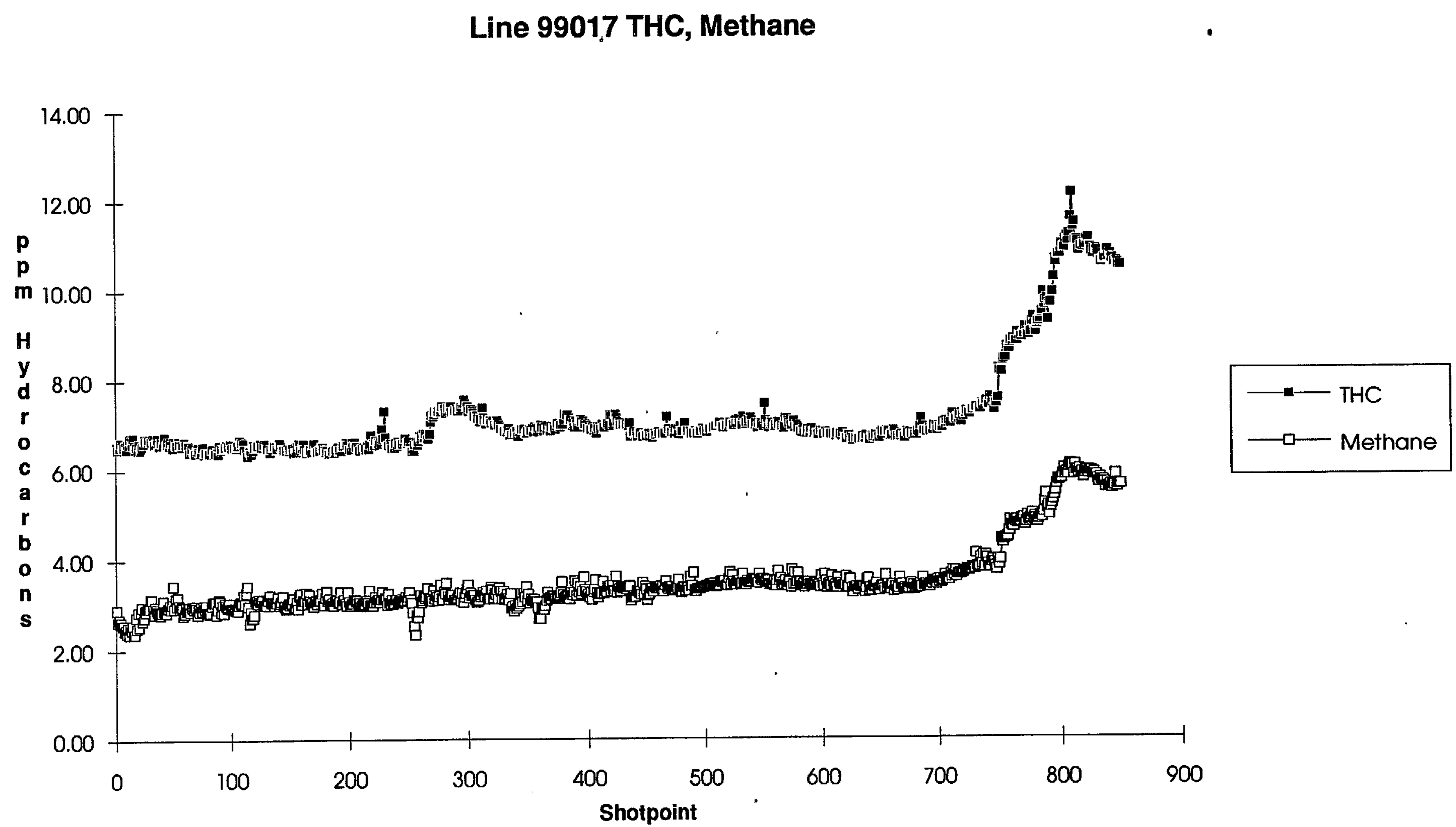
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	7.185	3.470	0.010	0.053	0.022	0.024	0.004	0.005	0.003	0.036	0.023	0.026	1.144
Std. Dev.	1.132	0.752	0.007	0.014	0.018	0.023	0.012	0.020	0.004	0.014	0.022	0.025	0.887
Minimum	6.322	2.323	0.004	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.154
Maximum	12.134	6.062	0.036	0.104	0.099	0.099	0.101	0.222	0.047	0.080	0.120	0.126	7.692

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.182	26.441	80.834	98.725	16.359
Std. Dev.	1.384	1.104	8.142	9.313	7.020
Minimum	58.270	24.750	49.900	64.400	7.500
Maximum	62.820	28.570	93.200	112.100	55.800

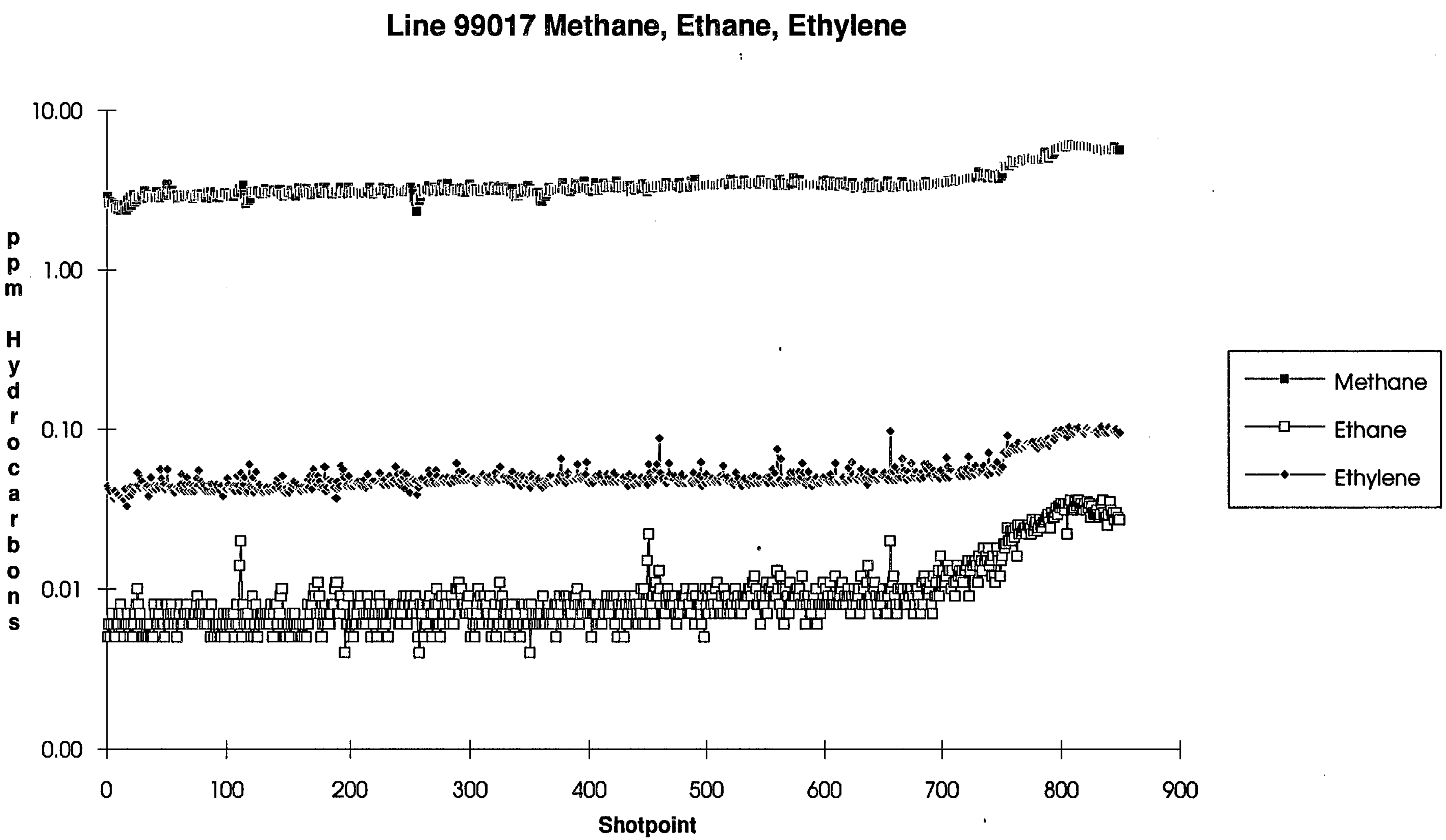
Notes

THC and butane anomaly at shotpoints 284 to 340

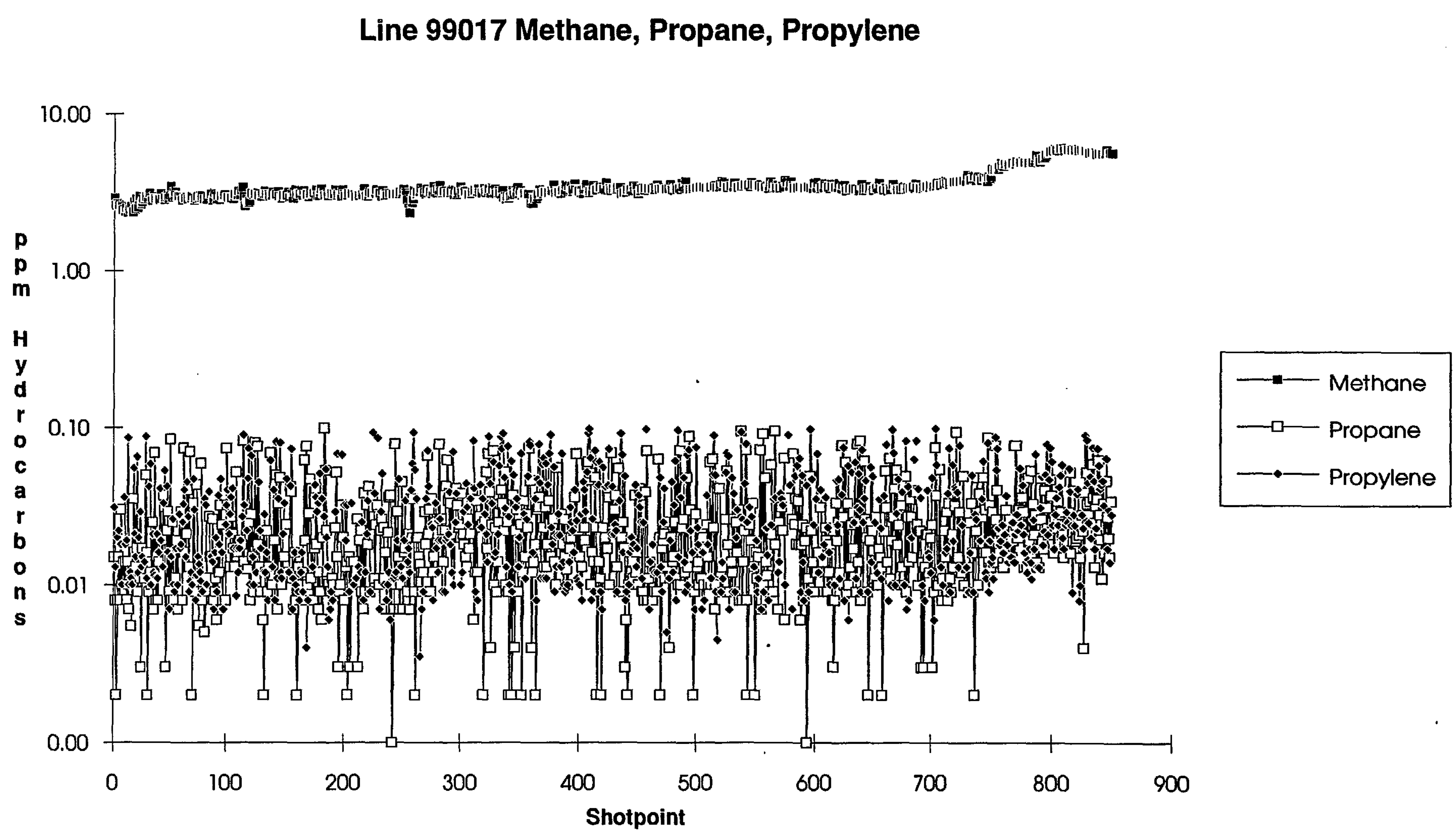
THC, methane, ethane, slight ethylene and n-butane amonaly at shotpoints 760 to 1058 associated with the Tern gas field



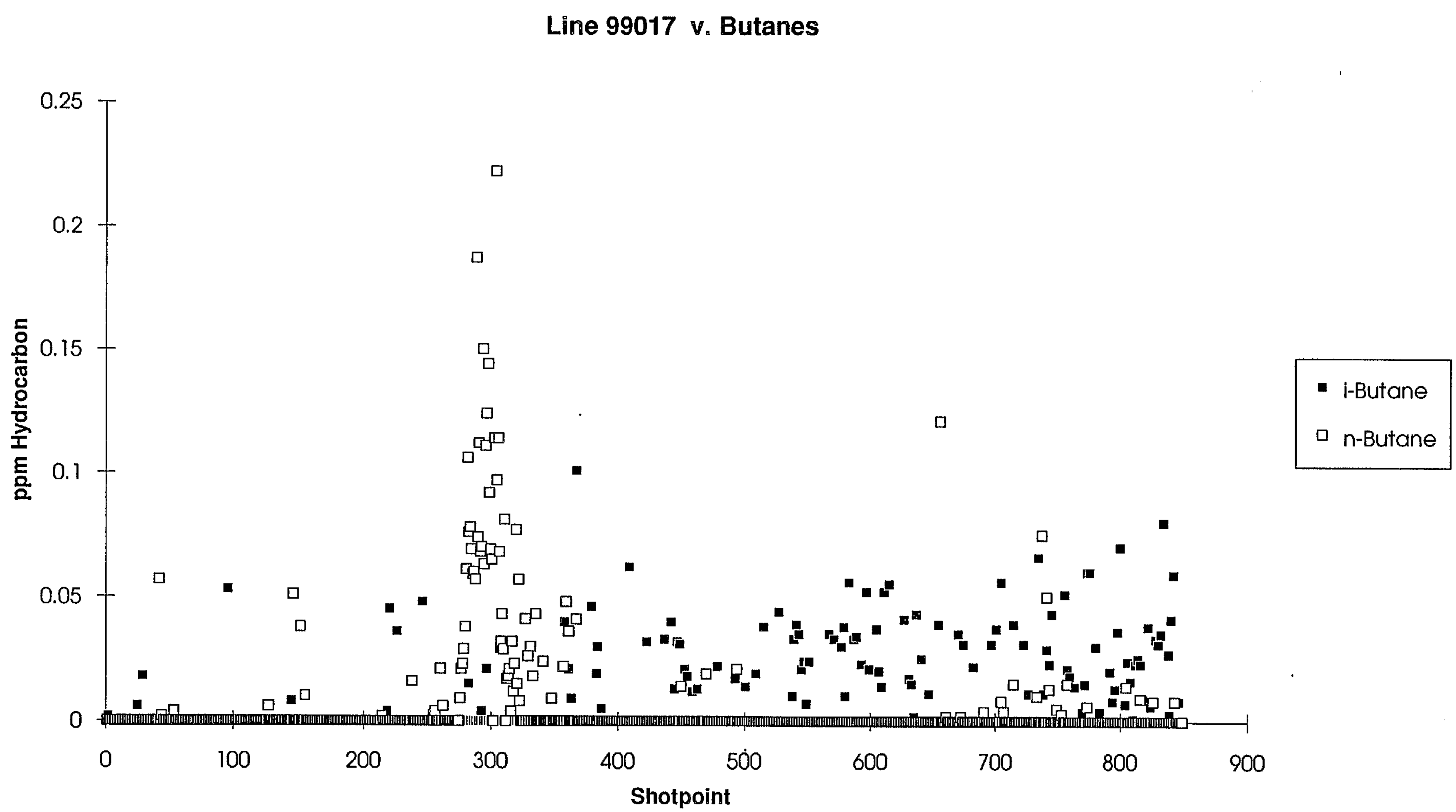
Line 99017 THC, Methane
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
THC
Methane



Line 99017 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
Methane
Ethane
Ethylene

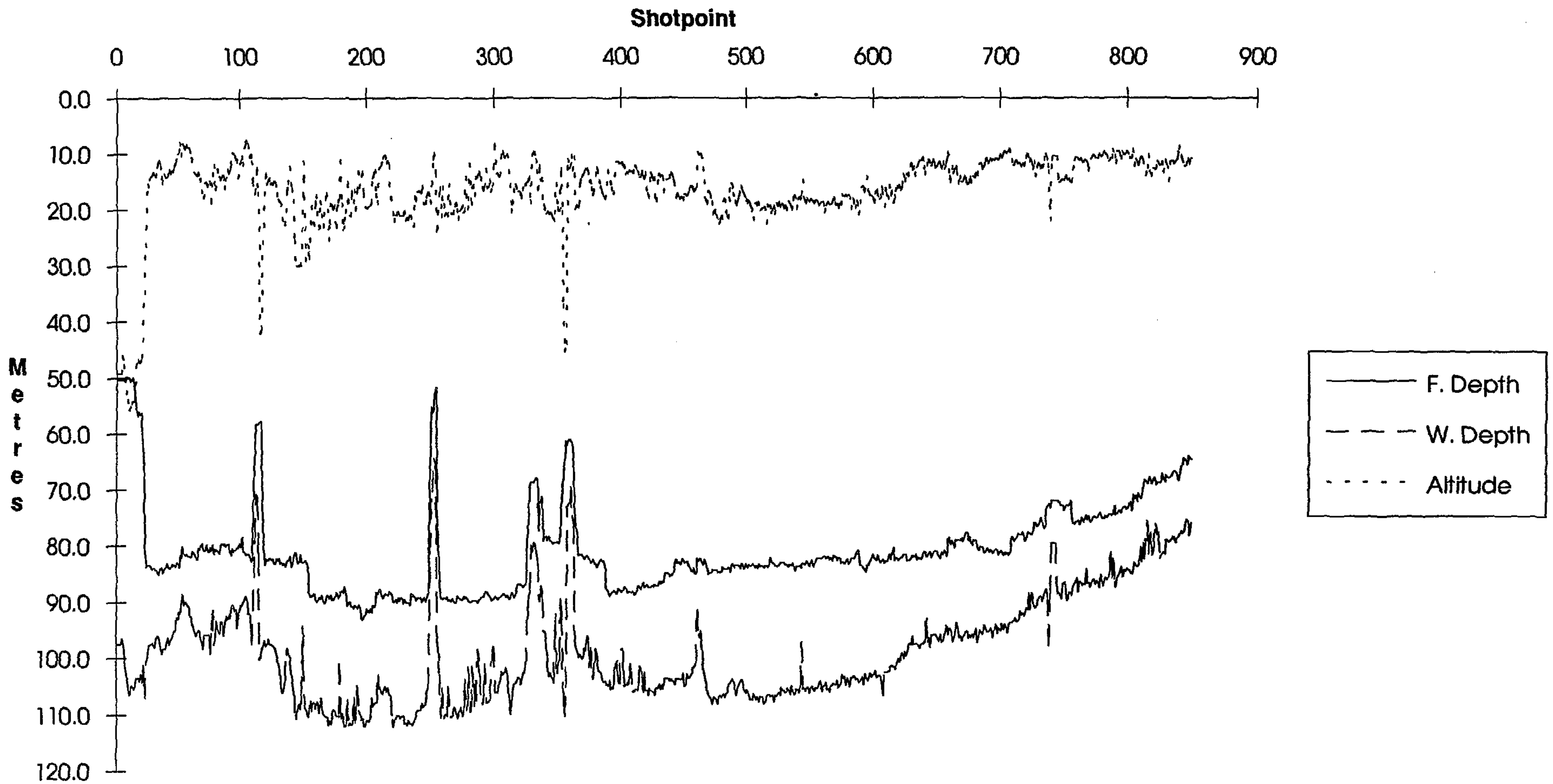


Line 99017 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
Methane
Propane
Propylene



Line 99017 v. Butanes
ppm Hydrocarbon
0.25
0.2
0.15
0.1
0.05
0
0
100
200
300
400
500
600
700
800
900
Shotpoint
i-Butane
n-Butane

Line 99017 Depths, Altitude



Line Summary

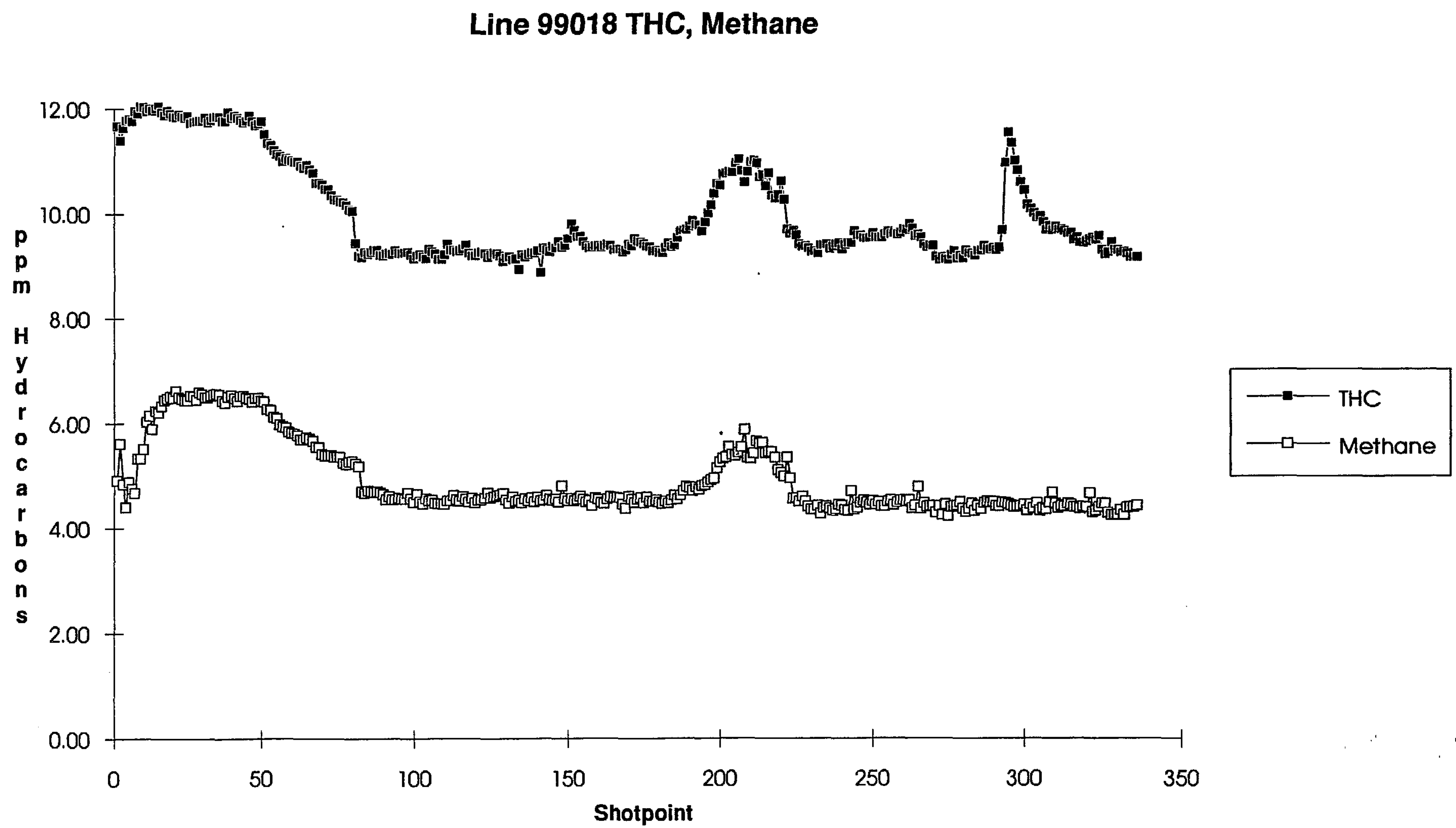
Line Number	99018
No. of Shotpoints	336

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	24-Feb-91	17:43:10	13	22.087	128	03.923
End	337	25-Feb-91	05:05:35	12	40.131	128	35.559

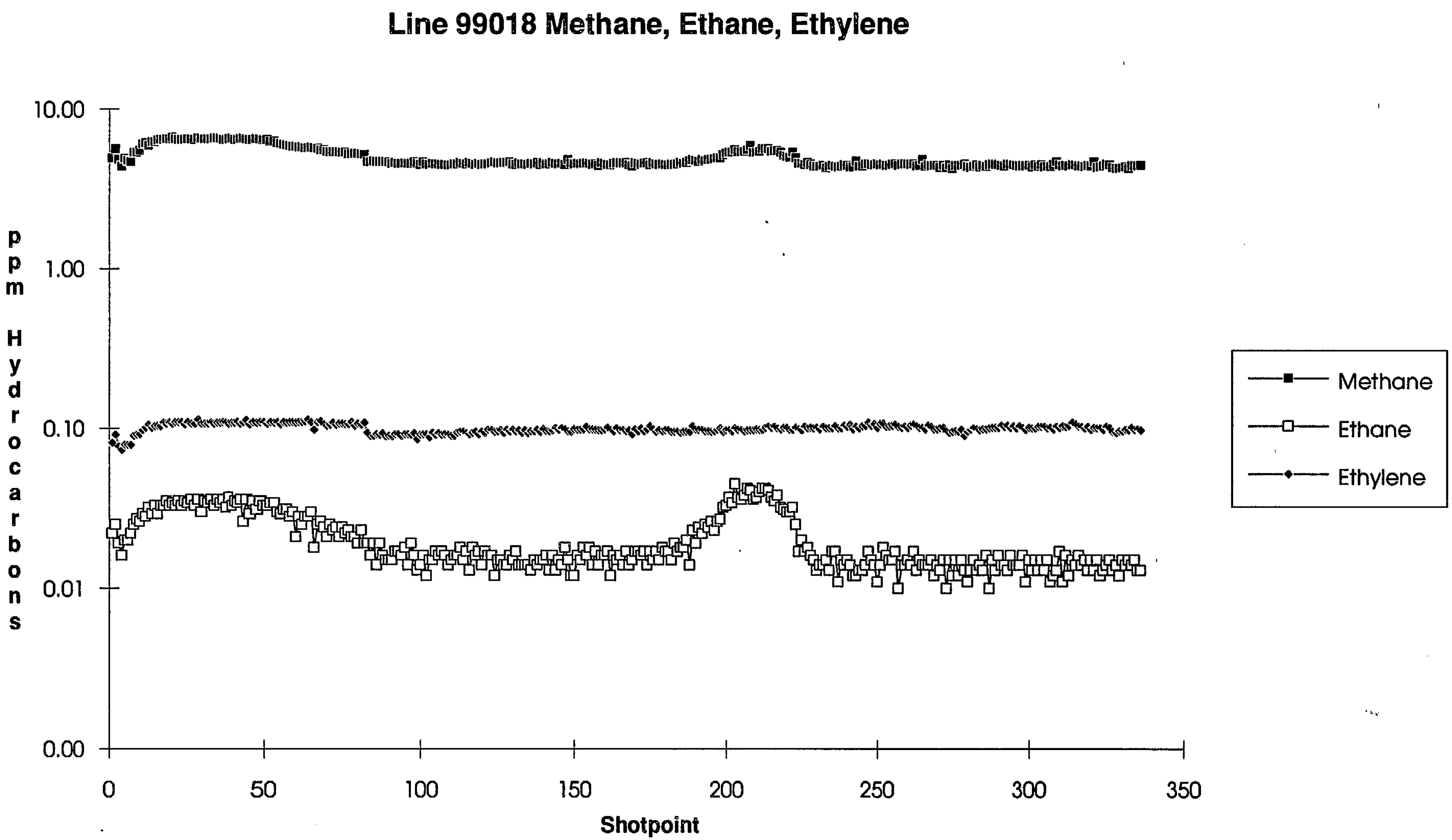
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.998	4.917	0.020	0.100	0.013	0.016	0.002	0.002	0.000	0.042	0.050	0.029	0.730
Std. Dev.	0.947	0.704	0.008	0.006	0.003	0.003	0.005	0.005	0.000	0.018	0.032	0.023	0.263
Minimum	8.867	4.224	0.010	0.073	0.005	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.423
Maximum	12.073	6.614	0.045	0.113	0.021	0.024	0.039	0.033	0.000	0.125	0.124	0.087	2.342

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.132	27.164	73.686	87.636	12.448
Std. Dev.	1.207	1.032	4.490	5.368	1.350
Minimum	59.260	25.550	60.400	70.900	8.900
Maximum	63.040	28.750	79.000	95.100	16.700

Notes
At start of line increase in levels of THC, methane and ethane, slight ethylene associated with Tern gas field
Propane and butane anomaly at shotpoint 150 to 210
THC, methane and ethane anomaly from shotpoint 196 to 221
THC anomaly at shotpoint 295 to 303

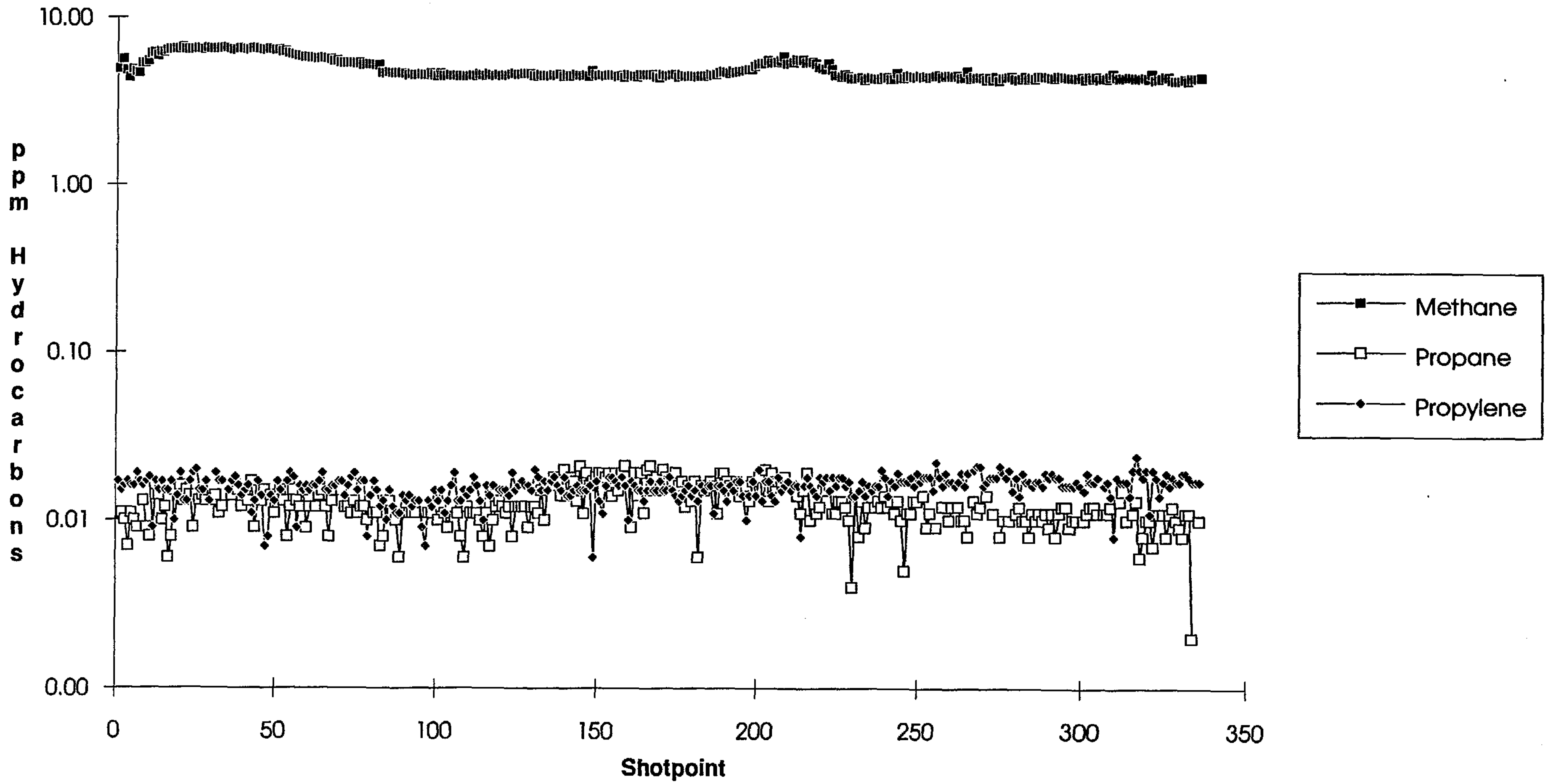


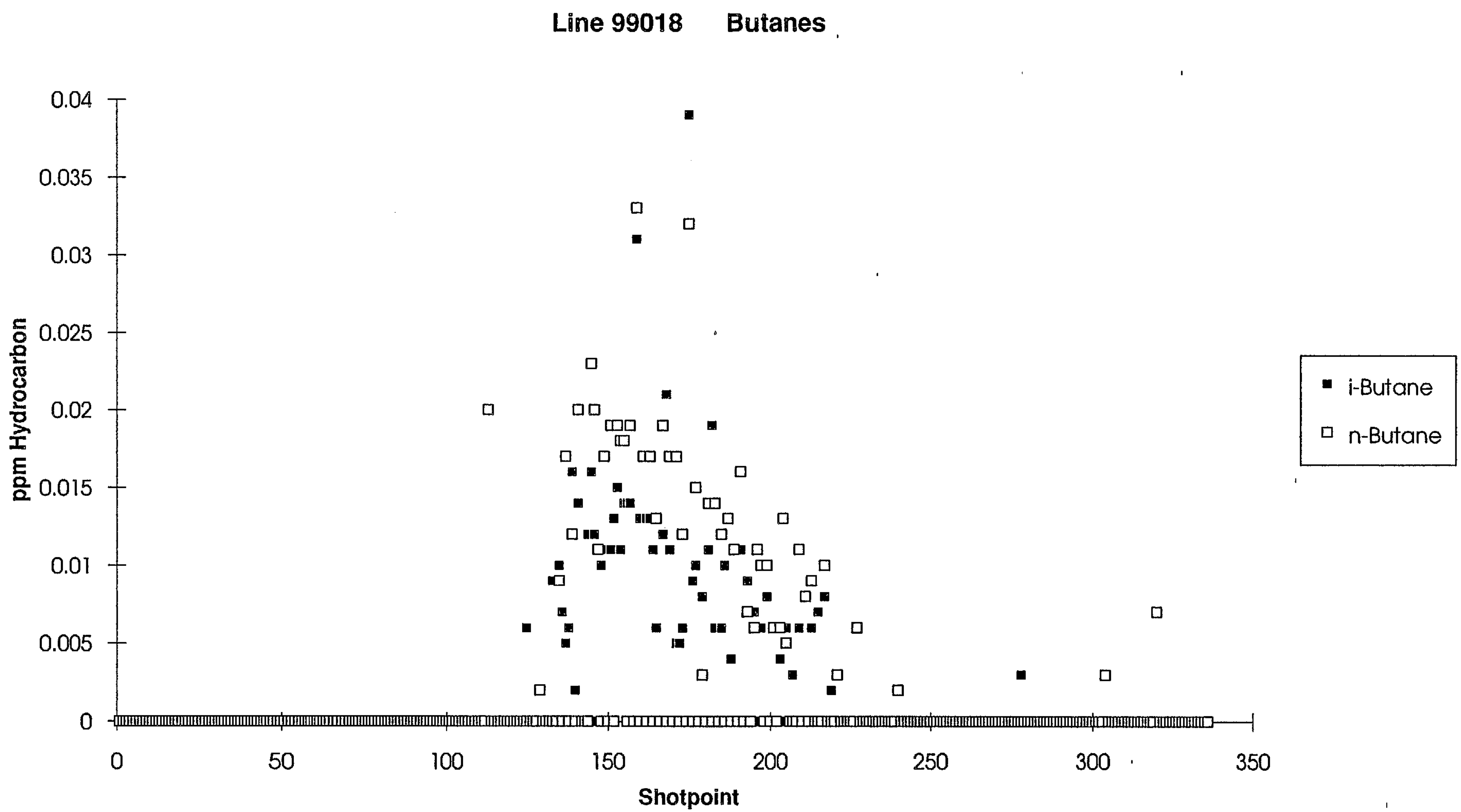
Line 99018 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
350
Shotpoint
THC
Methane



Line 99018 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
350
Shotpoint
Methane
Ethane
Ethylene

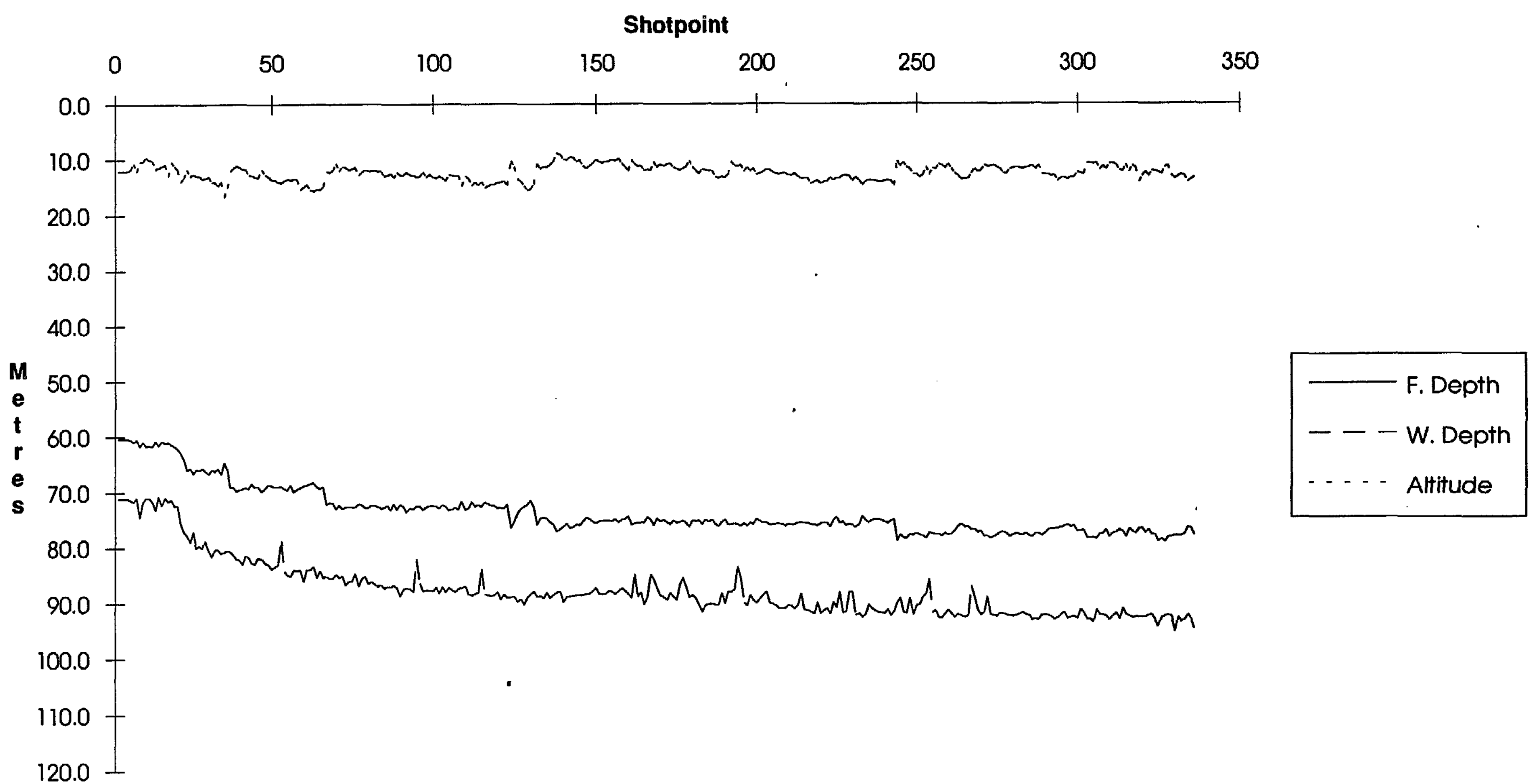
Line 99018 Methane, Propane, Propylene





Line 99018 Butanes
ppm Hydrocarbon
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
50
100
150
200
250
300
350
Shotpoint
i-Butane
n-Butane

Line 99018 Depths, Altitude



Line Summary

Line Number	99019
No. of Shotpoints	616

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	25-Feb-91	09:31:11	12	44.331	128	35.415
End	617	26-Feb-91	06:13:07	11	14.931	128	05.490

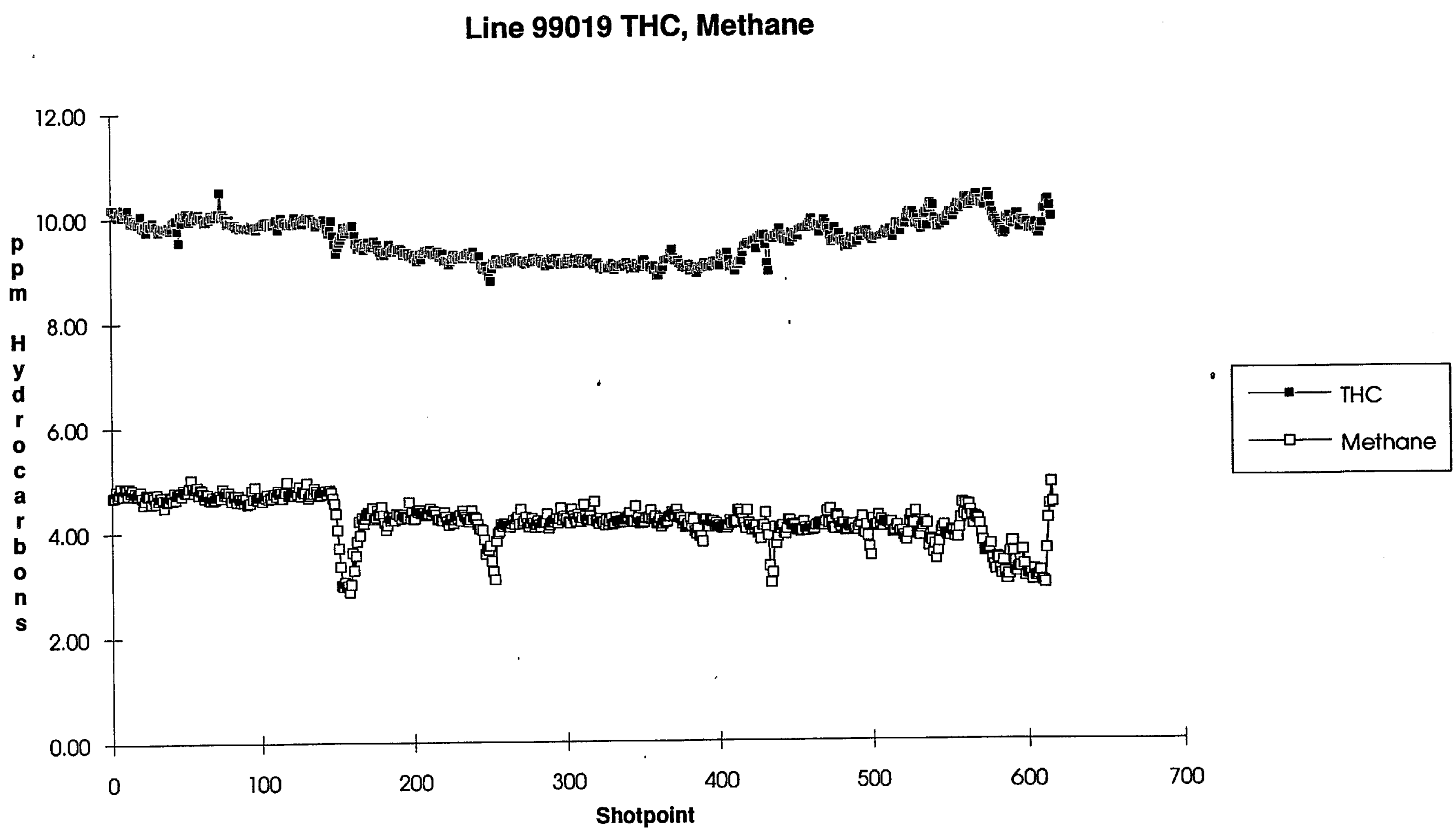
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.550	4.194	0.014	0.098	0.011	0.021	0.000	0.000	0.000	0.051	0.058	0.021	0.606
Std. Dev.	0.383	0.421	0.002	0.009	0.002	0.003	0.000	0.003	0.002	0.026	0.035	0.021	0.095
Minimum	8.769	2.864	0.008	0.066	0.005	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.360
Maximum	10.500	5.007	0.020	0.115	0.017	0.029	0.004	0.033	0.010	0.224	0.508	0.082	1.408

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	59.550	26.023	71.336	89.659	16.943
Std. Dev.	0.750	0.626	14.603	13.978	9.816
Minimum	57.550	24.390	33.100	38.900	5.000
Maximum	61.460	27.660	94.100	122.200	64.700

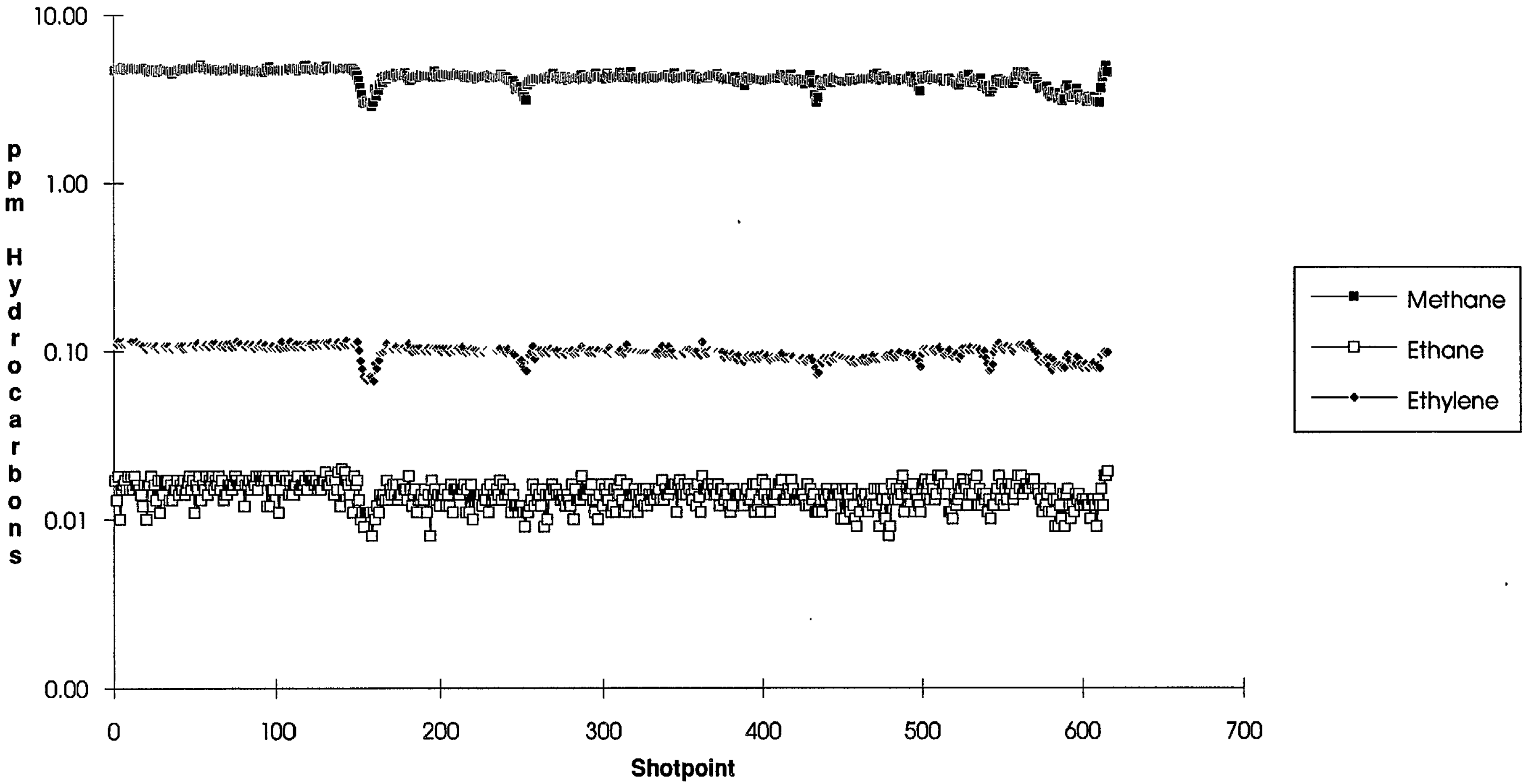
Notes

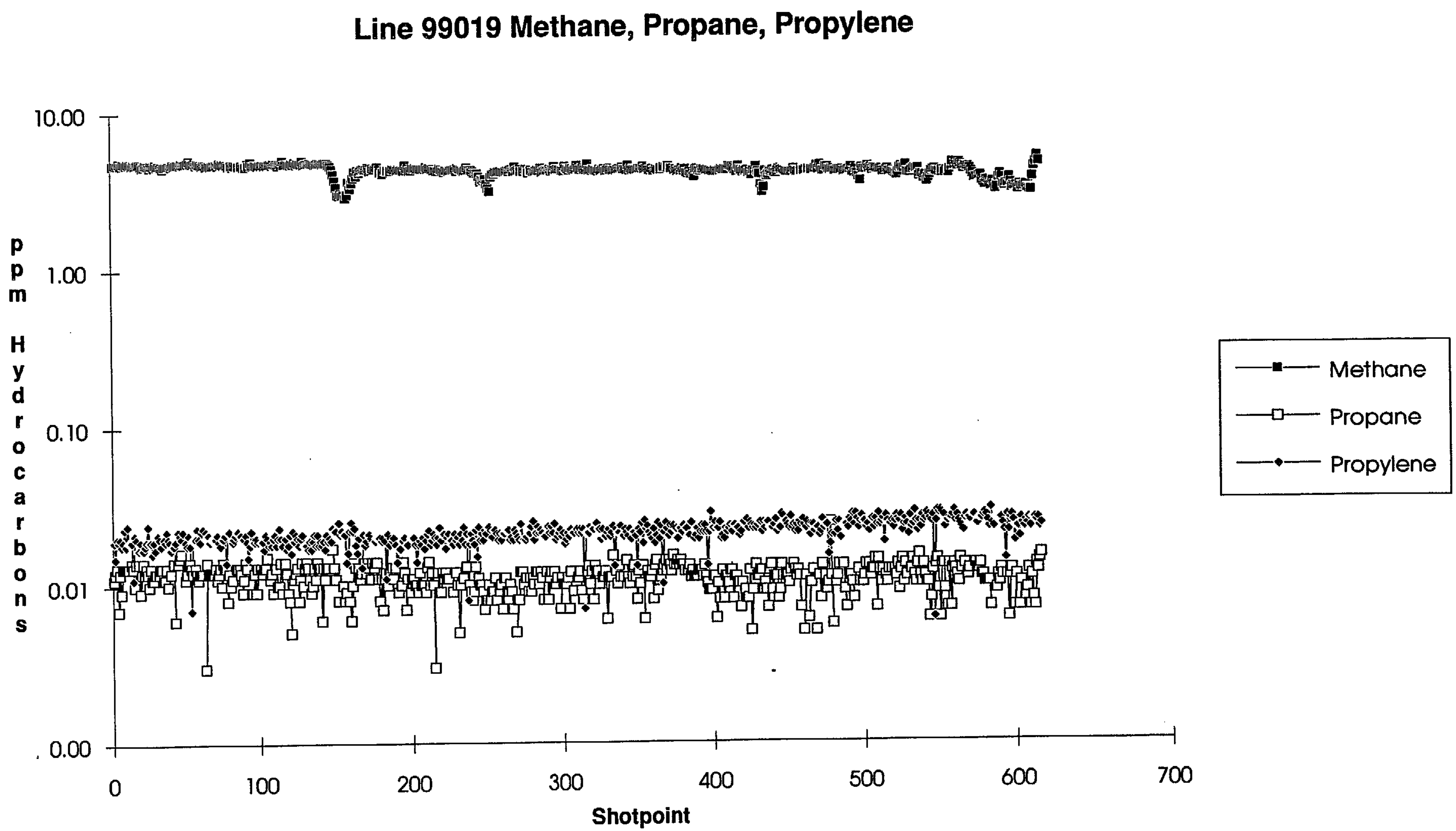
Variations in hydrocarbon levels due to variations in tow-fish depth and water depth

Line finished early due to faults in tow-fish


Line 99019 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane

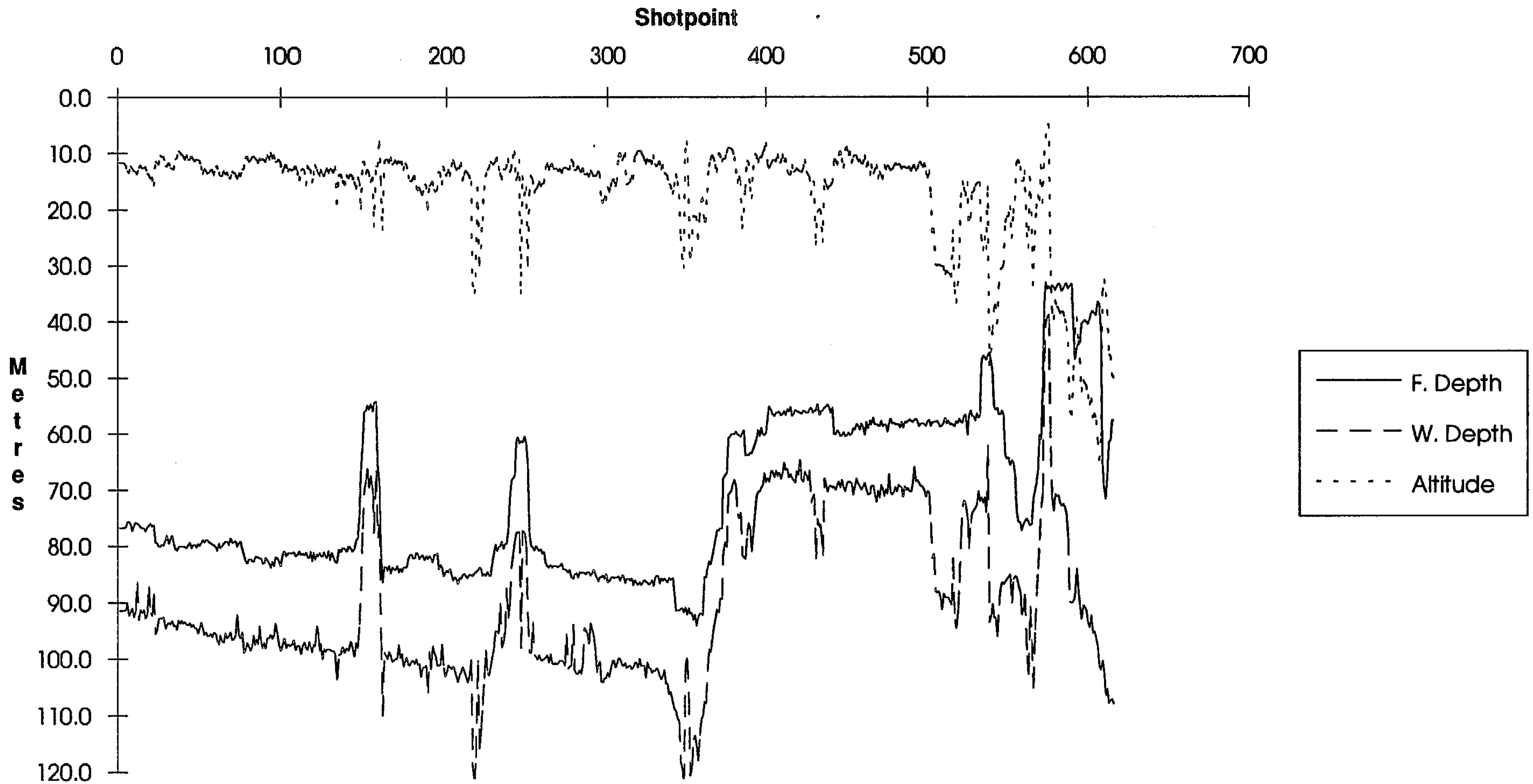
Line 99019 Methane, Ethane, Ethylene





Line 99019 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
Shotpoint
Methane
Propane
Propylene

Line 99019 Depths, Altitude



Line Summary

Line Number	99021
No. of Shotpoints	275

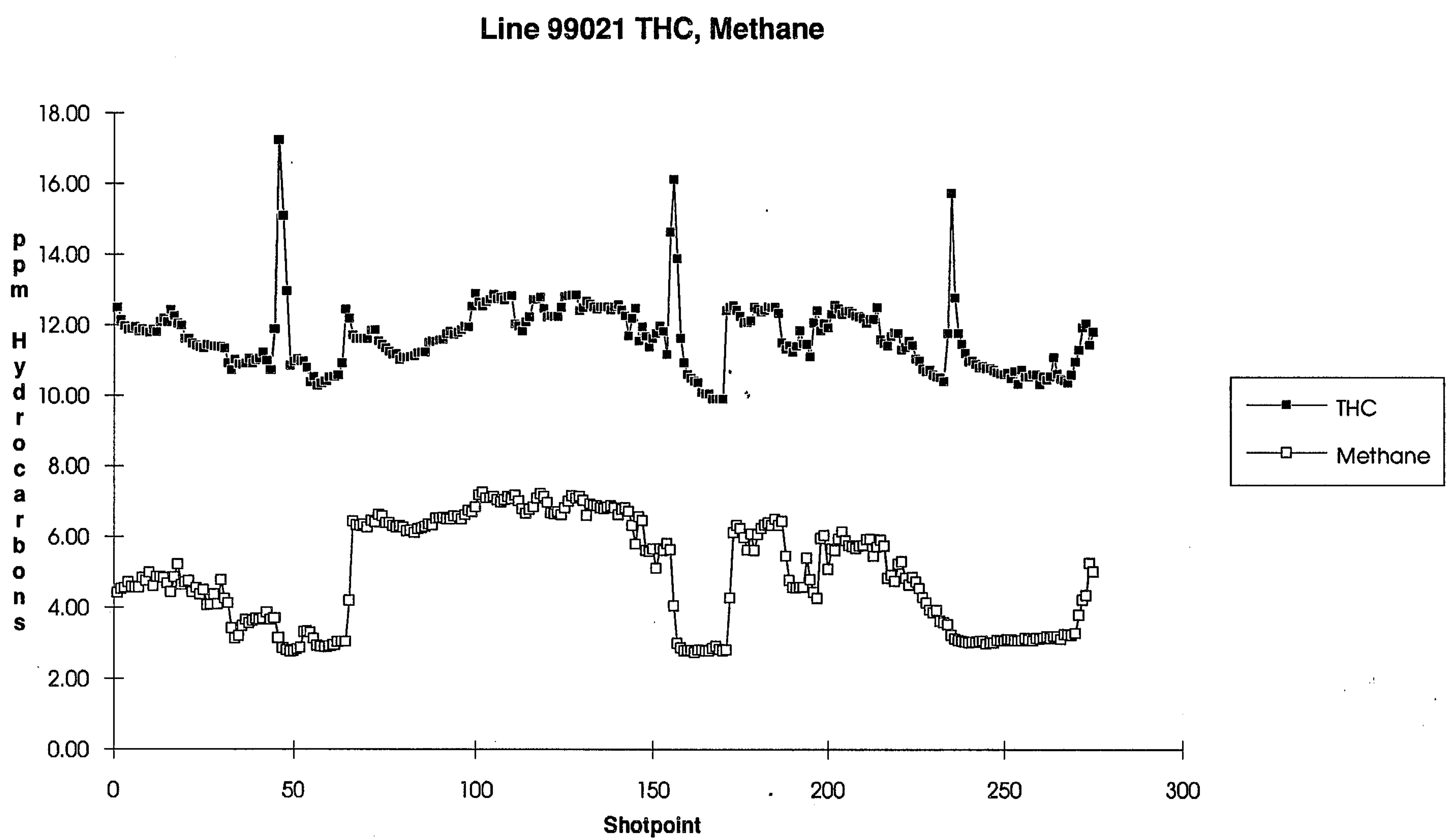
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	27-Feb-91	03:55:13	10	30.951	128	16.786
End	276	27-Feb-91	13:11:42	10	26.139	128	59.169

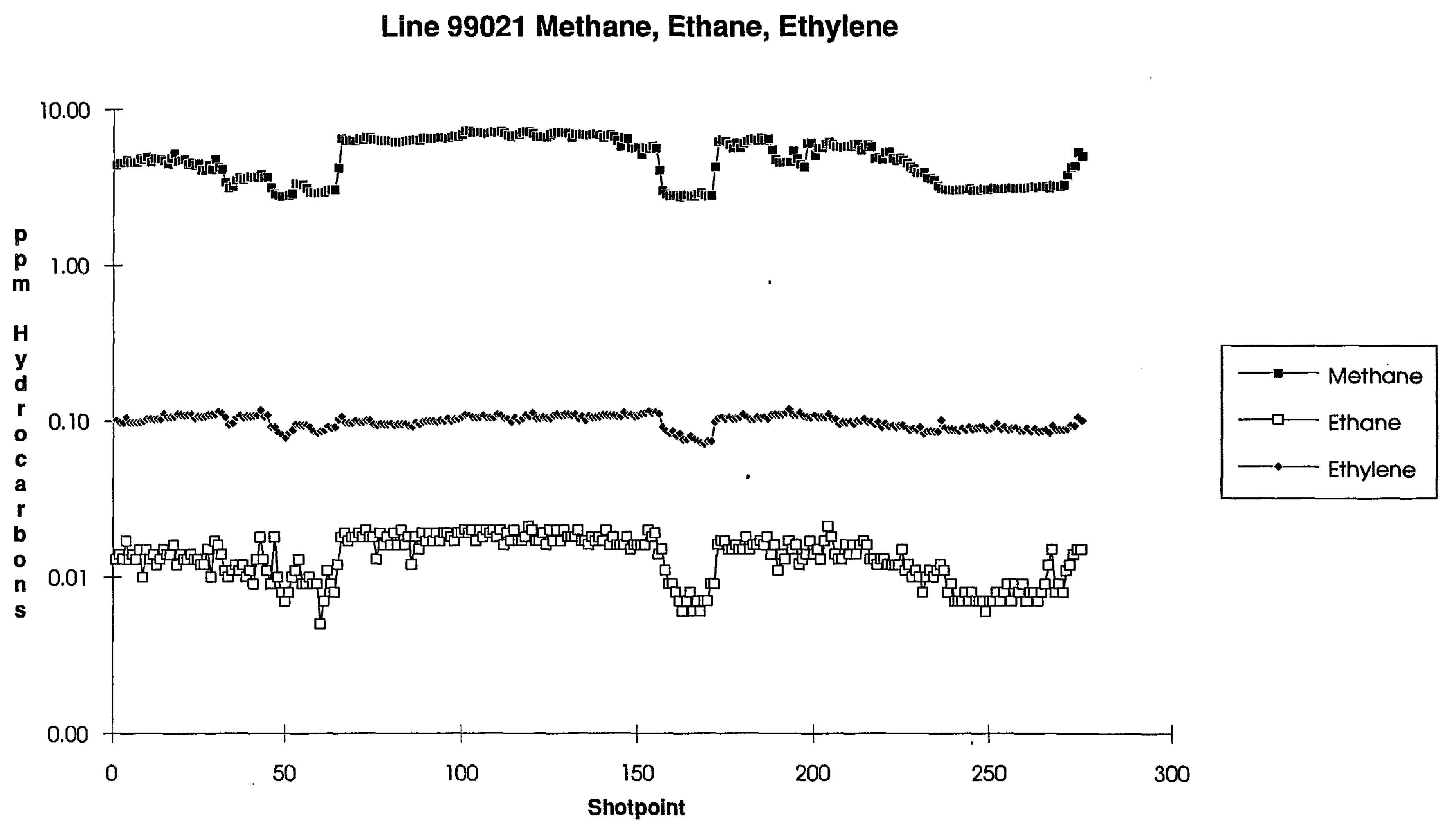
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	11.664	4.946	0.014	0.099	0.012	0.022	0.000	0.000	0.000	0.092	0.010	0.020	0.538
Std. Dev.	0.956	1.488	0.004	0.010	0.003	0.006	0.002	0.003	0.000	0.054	0.020	0.024	0.135
Minimum	9.900	2.742	0.005	0.071	0.004	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.362
Maximum	17.237	7.250	0.021	0.118	0.017	0.053	0.032	0.036	0.008	0.203	0.065	0.075	1.805

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	58.916	26.062	53.823	89.160	35.889
Std. Dev.	0.911	0.793	28.902	43.109	27.621
Minimum	57.010	24.390	11.400	23.600	7.700
Maximum	60.680	27.450	109.600	195.500	134.500

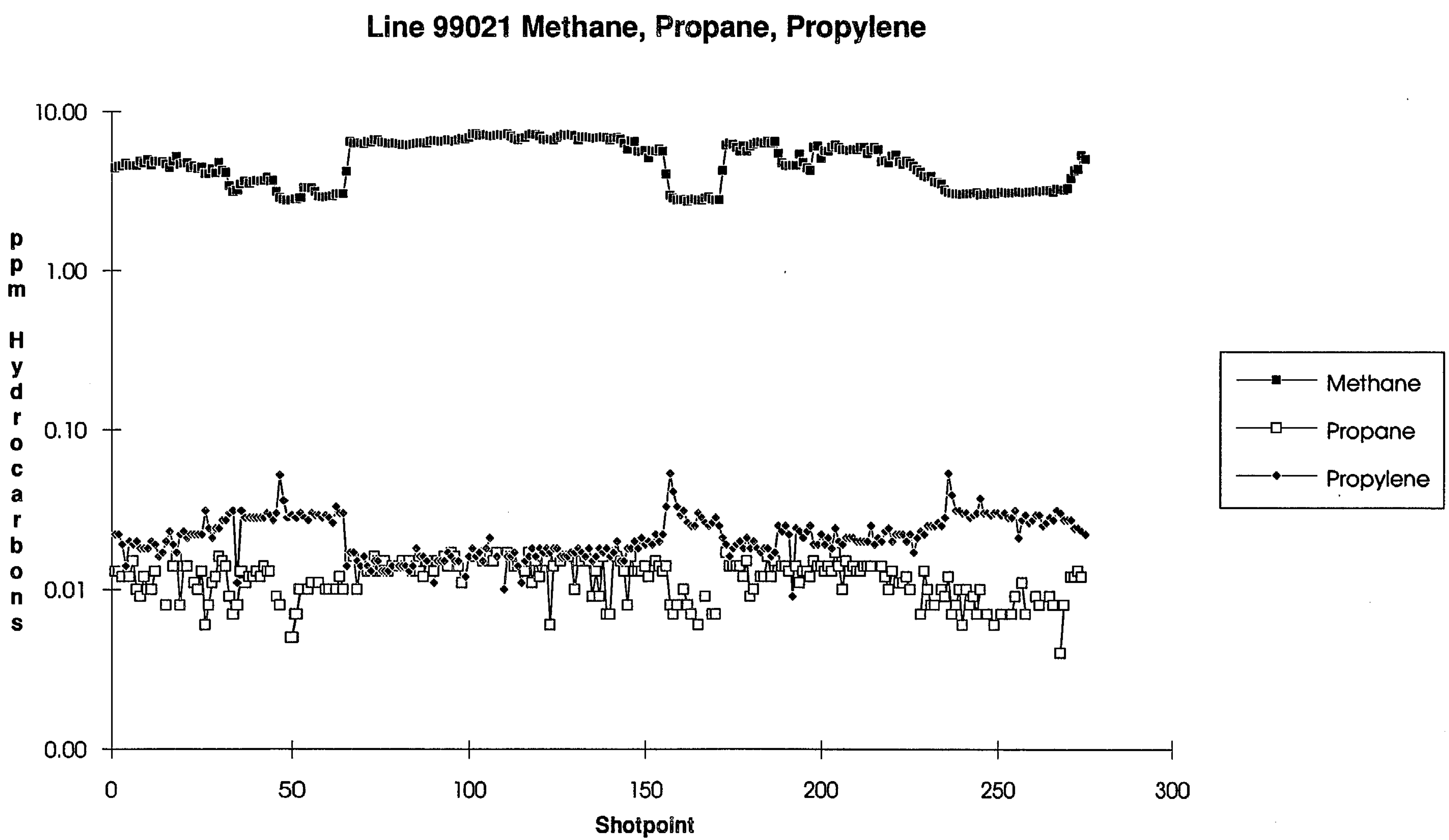
Notes

Variations in hydrocarbon levels due to variations in tow-fish depth and water depth


Line 99021 THC, Methane
ppm Hydrocarbons
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Shotpoint
THC
Methane

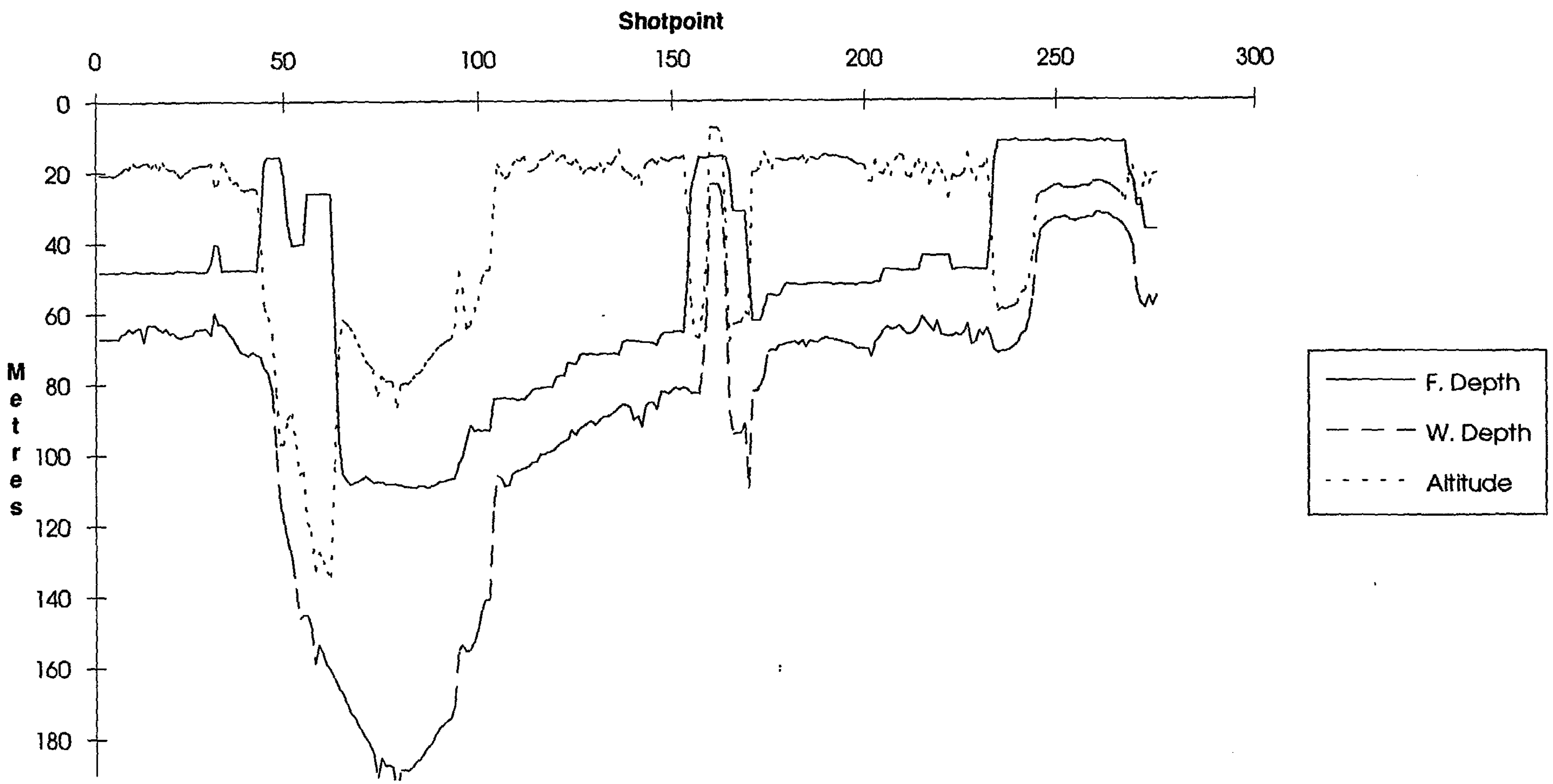


Line 99021 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
Shotpoint
Methane
Ethane
Ethylene



Line 99021 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
Shotpoint
Methane
Propane
Propylene

Line 99021 Depths, Altitude



Line Summary

Line Number	99022
No. of Shotpoints	520

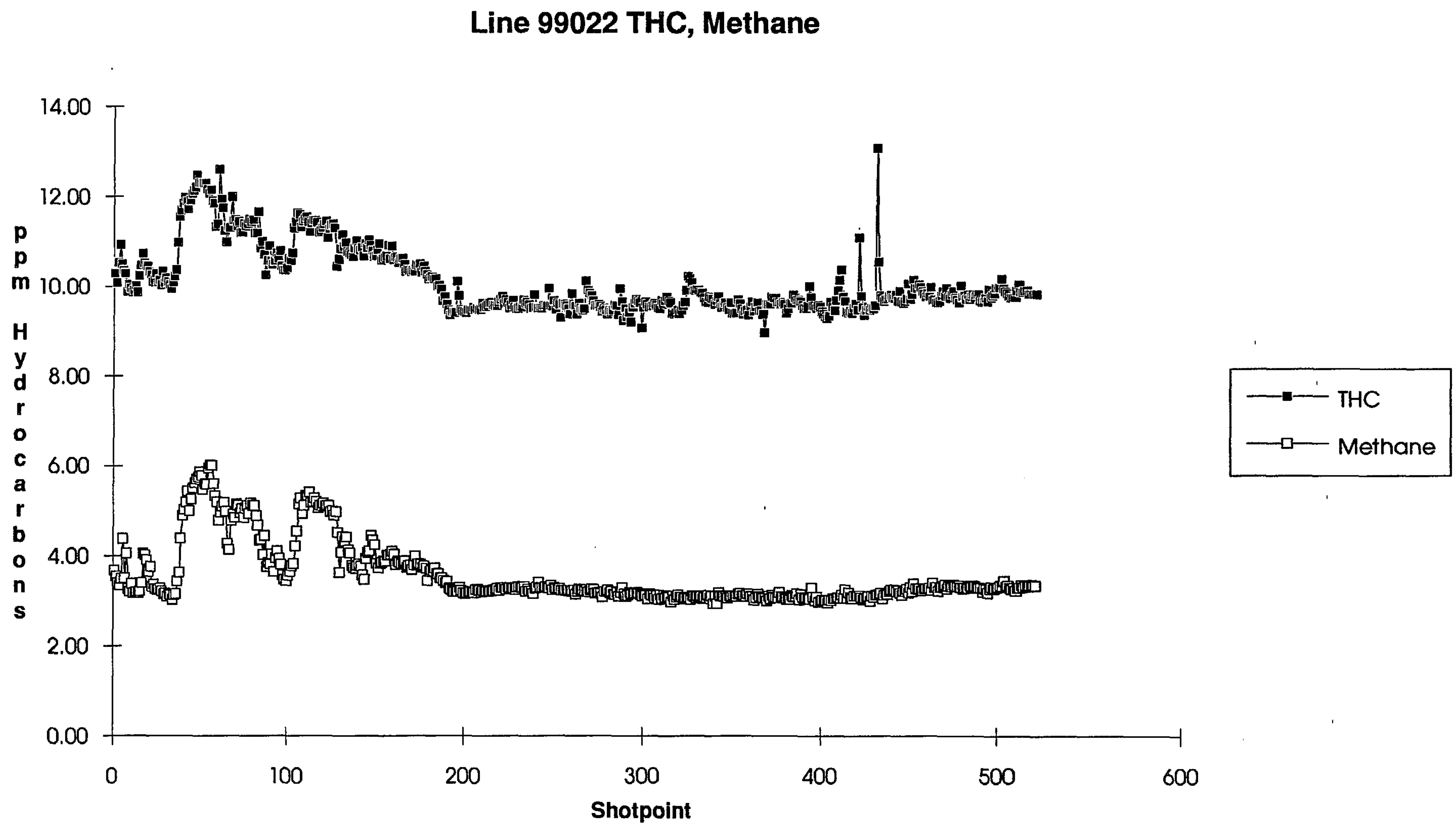
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	27-Feb-91	14:52:14	10	24.168	128	57.152
End	520	28-Feb-91	12:02:09	11	42.611	128	57.261

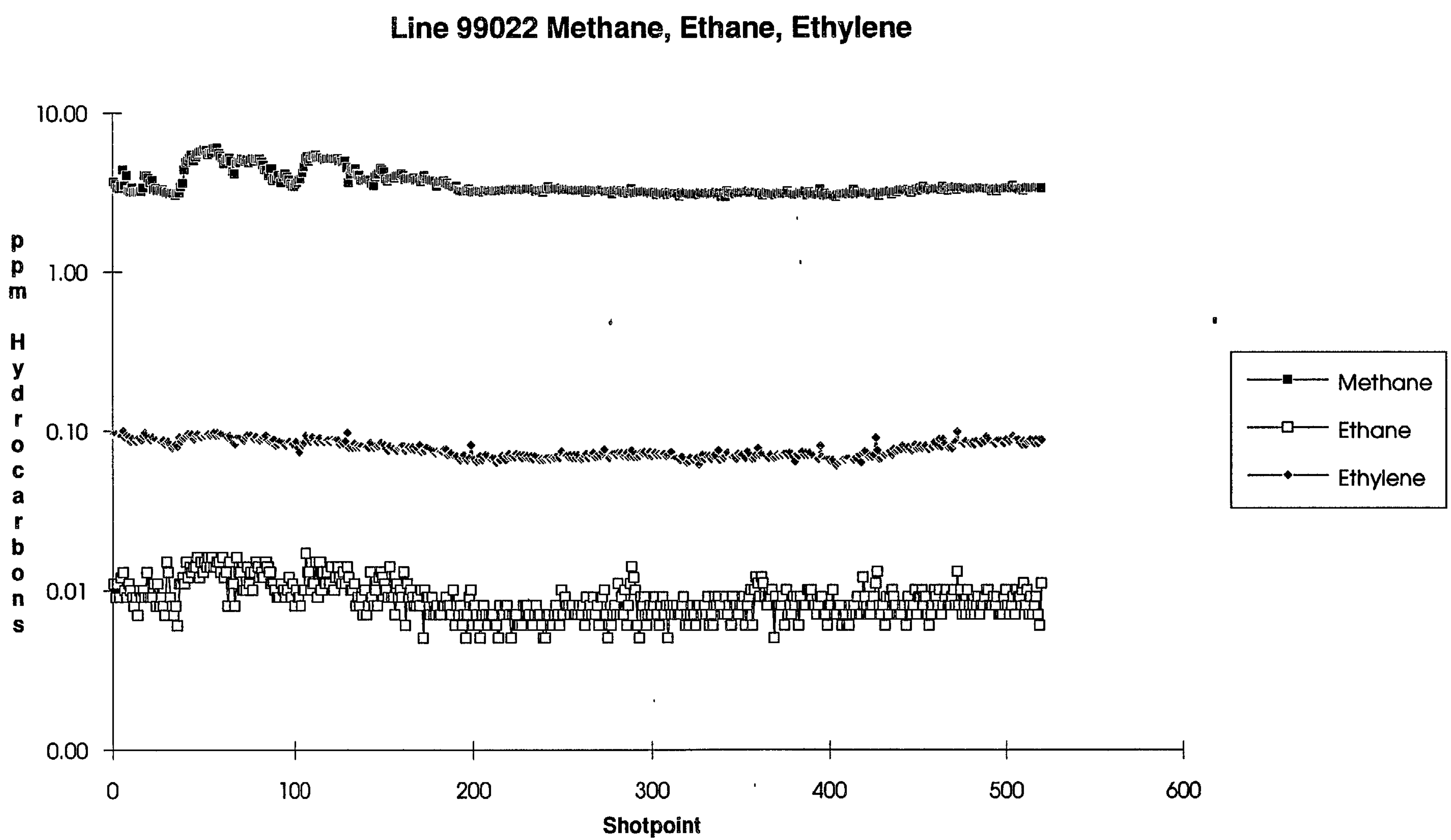
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	10.103	3.561	0.009	0.077	0.009	0.023	0.000	0.001	0.003	0.115	0.017	0.027	0.510
Std. Dev.	0.745	0.696	0.002	0.009	0.002	0.003	0.001	0.004	0.004	0.045	0.024	0.021	0.133
Minimum	8.965	2.937	0.005	0.060	0.004	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.312
Maximum	13.063	6.005	0.017	0.100	0.015	0.036	0.015	0.041	0.014	0.204	0.089	0.088	1.664

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.480	26.976	36.142	52.931	18.396
Std. Dev.	0.479	0.292	11.634	15.188	8.117
Minimum	59.490	26.120	11.600	24.700	4.000
Maximum	61.830	27.870	67.400	107.400	60.000

Notes

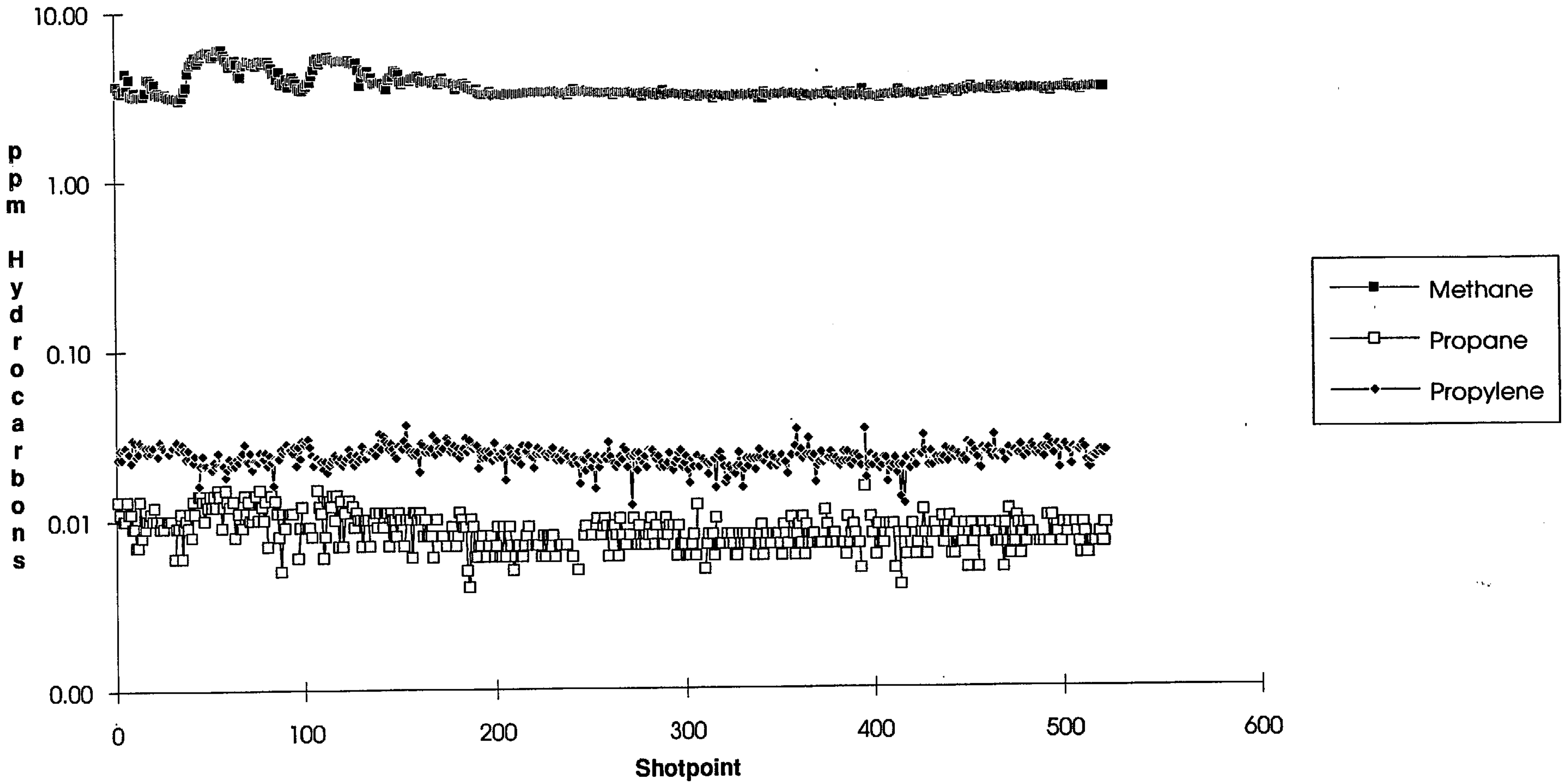
THC, methane and slight ethane anomaly at SP 39-129.

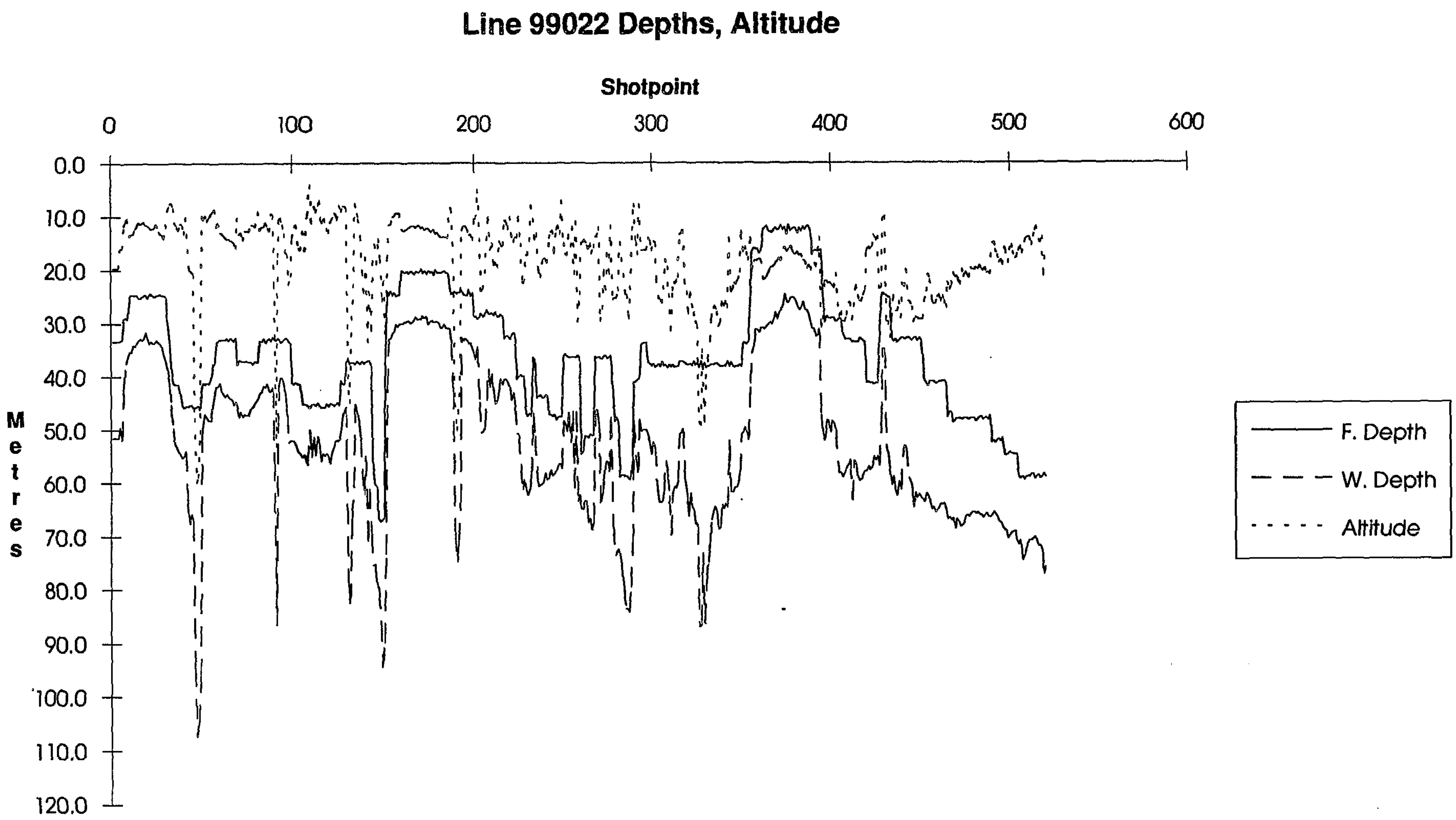

Line 99022 THC, Methane
ppm Hydrocarbons
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
Shotpoint
THC
Methane



Line 99022 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
Shotpoint
Methane
Ethane
Ethylene

Line 99022 Methane, Propane, Propylene




Line 99022 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
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	99023
No. of Shotpoints	563

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	28-Feb-91	13:57:13	11	44.571	128	49.576
End	796	1-Mar-91	16:43:27	12	48.782	127	49.112

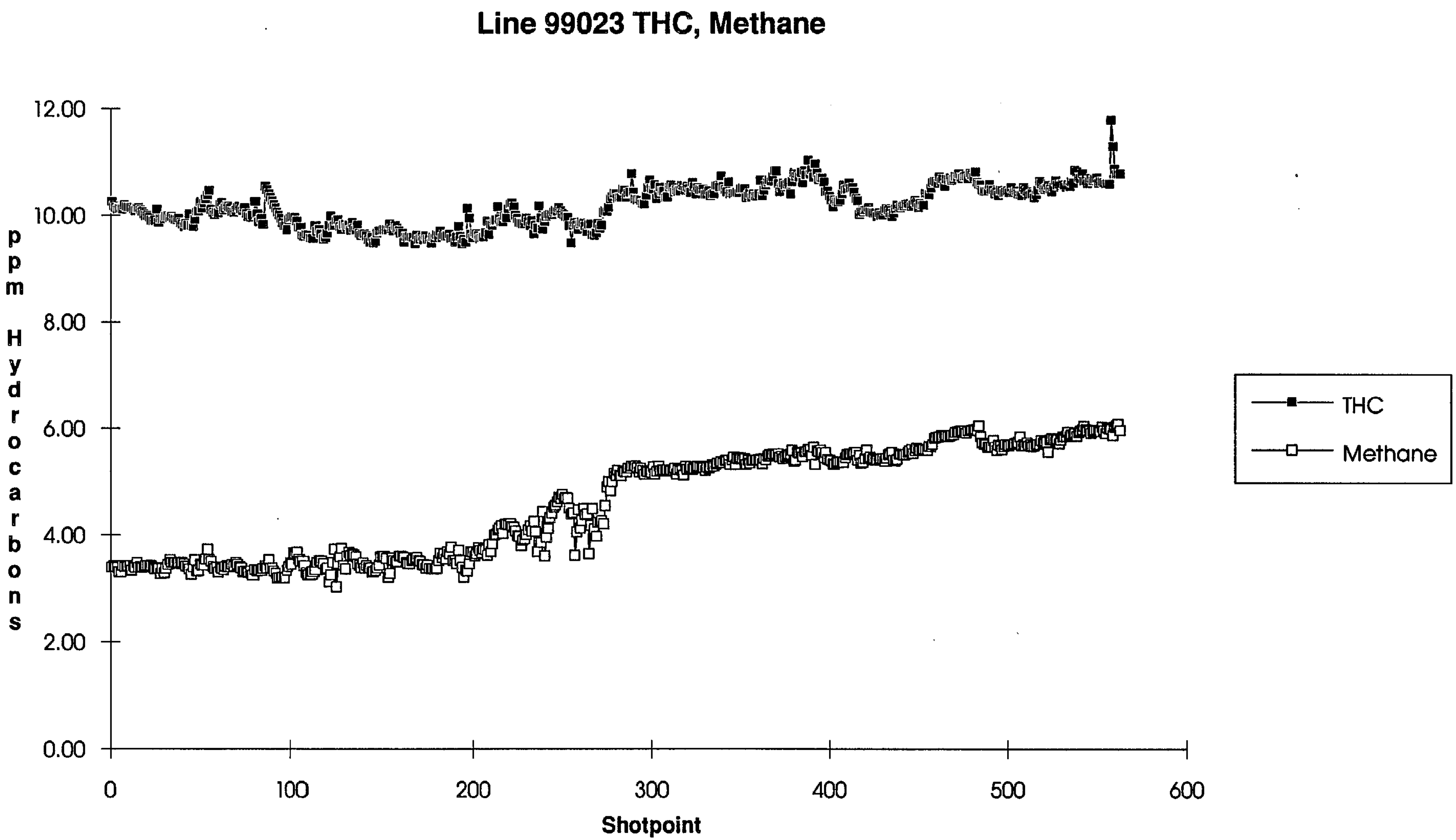
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	10.178	4.605	0.016	0.106	0.011	0.021	0.001	0.001	0.000	0.070	0.021	0.027	0.626
Std. Dev.	0.377	1.010	0.006	0.016	0.003	0.003	0.012	0.005	0.002	0.050	0.033	0.024	0.346
Minimum	9.462	3.030	0.006	0.073	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.363
Maximum	11.770	6.063	0.031	0.136	0.035	0.033	0.177	0.046	0.024	0.261	0.135	0.148	5.035

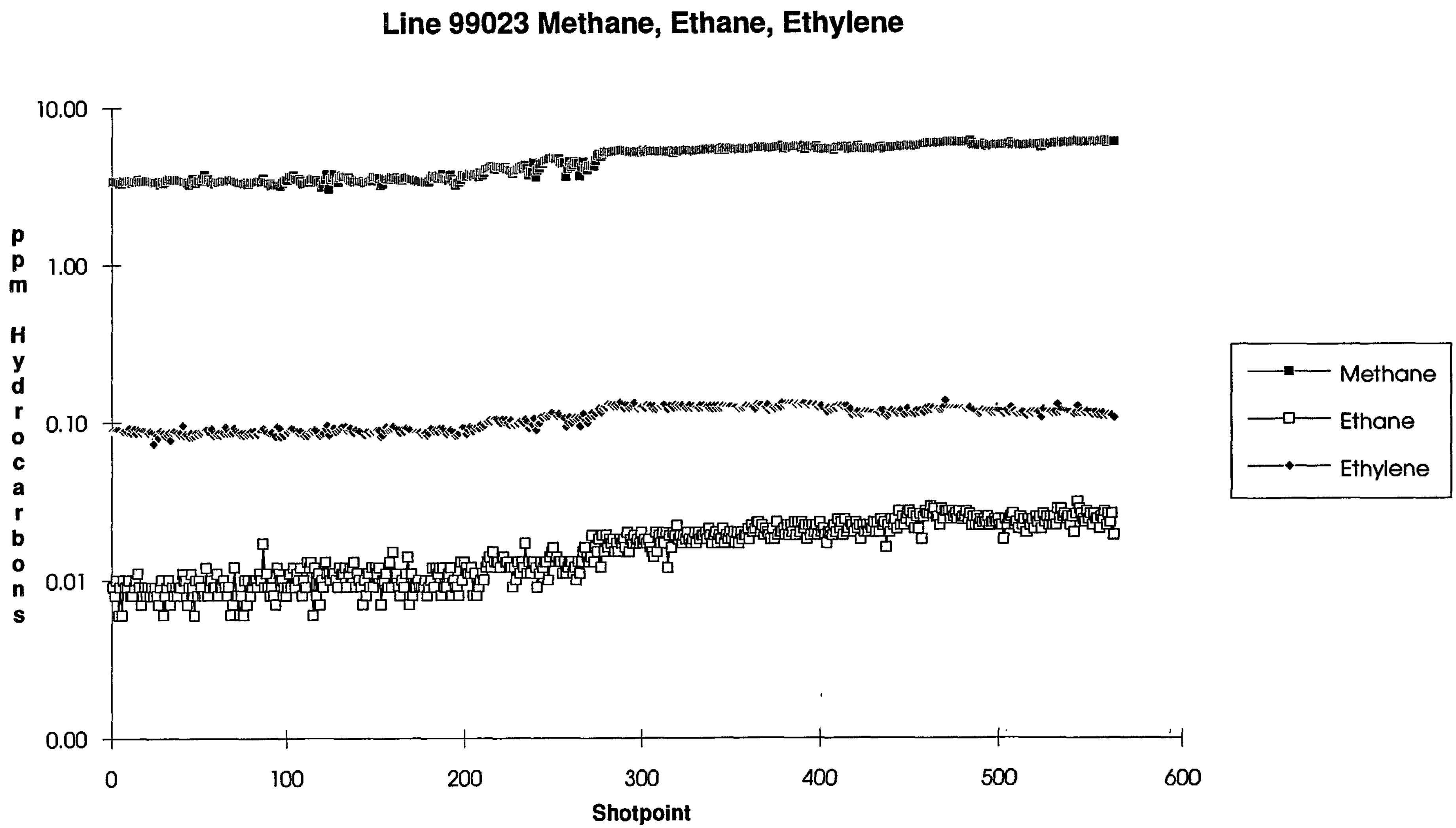
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.978	27.117	77.236	94.540	16.824
Std. Dev.	0.617	0.524	14.495	14.766	7.711
Minimum	60.160	26.470	48.000	60.300	8.200
Maximum	62.920	28.730	94.600	129.700	50.900

Notes

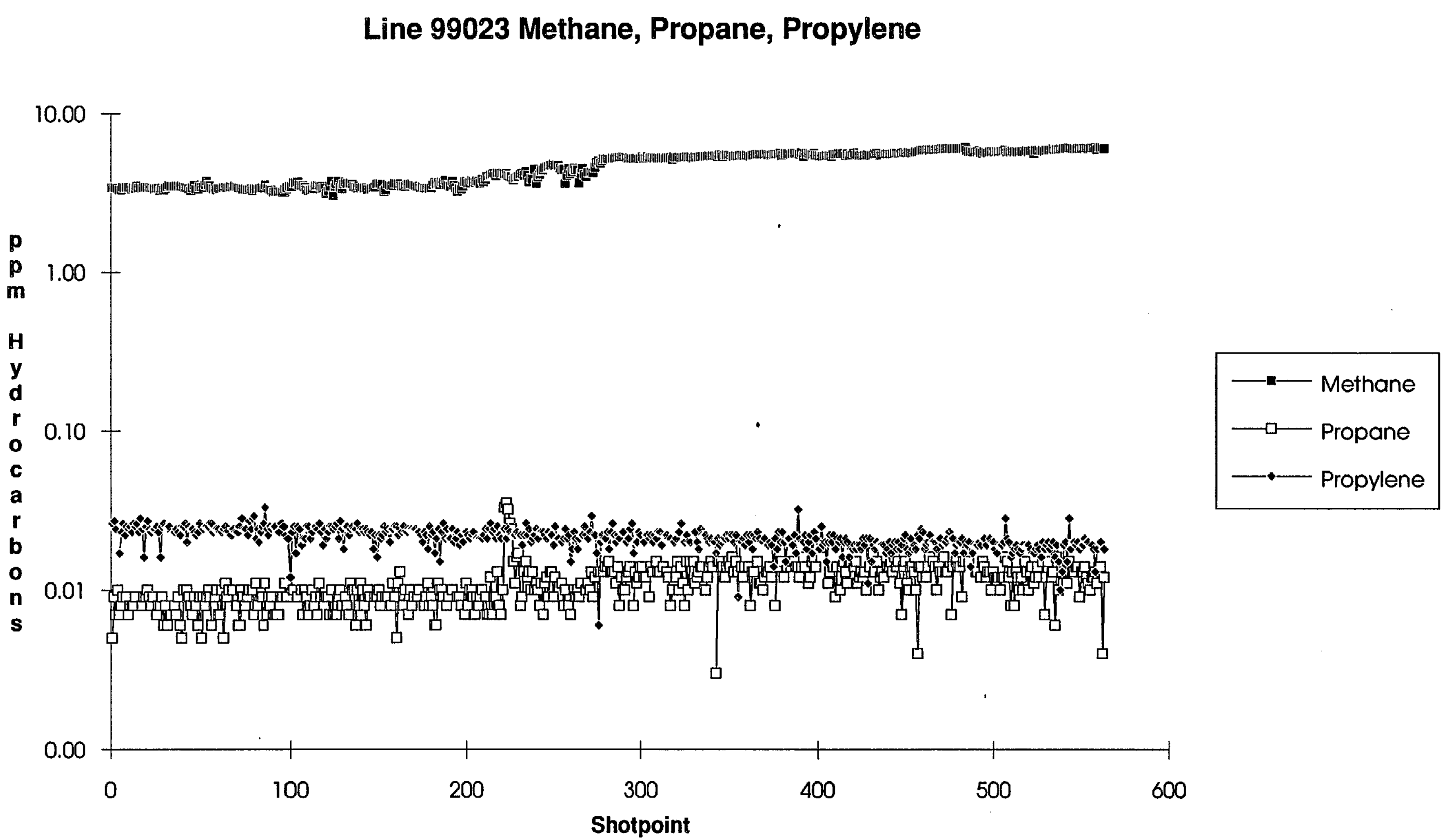
Slight regional increase in methane and ethane towards end of line.

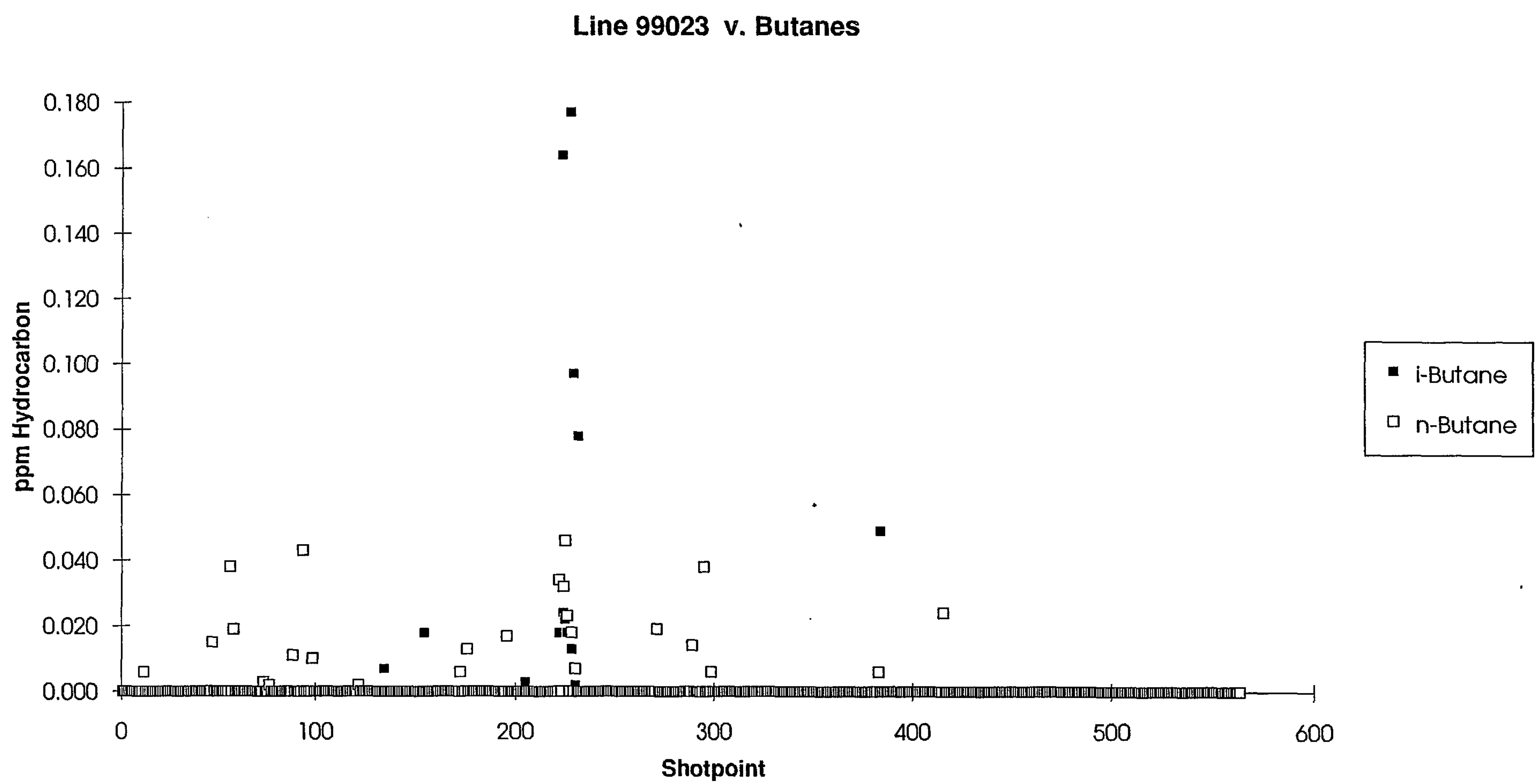
Propane and butane anomaly at SP 222-231

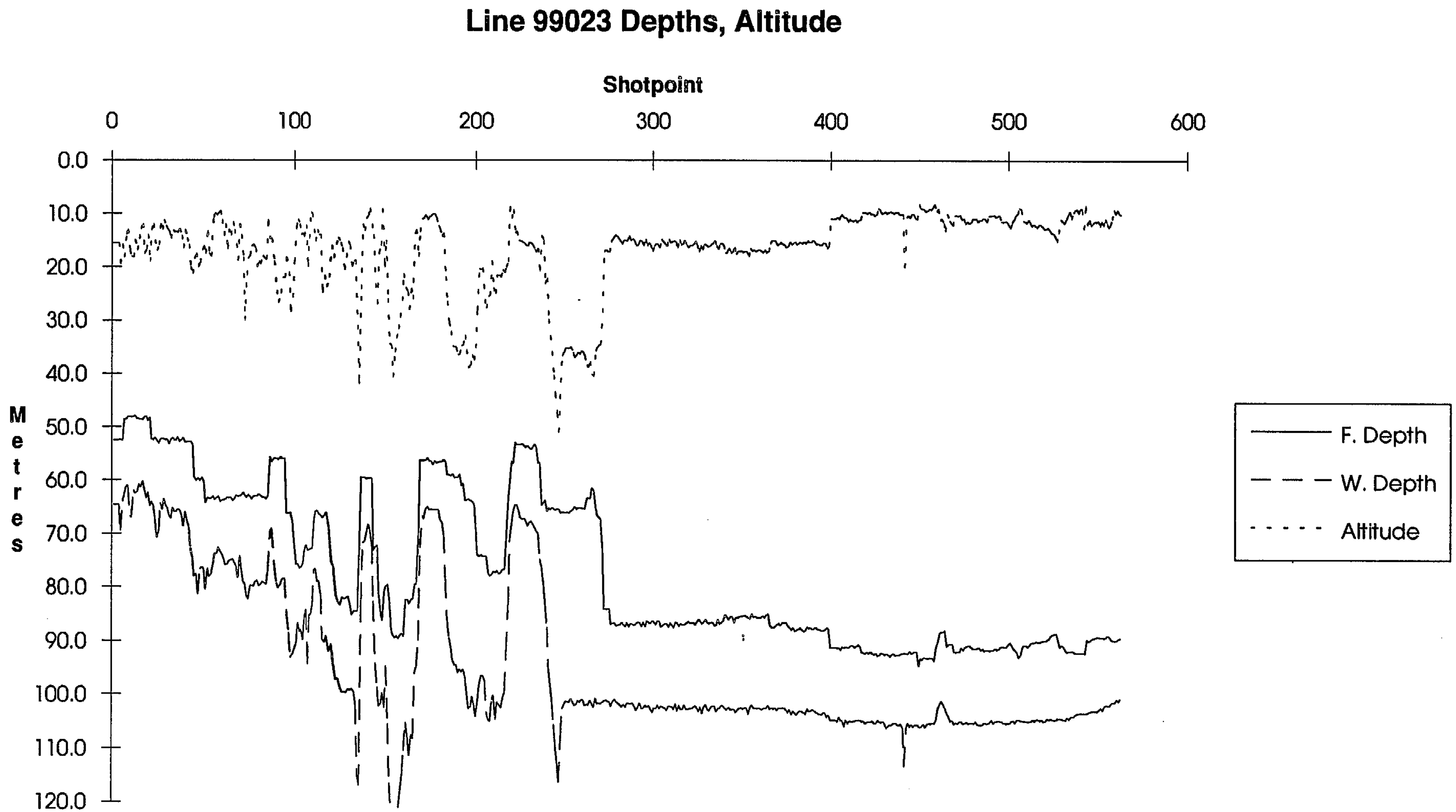

Line 99023 THC, Methane
ppm Hydrocarbons
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
Shotpoint
THC
Methane



Line 99023 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
Shotpoint
Methane
Ethane
Ethylene


Line 99023 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
Shotpoint
Methane
Propane
Propylene


Line 99023 v. Butanes
ppm Hydrocarbon
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0
100
200
300
400
500
600
Shotpoint
i-Butane
n-Butane



Line 99023 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
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	99024
No. of Shotpoints	127

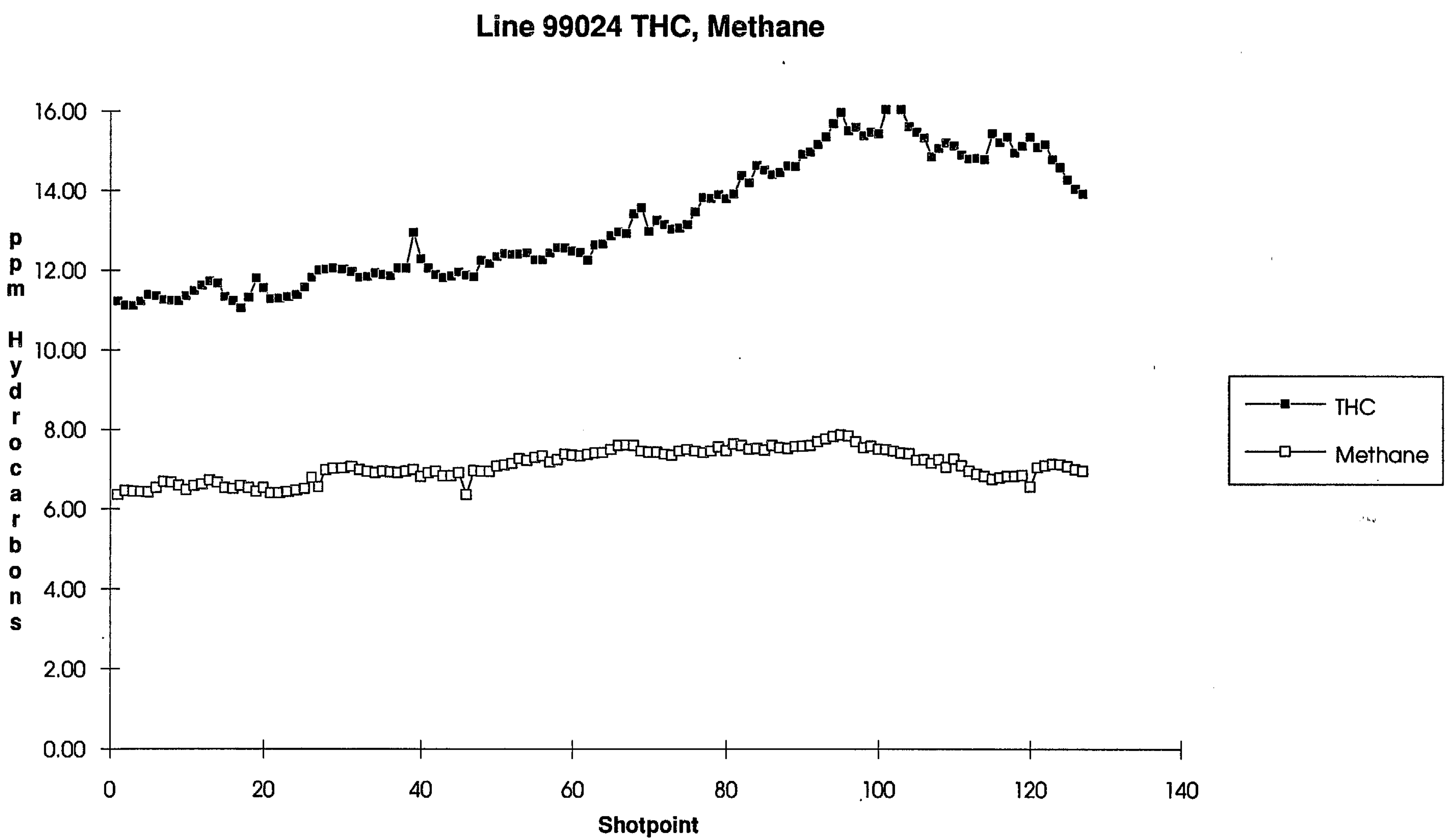
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	1-Mar-91	20:55:13	13	02.518	127	59.316
End	128	2-Mar-91	01:13:51	13	20.670	128	10.514

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	13.221	7.092	0.037	0.126	0.015	0.020	0.000	0.000	0.000	0.060	0.013	0.037	0.735
Std. Dev.	1.552	0.402	0.007	0.008	0.002	0.002	0.000	0.002	0.000	0.040	0.030	0.021	0.098
Minimum	11.058	6.358	0.026	0.107	0.008	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.551
Maximum	16.362	7.863	0.053	0.148	0.022	0.031	0.000	0.026	0.000	0.164	0.099	0.083	1.046

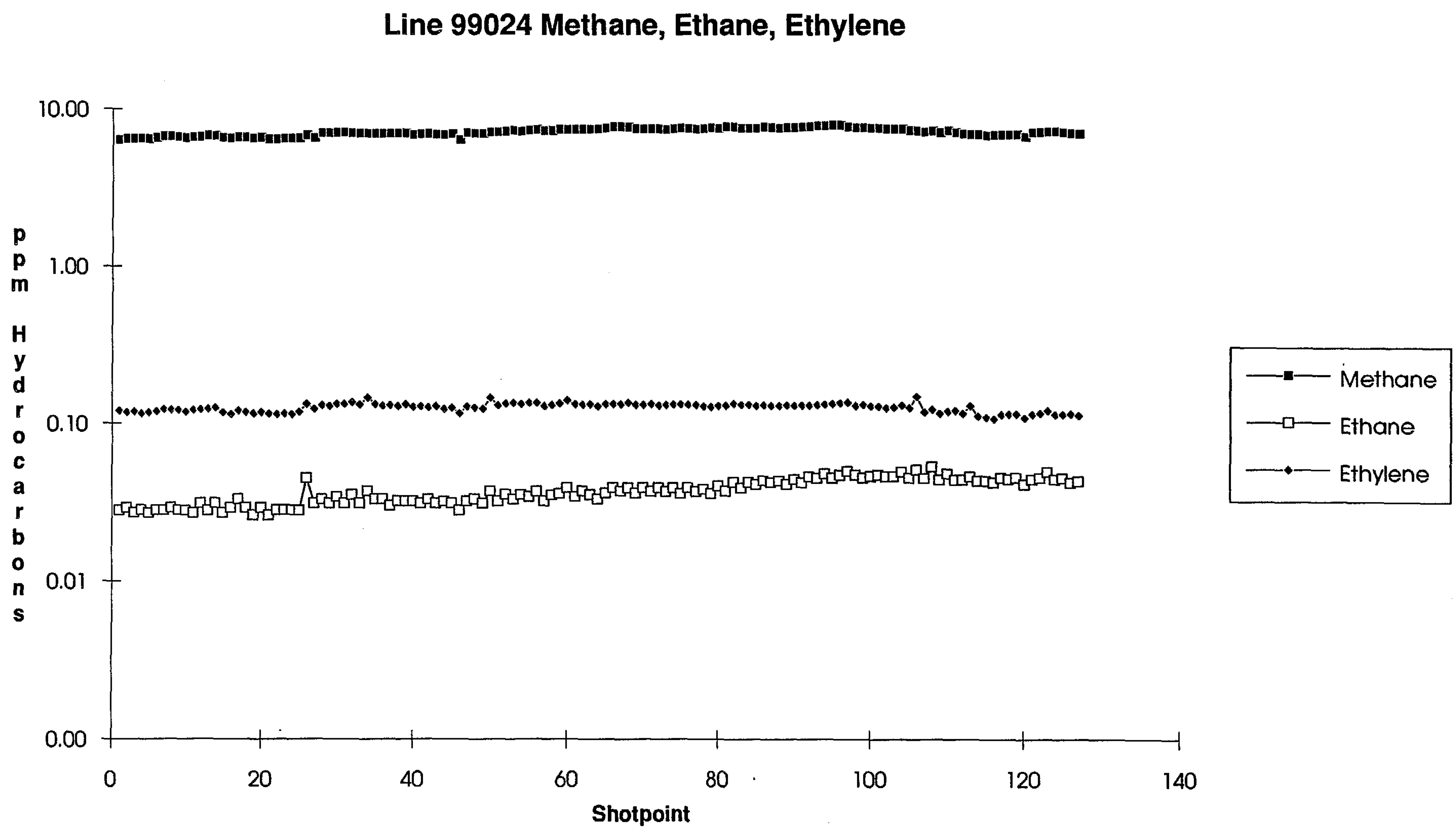
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.602	27.443	76.142	86.507	11.263
Std. Dev.	0.965	0.742	3.634	4.620	1.289
Minimum	60.420	26.530	68.000	76.500	8.600
Maximum	63.270	28.730	82.800	94.400	14.900

Notes

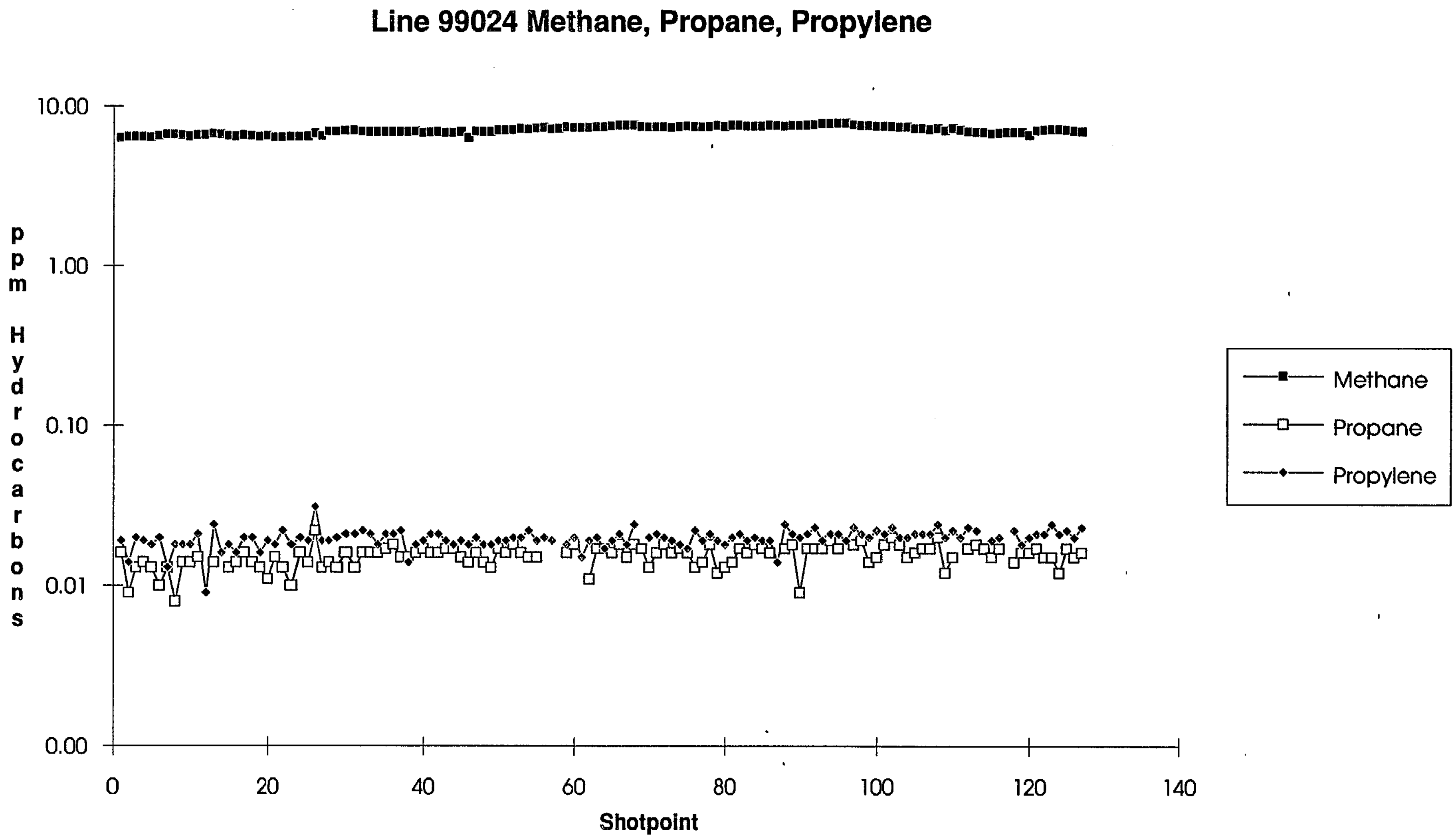
Increase in THC and slight increass in methane and ethane towards end of line.
This line resurveys the later part of line 99017.



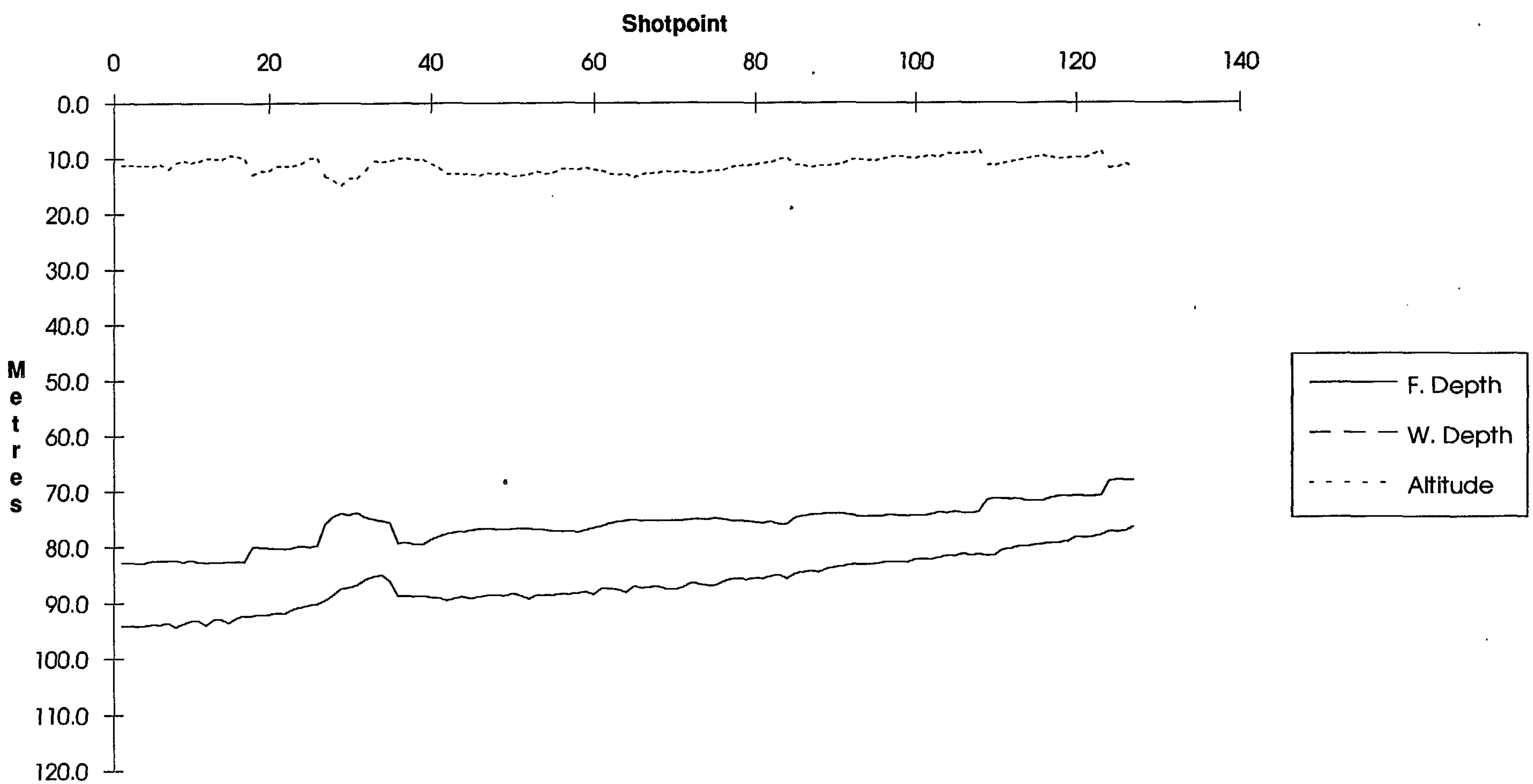
Line 99024 THC, Methane
ppm Hydrocarbons
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
20
40
60
80
100
120
140
Shotpoint
THC
Methane



Line 99024 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Ethane
Ethylene


Line 99024 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 99024 Depths, Altitude



Line Summary

Line Number	99025
No. of Shotpoints	806

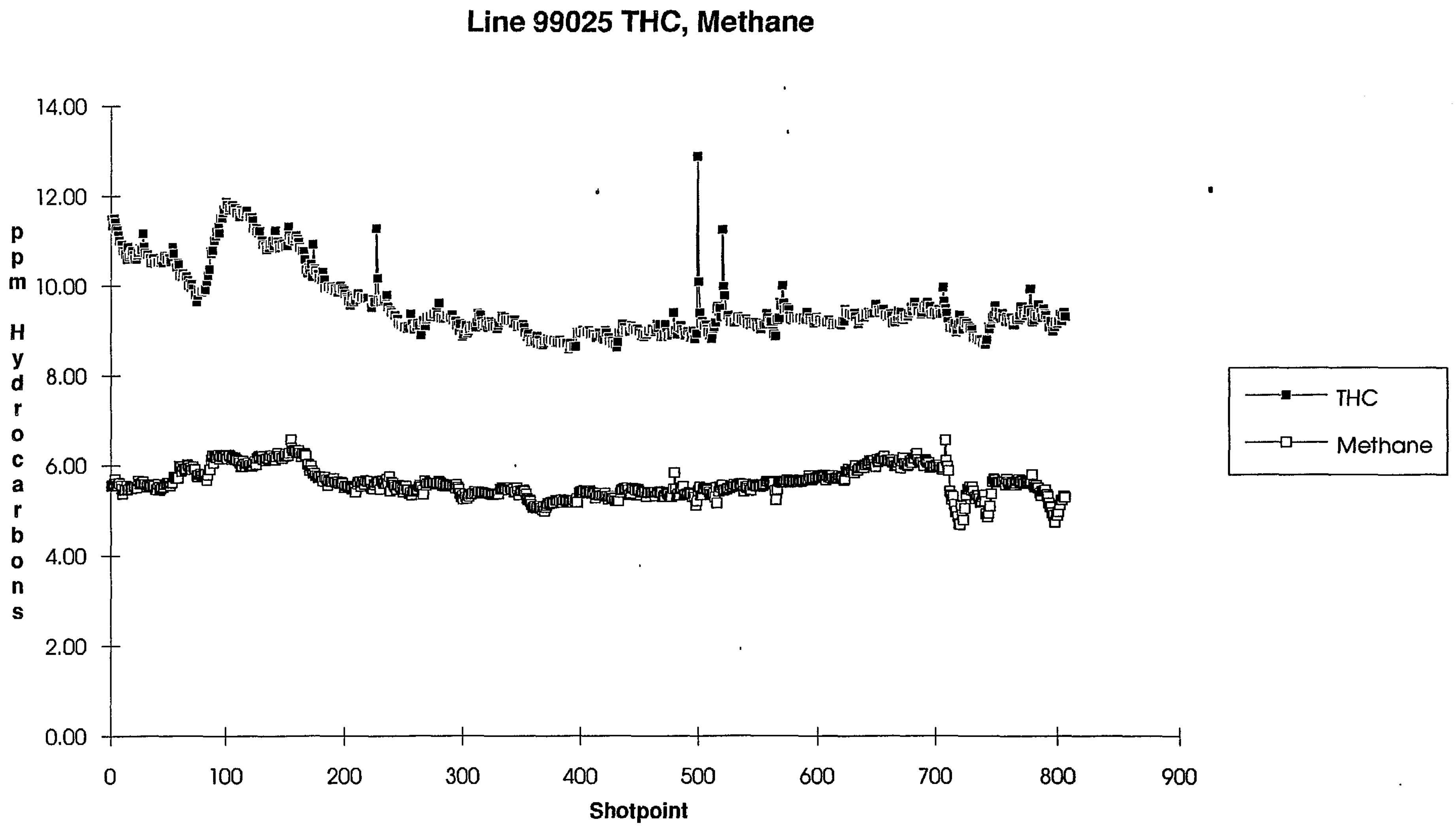
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	2-Mar-91	08:56:37	13	12.658	128	28.113
End	922	3-Mar-91	15:50:53	11	16.340	127	21.692

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.572	5.605	0.021	0.115	0.014	0.021	0.000	0.000	0.000	0.039	0.026	0.028	0.616
Std. Dev.	0.774	0.320	0.004	0.008	0.002	0.003	0.002	0.004	0.001	0.021	0.041	0.025	0.118
Minimum	8.578	4.673	0.012	0.094	0.003	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.285
Maximum	12.864	6.564	0.041	0.147	0.023	0.039	0.039	0.069	0.007	0.137	0.197	0.164	1.855

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.569	26.945	91.585	109.761	16.958
Std. Dev.	0.912	0.728	8.269	12.544	6.125
Minimum	58.950	25.950	71.200	78.900	7.800
Maximum	63.440	29.330	102.400	130.200	49.800

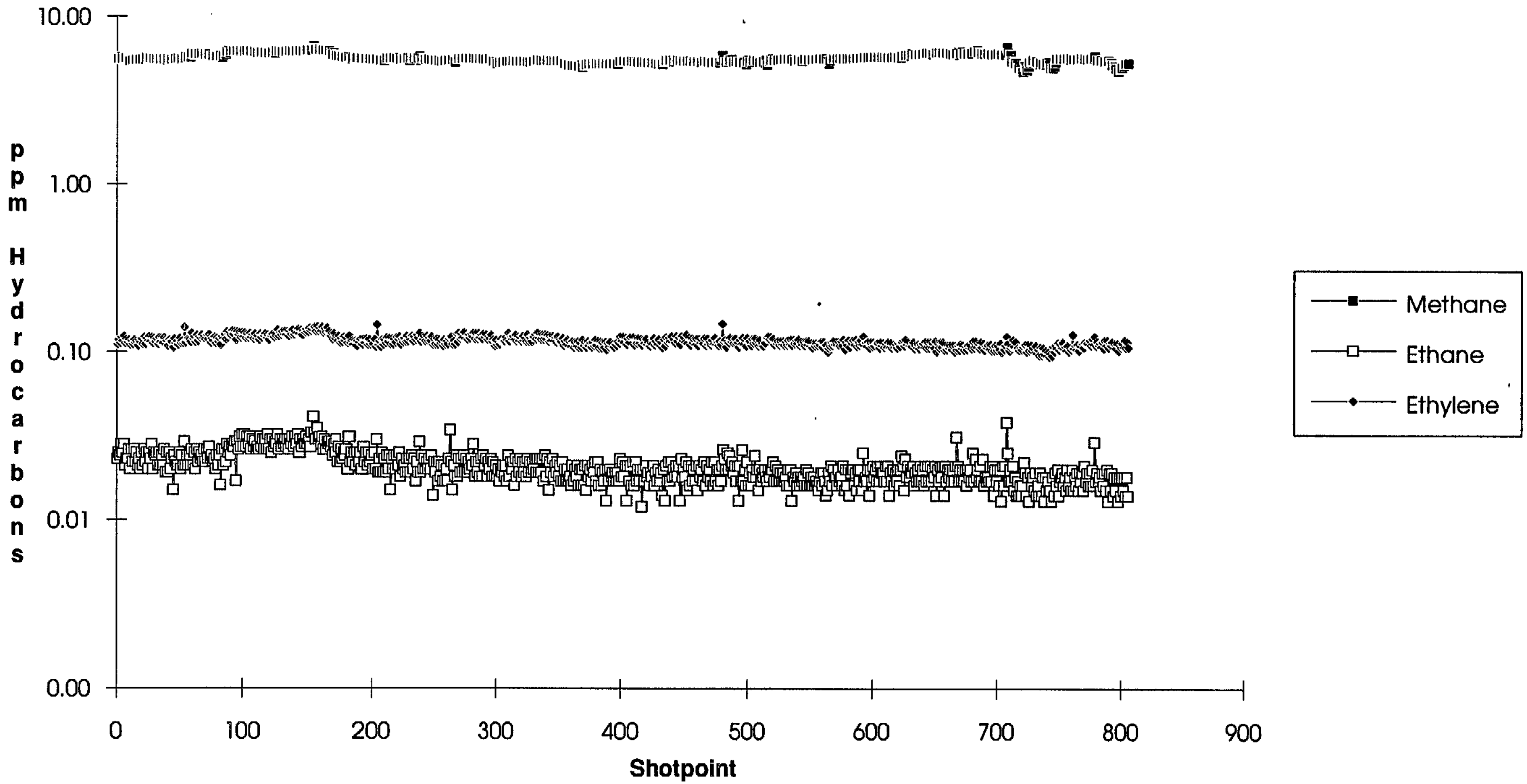
Notes

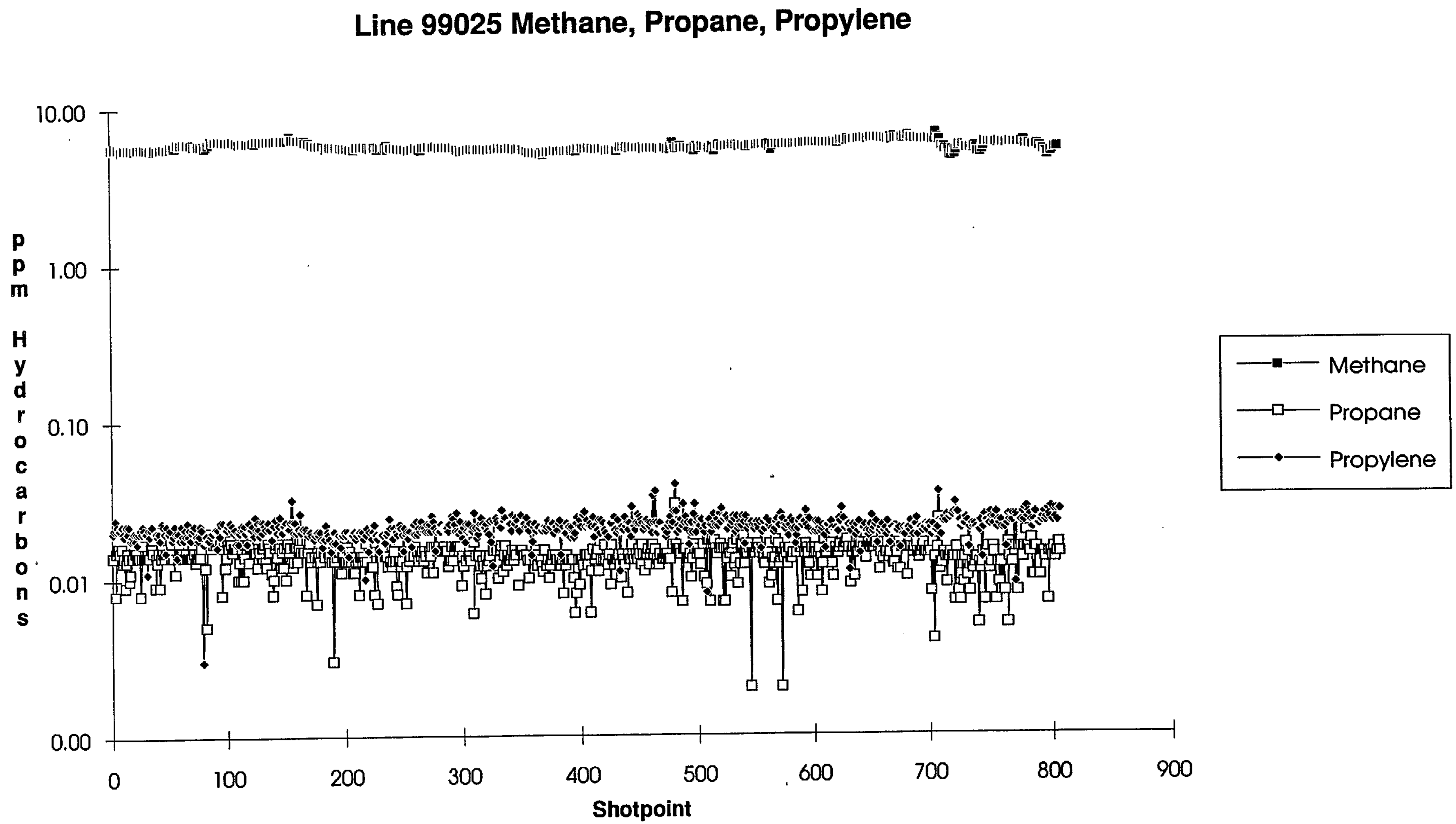
THC anomaly from shotpoint 90 to 150, with trace increases in ethane, propane and butane.



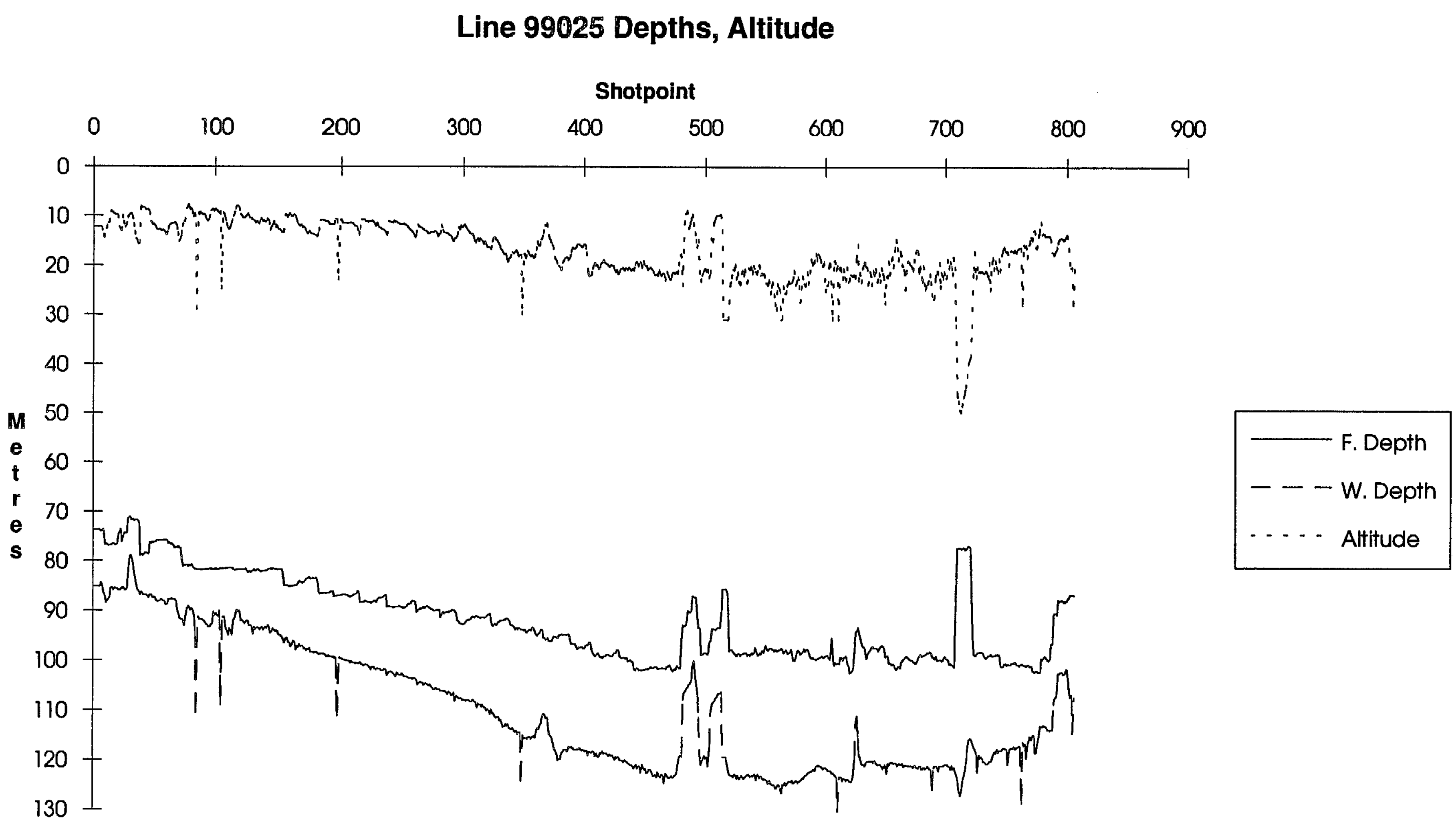
Line 99025 THC, Methane
ppm Hydrocarbons
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
100
200
300
400
500
600
700
800
900
Shotpoint
THC
Methane

Line 99025 Methane, Ethane, Ethylene





Line 99025 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
900
Shotpoint
Methane
Propane
Propylene



Line 99025 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Metres
F. Depth
W. Depth
Altitude

Line Summary

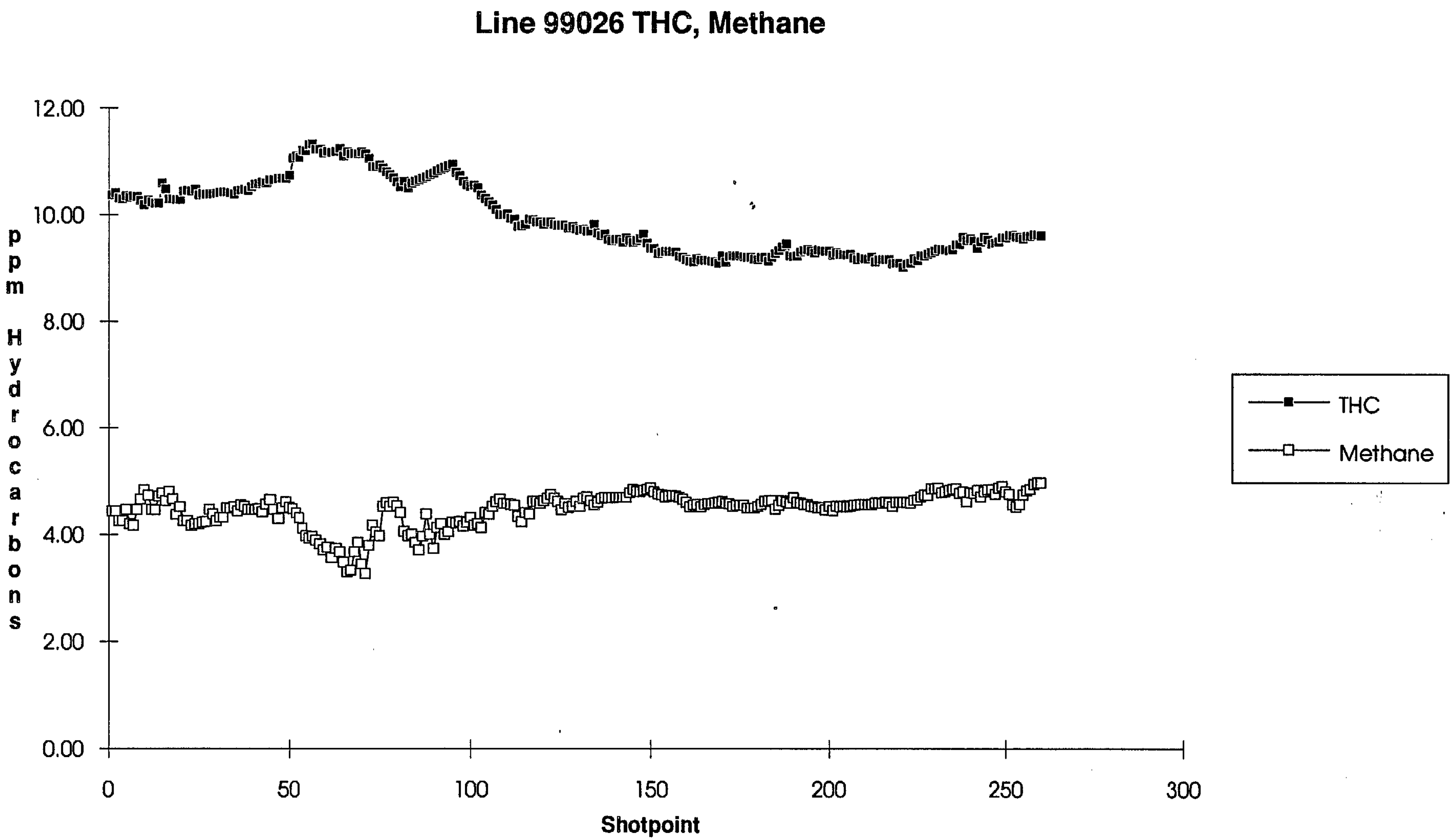
Line Number	99026
No. of Shotpoints	260

	Shotpoint	Date	Time	Latitude		Longitude	
Start	42	4-Mar-91	02:11:14	11	00.225	126	31.164
End	513	4-Mar-91	18:14:40	11	22.190	125	53.574

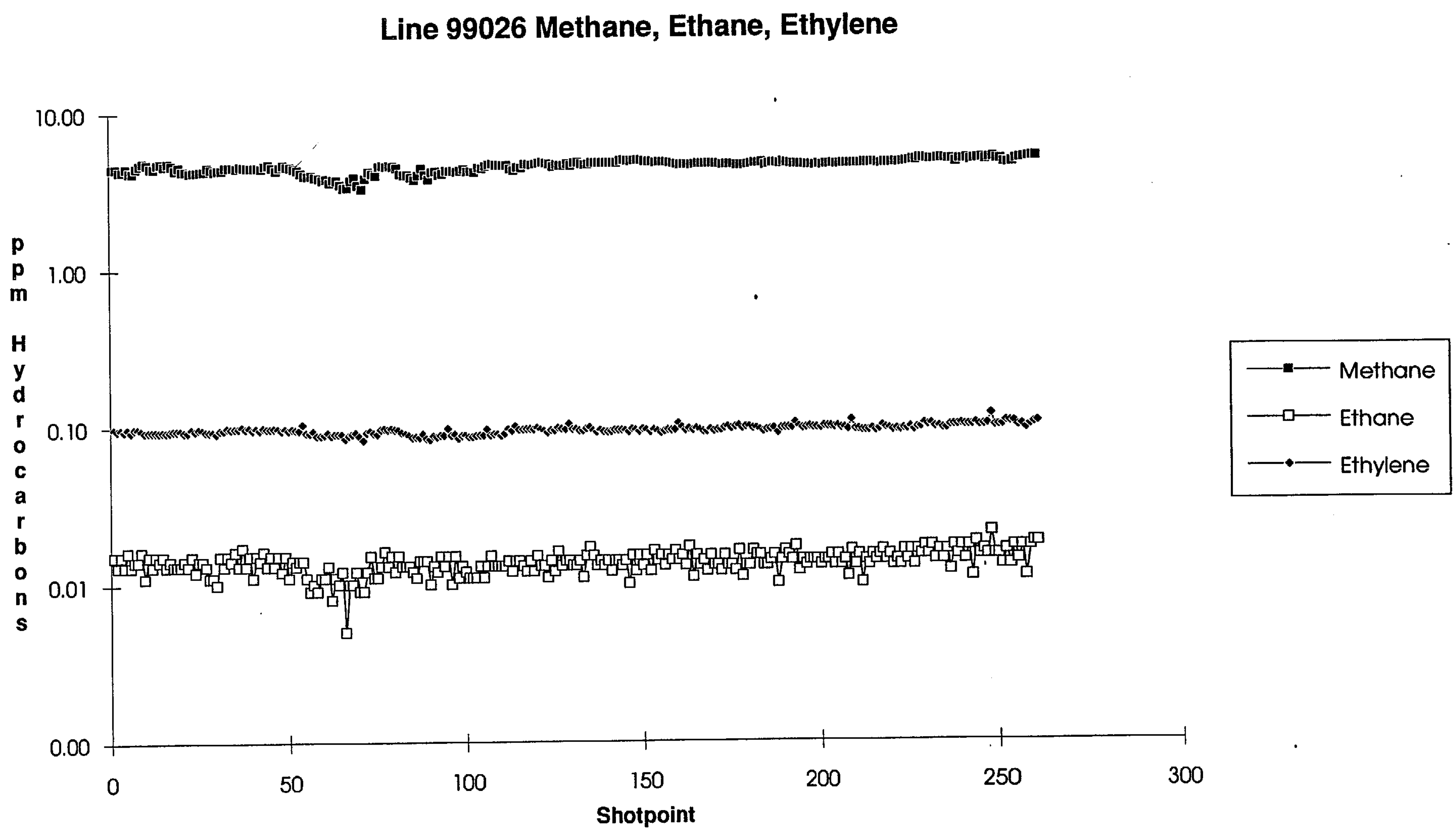
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.923	4.474	0.014	0.094	0.012	0.019	0.000	0.000	0.000	0.060	0.037	0.036	0.562
Std. Dev.	0.672	0.313	0.002	0.004	0.002	0.003	0.001	0.001	0.000	0.037	0.049	0.028	0.072
Minimum	9.015	3.262	0.005	0.082	0.003	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.302
Maximum	11.323	4.972	0.021	0.116	0.016	0.032	0.007	0.023	0.000	0.204	0.211	0.130	1.063

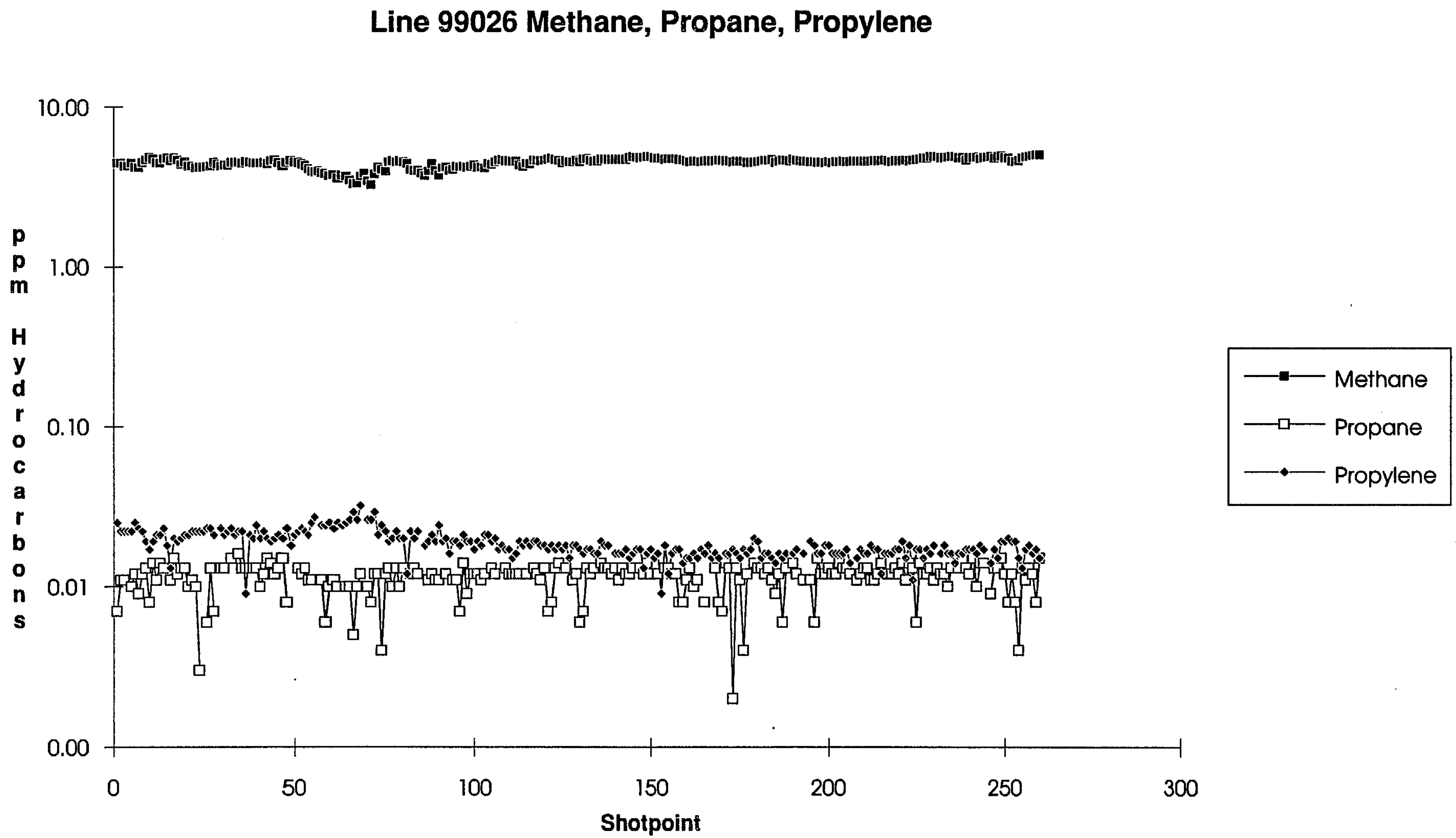
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.777	27.303	77.204	91.953	15.474
Std. Dev.	1.845	1.451	3.570	5.780	5.183
Minimum	58.650	25.600	67.200	76.800	7.400
Maximum	63.310	29.280	83.600	114.600	40.200

Notes
No hydrocarbon anomalies detected.
This line is a resurvey of line 99005.

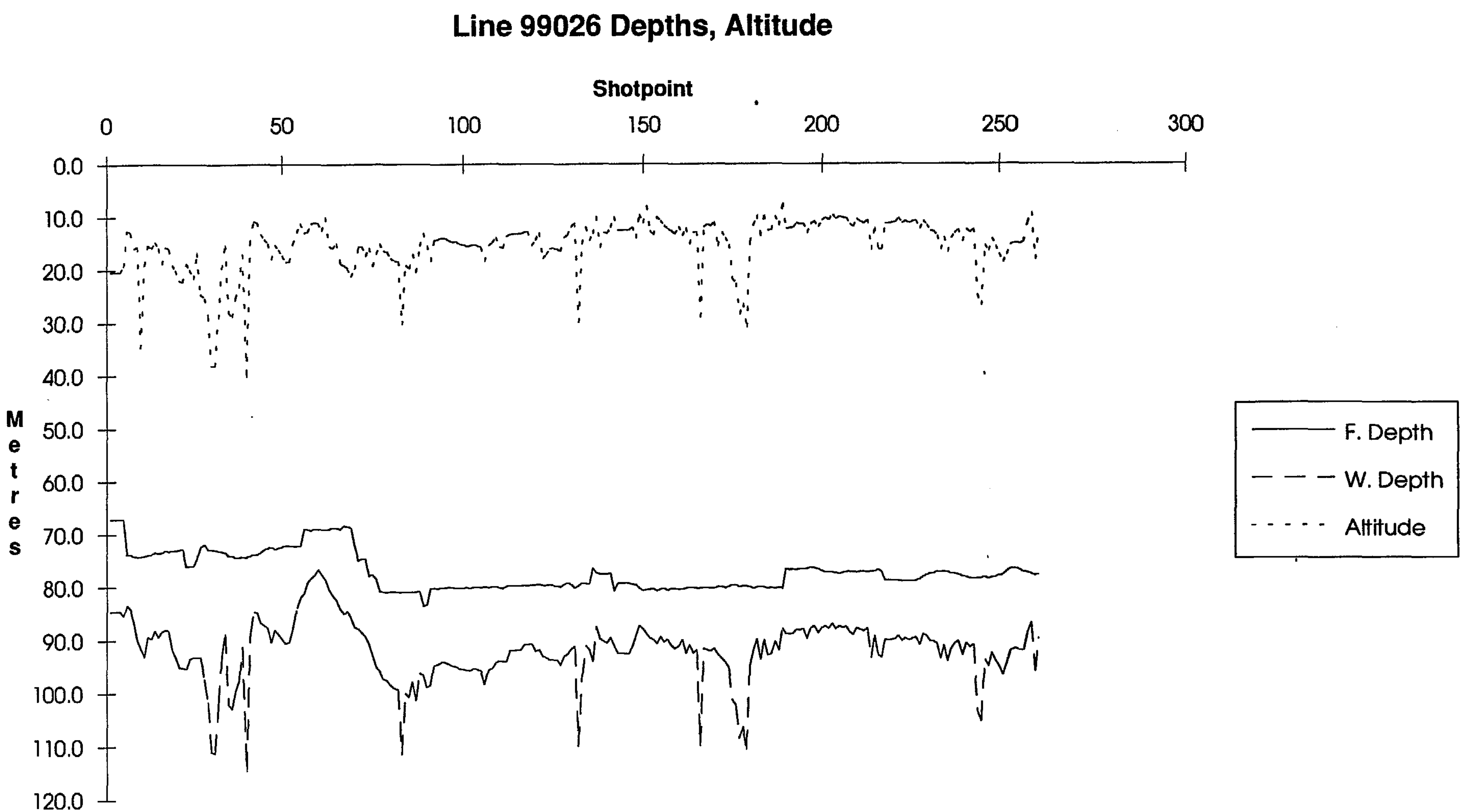


Line 99026 THC, Methane
12.00
10.00
8.00
6.00
4.00
2.00
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
Shotpoint
THC
Methane


Line 99026 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
Shotpoint
Methane
Ethane
Ethylene



Line 99026 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
50
100
150
200
250
300
Shotpoint
Methane
Propane
Propylene



Line 99026 Depths, Altitude
Shotpoint
0
50
100
150
200
250
300
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

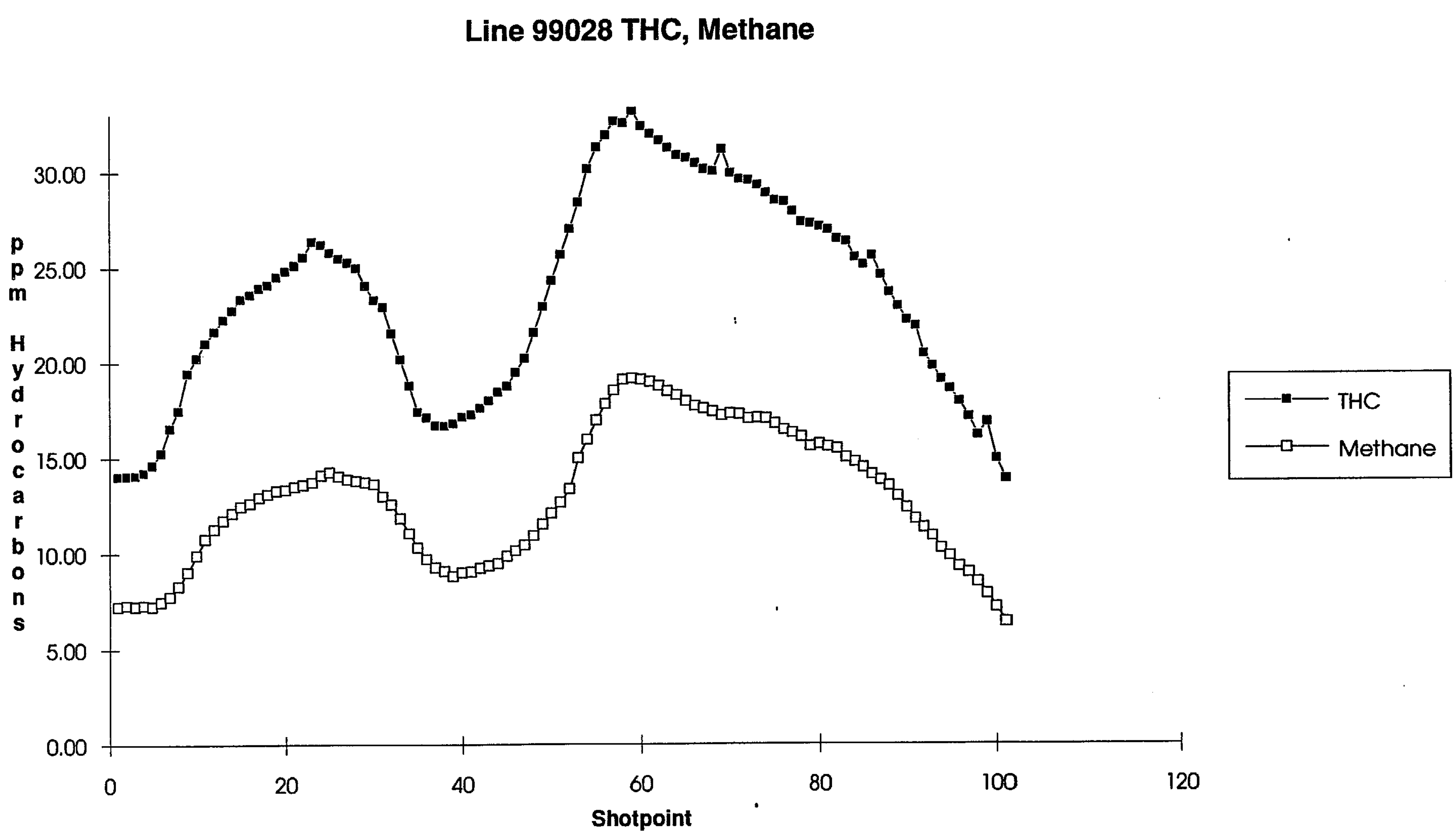
Line Number	99028
No. of Shotpoints	101

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	6-Mar-91	12:47:40	12	47.417	128	42.376
End	102	6-Mar-91	16:18:08	13	00.189	128	30.353

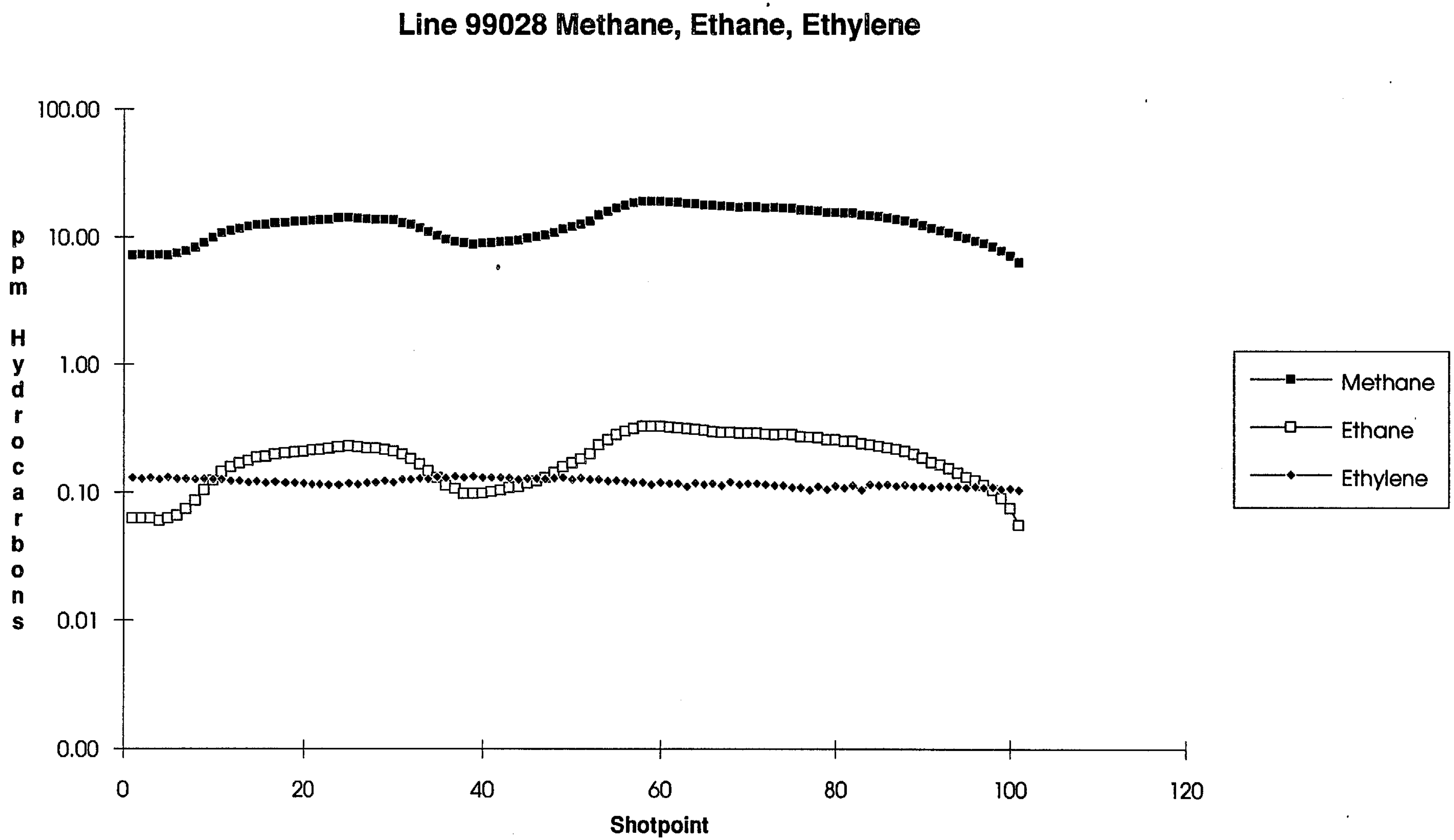
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	23.458	12.890	0.194	0.120	0.044	0.022	0.005	0.008	0.000	0.067	0.002	0.024	1.828
Std. Dev.	5.411	3.521	0.080	0.008	0.014	0.002	0.014	0.021	0.003	0.028	0.006	0.017	0.372
Minimum	13.834	6.364	0.056	0.104	0.015	0.010	0.000	0.000	0.000	0.000	0.000	0.000	1.048
Maximum	33.168	19.141	0.331	0.133	0.070	0.027	0.103	0.164	0.024	0.129	0.036	0.133	3.567

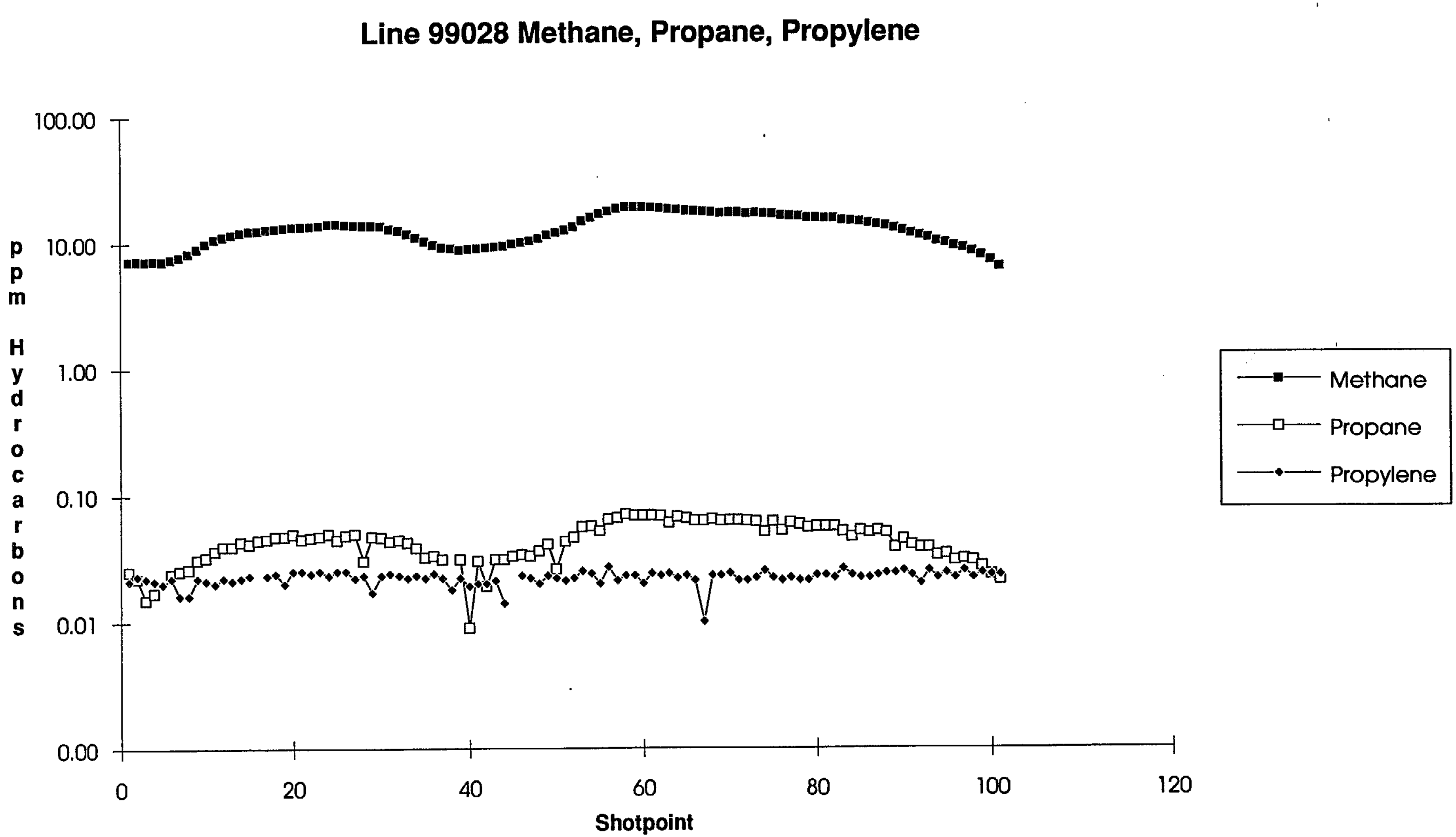
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	60.965	27.036	75.746	86.621	11.500
Std. Dev.	0.042	0.018	1.454	1.010	1.862
Minimum	60.880	26.990	74.100	83.700	7.100
Maximum	61.060	27.090	78.600	90.500	15.000

Notes
Hydrocarbon anomalies are associated with the Petrel gas field

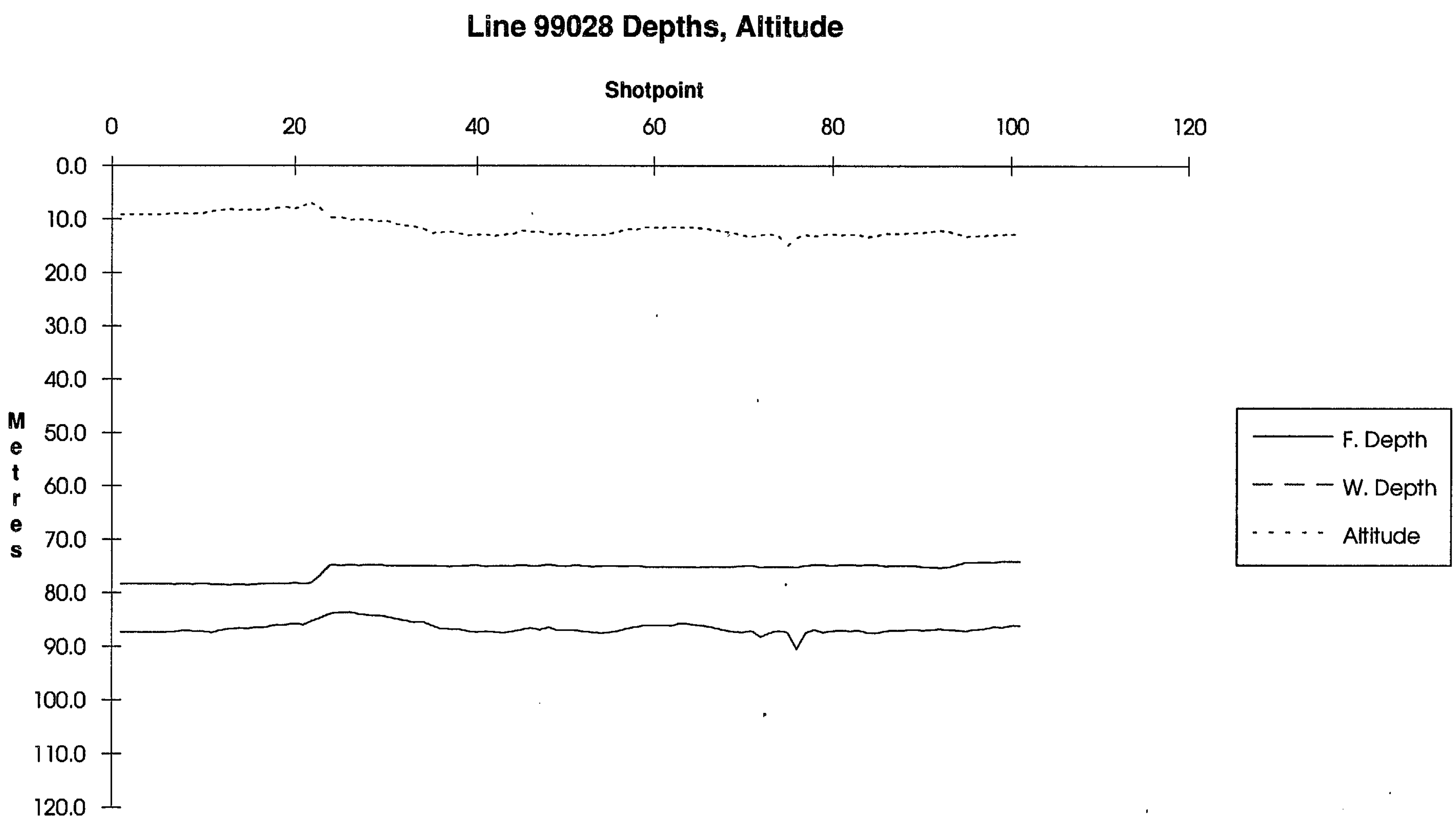


Line 99028 THC, Methane
ppm Hydrocarbons
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
20
40
60
80
100
120
Shotpoint
THC
Methane


Line 99028 Methane, Ethane, Ethylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
Shotpoint
Methane
Ethane
Ethylene



Line 99028 Methane, Propane, Propylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
Shotpoint
Methane
Propane
Propylene


Line 99028 Depths, Altitude
Shotpoint
0
20
40
60
80
100
120
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	99029
No. of Shotpoints	128

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	6-Mar-91	19:04:50	13	03.353	128	41.743
End	128	6-Mar-91	23:22:54	12	42.876	128	34.861

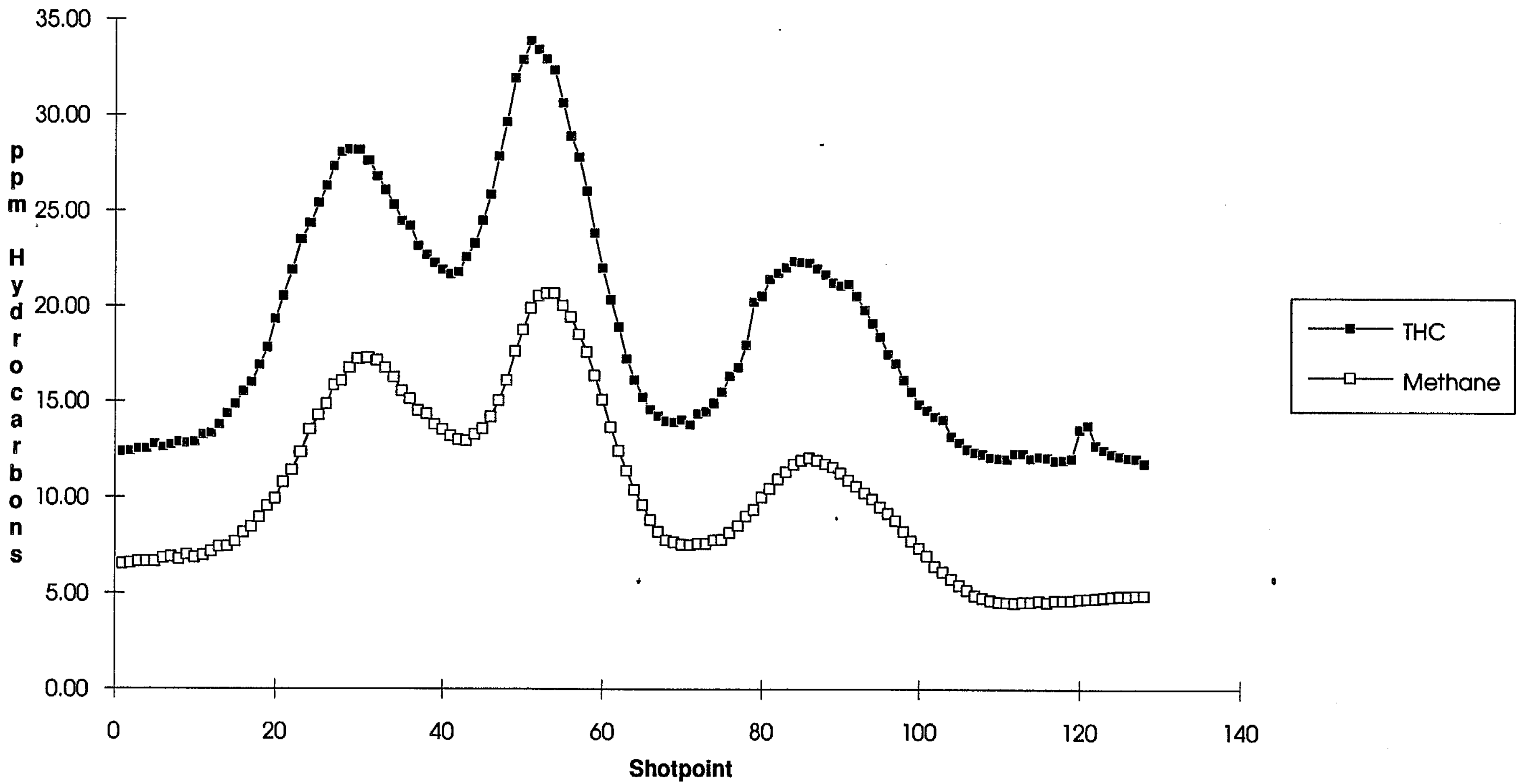
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	18.792	10.222	0.132	0.123	0.034	0.022	0.001	0.003	0.000	0.055	0.009	0.028	1.459
Std. Dev.	6.148	4.540	0.095	0.009	0.018	0.003	0.003	0.009	0.000	0.024	0.021	0.017	0.445
Minimum	11.774	4.489	0.020	0.105	0.009	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.615
Maximum	33.853	20.665	0.382	0.142	0.079	0.031	0.014	0.067	0.000	0.110	0.078	0.064	2.298

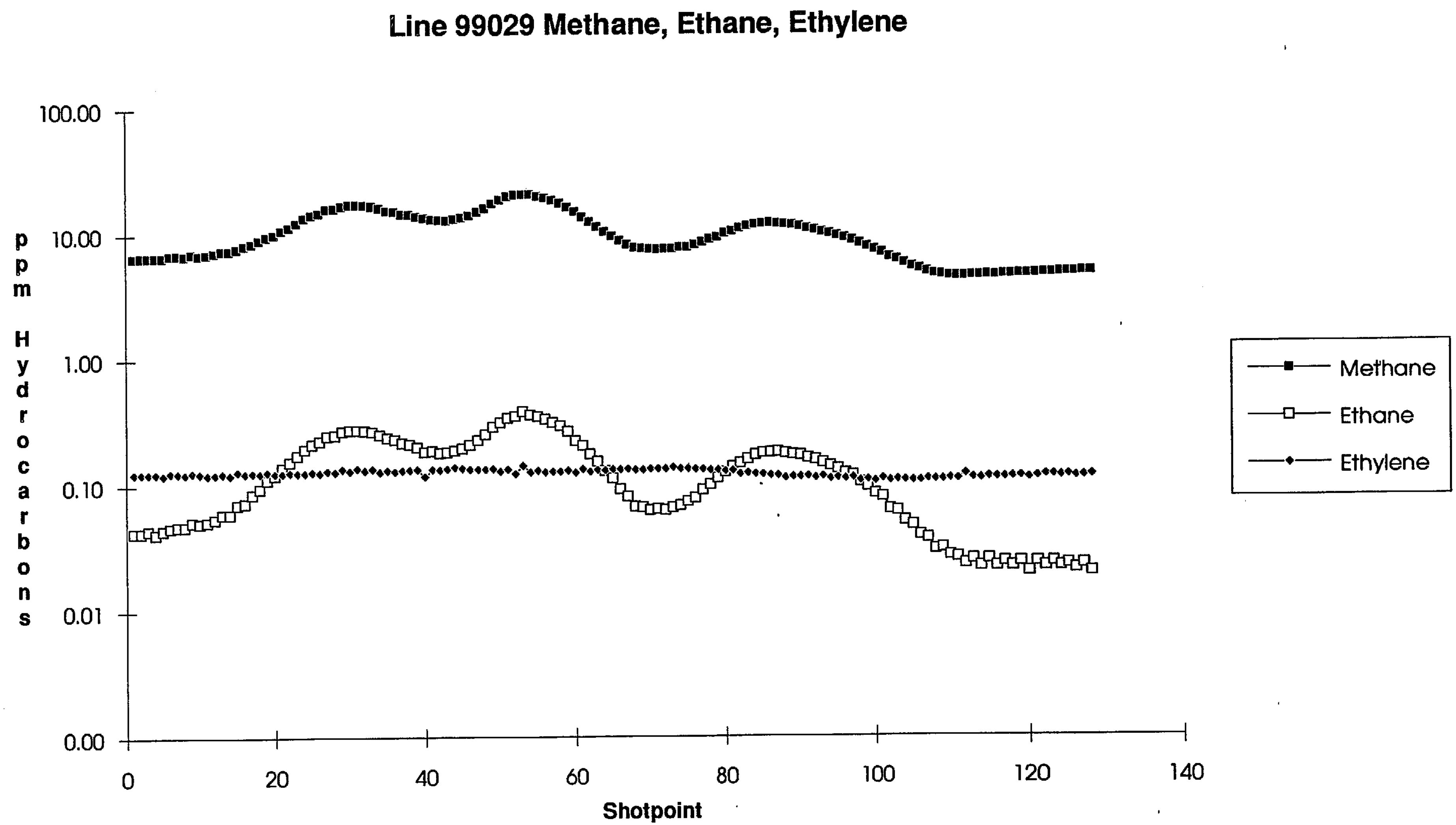
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.134	27.178	73.659	85.995	13.400
Std. Dev.	0.240	0.173	2.682	3.375	0.772
Minimum	60.850	26.980	68.800	80.600	10.800
Maximum	61.830	27.740	79.000	91.700	15.500

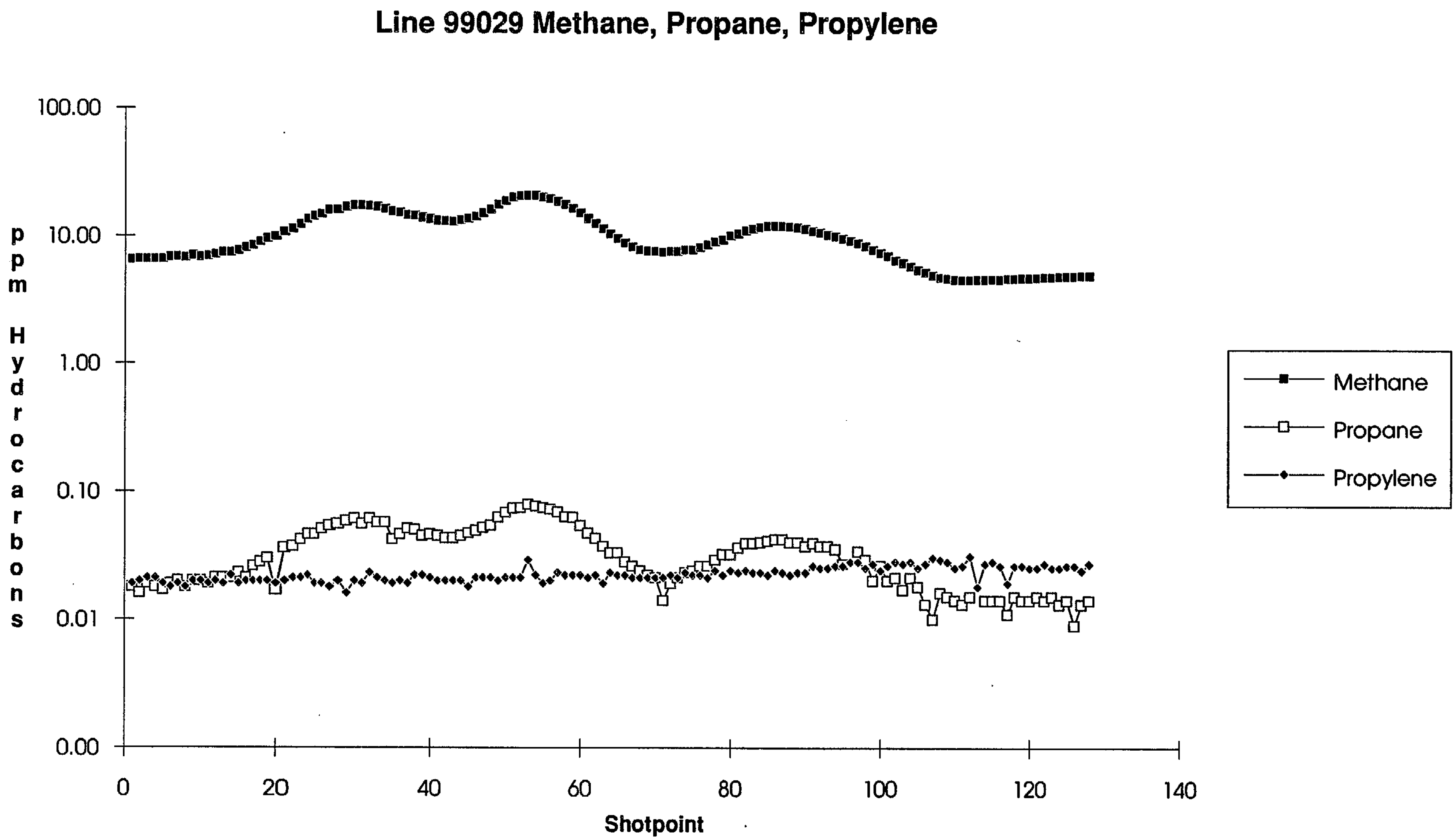
Notes

Hydrocarbon anomalies are associated with the Petrel gas field

Line 99029 THC, Methane

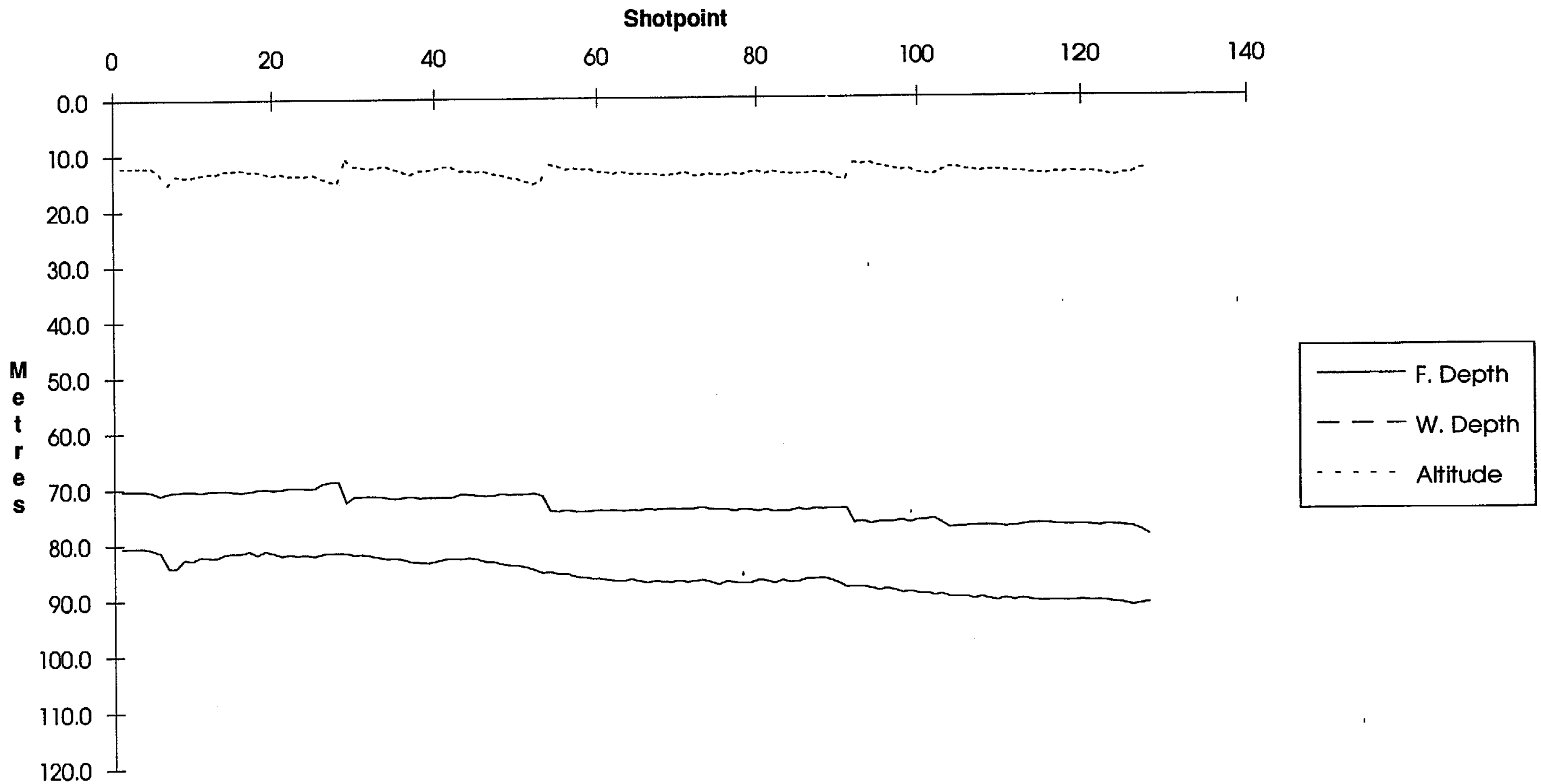



Line 99029 Methane, Ethane, Ethylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Ethane
Ethylene



Line 99029 Methane, Propane, Propylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Propane
Propylene

Line 99029 Depths, Altitude



Line Summary

Line Number	99030
No. of Shotpoints	128

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	7-Mar-91	02:24:35	12	51.566	128	28.653
End	129	7-Mar-91	06:49:12	12	47.405	128	50.651

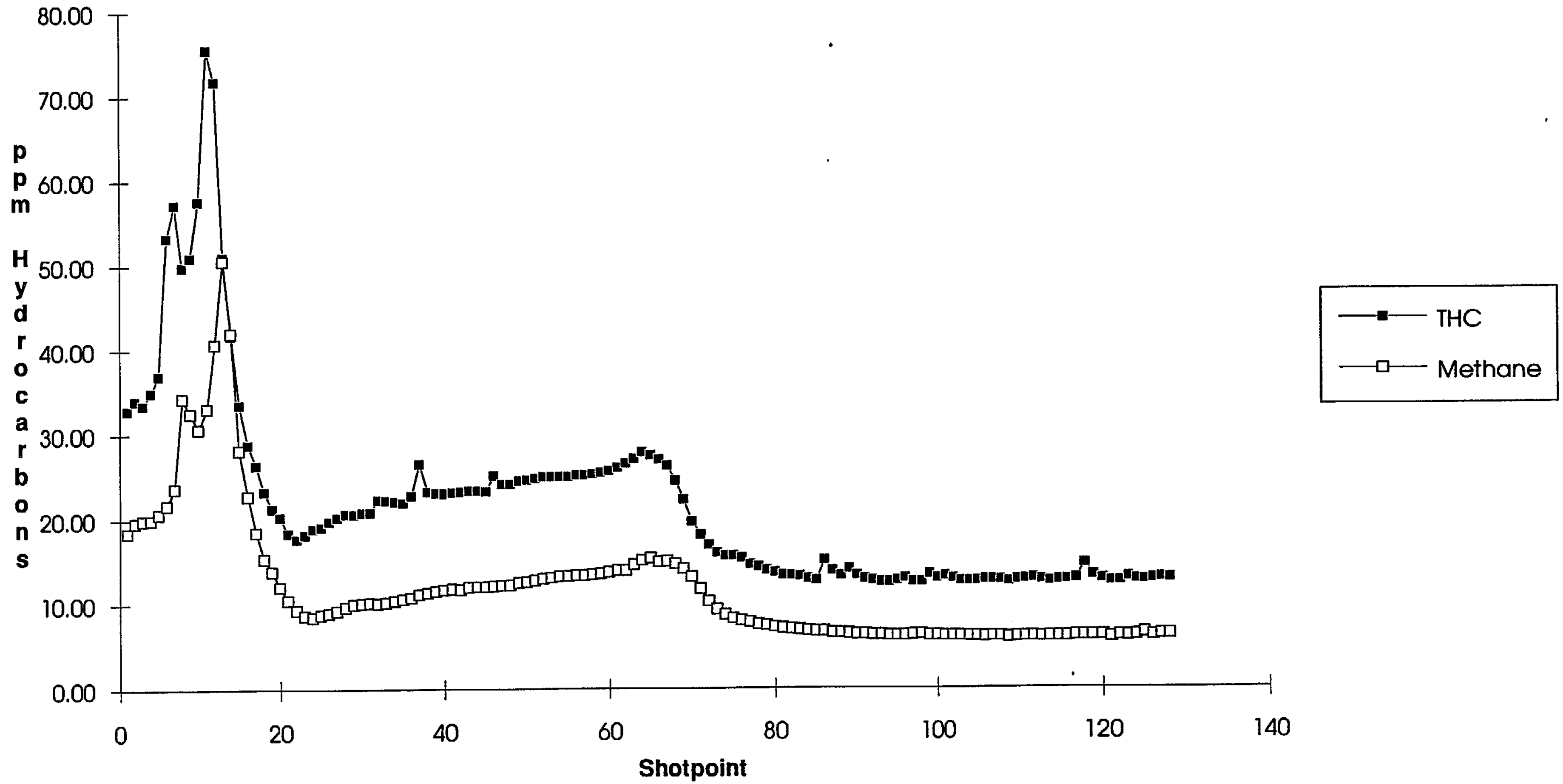
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	21.712	11.766	0.166	0.131	0.040	0.024	0.002	0.004	0.000	0.066	0.032	0.052	1.439
Std. Dev.	11.713	7.815	0.188	0.011	0.033	0.003	0.006	0.009	0.001	0.035	0.058	0.043	0.628
Minimum	12.524	5.950	0.021	0.113	0.006	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.558
Maximum	75.516	50.547	1.089	0.158	0.199	0.037	0.053	0.048	0.005	0.191	0.224	0.178	2.611

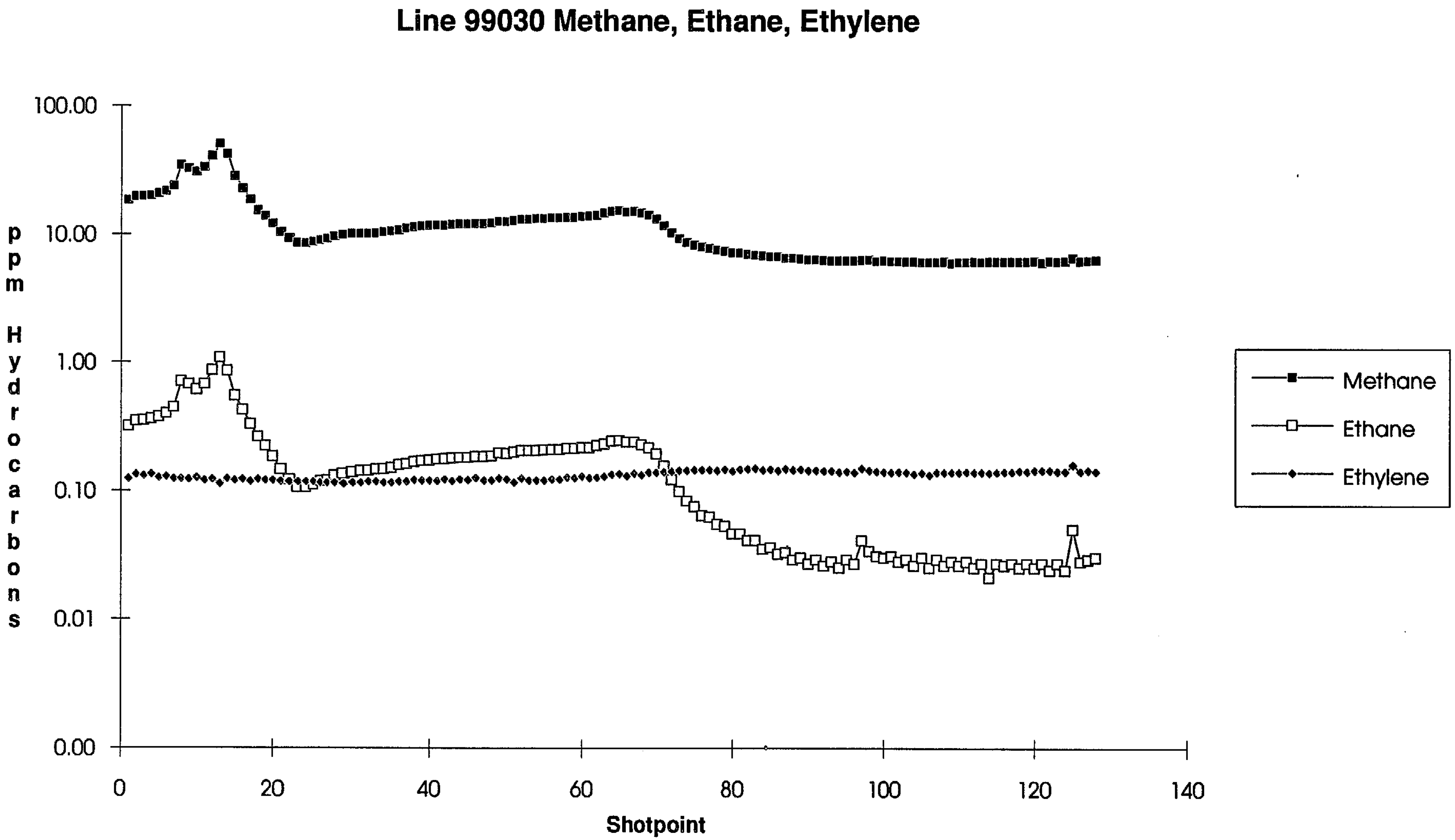
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	64.605	29.876	77.755	86.936	9.502
Std. Dev.	0.229	0.167	2.391	2.882	1.099
Minimum	63.680	29.200	73.700	83.000	6.700
Maximum	64.830	30.070	81.500	95.100	13.300

Notes

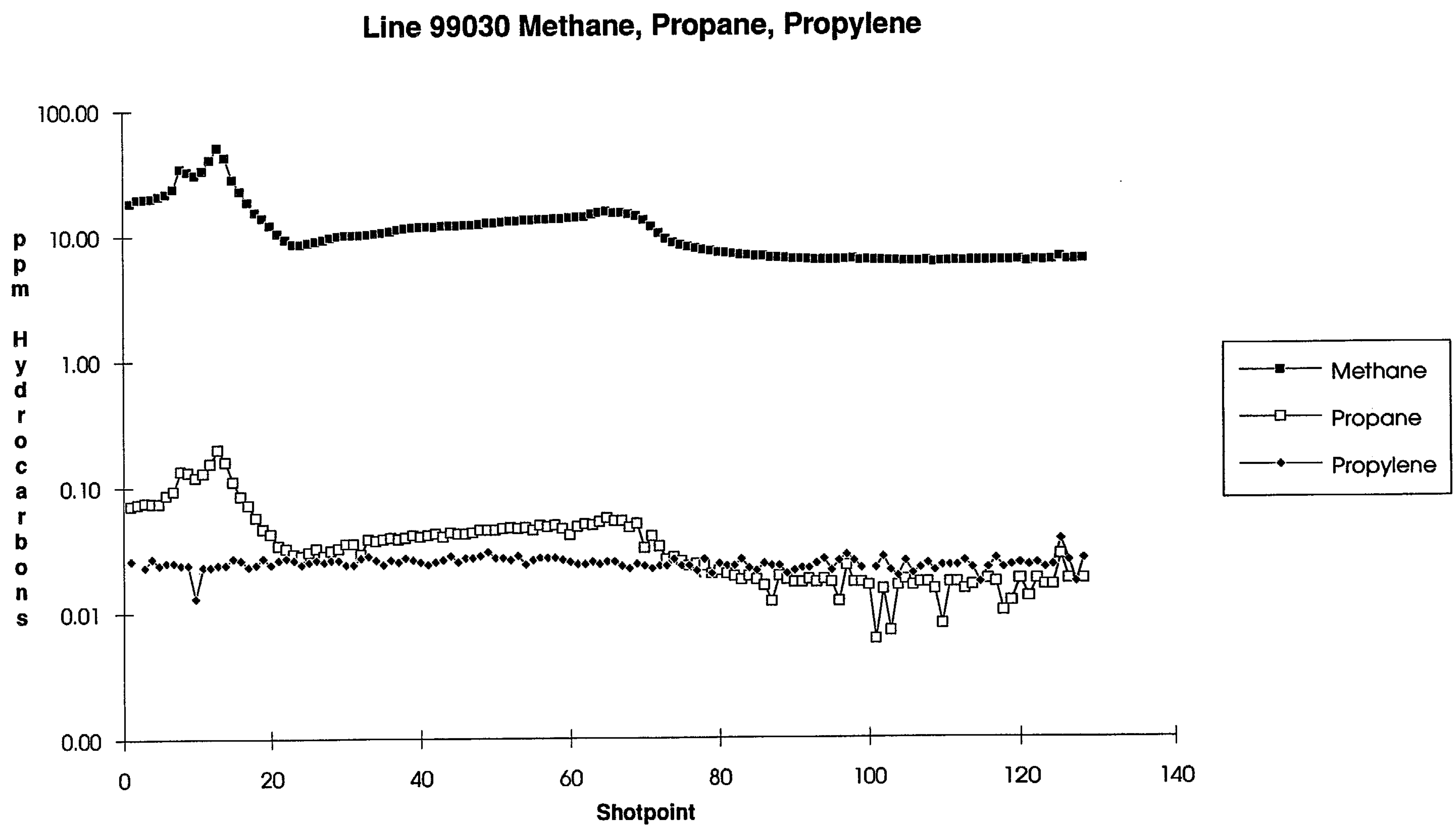
Hydrocarbon anomalies are associated with the Petrel gas field

Line 99030 THC, Methane



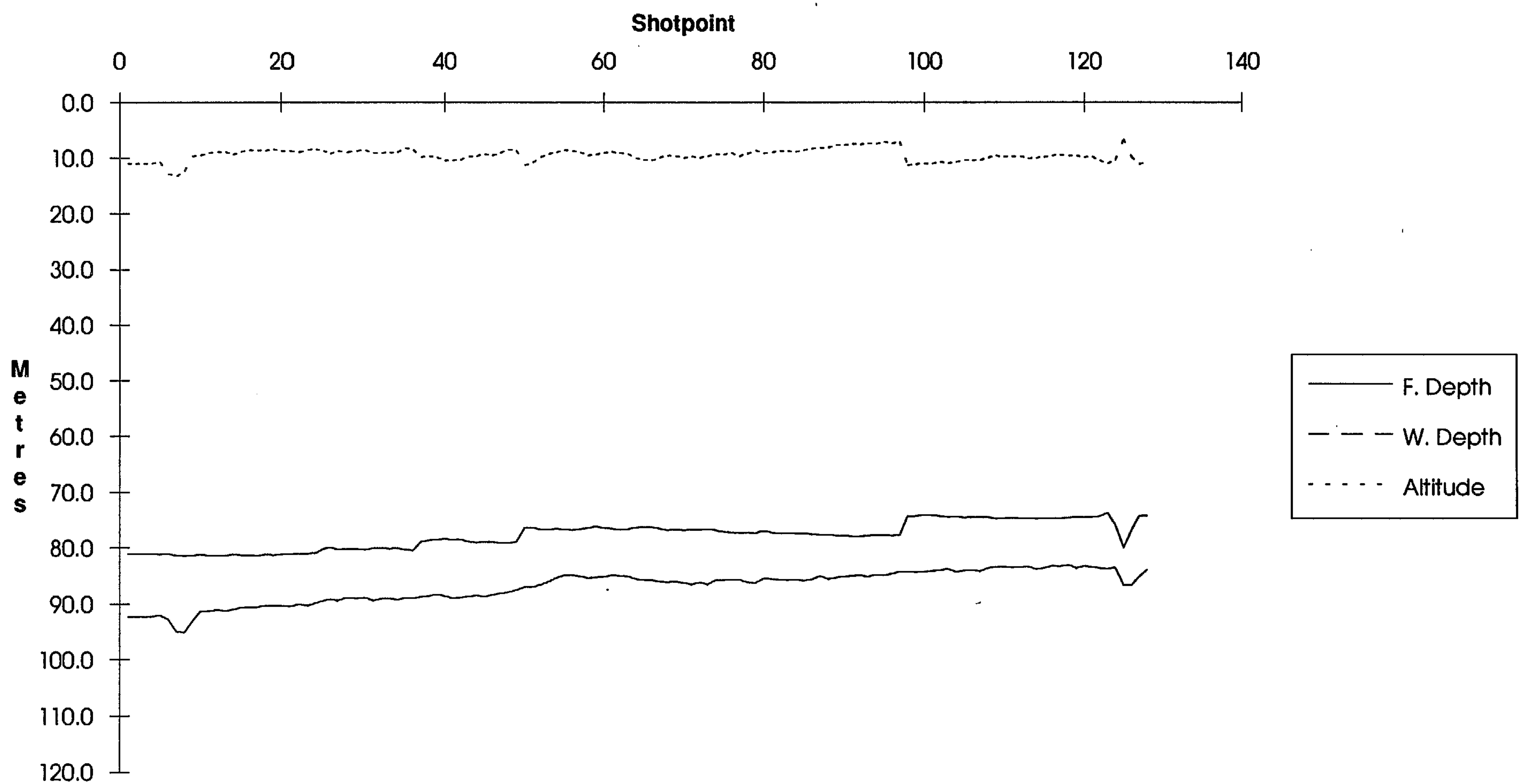


Line 99030 Methane, Ethane, Ethylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Ethane
Ethylene



Line 99030 Methane, Propane, Propylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
140
Shotpoint
Methane
Propane
Propylene

Line 99030 Depths, 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 Mermaid Searcher. Echo sounder data and GPS navigation are displayed in the laboratory and these, together with the side scan sonar, 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

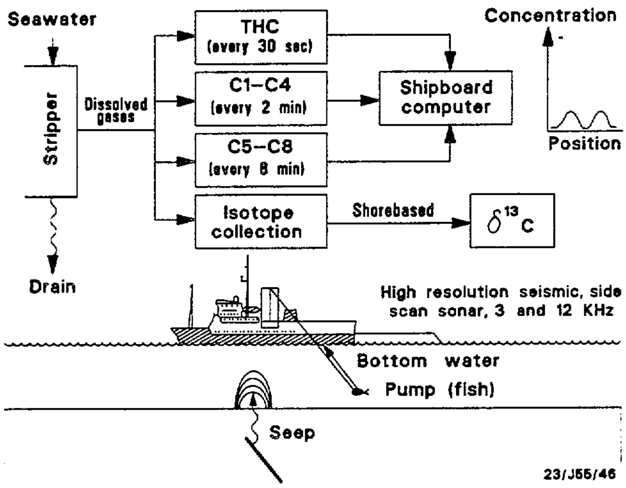


Figure II -1. Schematic of the geochemical equipment aboard Rig Seismic for the continuous profiling of hydrocarbons in seawater: the bottom-water DHD technique.

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 (ie., 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 (eg., 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 (eg., 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 that where methane is plotted versus percent hydrocarbon wetness (wetness % = $[SUM(C_2\text{-}C_4)/SUM(C_1\text{-}C_4)] \times 100$) to delineate seepage. The rationale behind this plot (Figure II-1) is that different hydrocarbon 'sources' eg., 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 ie., 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 (eg., 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 (eg., 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.

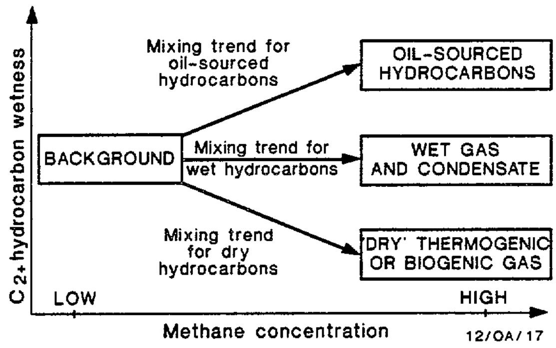


Figure III-1. Cross-plot of methane versus hydrocarbon wetness, showing the general decrease in wetness with increasing methane for gas-prone or biogenic sources. Conversely, oil-prone sources are indicated by increasing wetness with increasing wetness with increasing methane. Gas-condensate sources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

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APPENDIX IV

SYSTEMS OPERATION REPORT

The following is the system report detailed at the time of the cruise.

Background values for hydrocarbons were very similar to those measured on Survey 97, with total hydrocarbons (THC) around 8-10 ppm, methane around 3-5 ppm, and C2 and C3 hydrocarbons in the range 10-100 ppb.

Anomalies - a brief summary of the anomalies detected are given below. With the exception of the seeps in the Tern/Petrel area, there appears to be a general lack of hydrocarbon seepage over most of the survey area.

VP99001 Vertical Profile used to calibrate Druck pressure transducer and test Mesotech altitude sonar.

99001 No ethane (C2) detected until carrier gas change near end of line.

99013 The end-of-line waypoint was a reported seep, however no anomaly was observed.

99014 A large THC anomaly with a maximum of about 11.5 ppm, halfway between the ties with lines 99012 and 99013.

99016 Two small THC anomalies, plus a regional THC anomaly towards the end of the line.

99017 Two interesting seeps on this line - a propane + n-butane anomaly approximately 4-5 miles from the reported seep of line 99013; plus a THC/C1/C2 seep over the Tern gas field.

99018 Geochemically, probably the most interesting line of the survey. The THC/C1/C2 anomaly was repeated over Tern. Further along the line, a C3+C4 anomaly, overlapping a C2 anomaly.

T99019 During the tie line/turn from line 99018 to 99019, a THC/C1/C2 anomaly was detected, approximately 8 miles east of the Petrel gas field, and was later investigated during lines 99028-99030.

99019 No data was collected from 057.0610 onwards due to problems with the pump in the fish.

99020 Pump problems continued - the new pump was contaminating the sampled water, thus data collected on this line is of little use.

99022 Small THC/C1 anomalies near Heron #1.

99023 Small C3+C4 anomaly

99024 This line was a repeat of the last part of line 99017 (so that seismic acquisition could be completed). The THC/C1/C2 anomaly over the Tern gas field was repeated.

99025 The C4 anomaly seen on 99018 was repeated.

DHD

The DHD system comprises 4 principal subsystems: 1) fish/cable/winch, 2) gas extractor, 3) gas analysis, and 4) control and data acquisition. The operational problems are described under these 4 categories.

The only problems which have affected data acquisition and quality are the fish towing/fairing problem, and the sub pump replacement on lines 99/019 & 020.

Fish/cable/winch subsystem

Pump: due to low flow rate, the submersible pump in the fish was replaced while looping during line 99019. Unfortunately. several problems occurred with the new sub-pump, including a motor burnout, electrical short, and hydrocarbon contamination. The result of this was that no data was collected for the rest of line 99019 (057.0610 onwards), and data from line 99020 is very suspect due to the contamination.

Druck pressure transducer: the Druck was initially calibrated from the VP99001 vertical profile and worked well until approximately shotpoint 300 (050.2130, after which it was observed that the indicated depth of the fish was greater than the water depth at the time! The cause of the problem appears to be pressure-related, ie. below a certain depth, the output 'jumps' or becomes non-linear.

Sonar: the new Mesotech altitude sonar was installed in the towfish and tested during the pre-cruise sea-trials, where it worked well. However, once the survey had commenced, it was observed that the sonar often over-ranged, producing a noisy signal, and inconsistent altitude figures. A DGH Voltage to RS-232 A/D converter was used to interface the sonar unit to the DHD data acquisition software. The software reads the digitised voltage from the DGH unit approximately 4 times per second, and a simple algorithm was developed and programmed to filter out the noisy values where possible.

Two audible alarms were installed that can be adjusted to sound when the altitude of the fish goes outside minimum and maximum limits. This has proved very useful, particularly in poorly charted areas where there is a lot of variation in water depths.

Overall, the echo sounder has been a success, and a vast improvement (100% !) over the previous system (Koden).

Fairings are used to reduce the drag on the tow cable, such that the desired fish depth/altitude is achieved with the minimum amount of cable deployed. This is necessary for two reasons - firstly to avoid the seismic streamer and guns, and secondly, and more importantly, allows the fish to be raised more-or-less vertically to avoid seabed obstacles.

The fairings are affixed to the tow-cable by folding the one-piece fairing around the cable, and joining the two halves together using two or three plastic fasteners (Christmas trees) and two staples along the trailing edge of the fairing. Bungee cord (elasticised shock cord) is passes through the trailing edge of each fairing to help keep them aligned. In addition, a tab on each fairing fits into a socket on the adjoining fairings to keep them in line.

Gas extractor subsystem

Gas Extractor: generally very reliable, with only routine maintenance required. However, on 3 or 4 occasions, the high level alarm was activated for no apparent reason; this did not affect operations.

Gas Analysis subsystem

Gas Chromatographs

Valve / valve actuator problems were experienced with LHC2 (used for C1-C4 analysis). After several attempts, this problem was cured.

It appears that CIG (Commonwealth Industrial Gases) Darwin's quality control is not as good as it should be, since during the cruise, we discovered that 3 cylinders of 'Instrument Grade' Air and 2 cylinders of 'High Purity' Nitrogen were contaminated, to the extent that we could not use them for the FIDs (air) or carrier gas (nitrogen). The air contamination was not a problem, since we were able to use these cylinders for the pneumatic valve actuators; however, the nitrogen contamination would have caused serious problems had the cruise lasted any longer, since at the end of the cruise, we were using our last 'good' nitrogen cylinder.

Examination of the C2-C4 hydrocarbon data from LHC1 and LHC2 shows noise (ie. poor integration) on a noticeable number of shotpoints (analyses) prior to line 99018. While looping for this line, a number of changes were made to the integrator methods, the result of which has been a significant reduction in poor integration.

The calibration of the chromatographs were checked against a standard gas of known composition (BMR Standard 'C') on a semi-regular basis, typically every 24 hours, during line transits.

Control and data acquisition

The integrators which control the gas chromatographs are themselves controlled by a 286 AT-compatible PC running a program called 'SNIFFER' which was originally developed by TEG. The source code for the program was obtained from TEG, and prior to the cruise and during sea-trials, modifications were made to fix some known bugs, and add some features.

Navigation information is obtained from the DAS system via RS-232. Modifications were made to the TEGW program (on the HP) and the SNIFFER program (on the PC) to obtain extra information including DAS time and water depth. The water depth value was used in conjunction with the fish depth value to give a calculated altitude, which was then available for comparison with the 'true' echo sounder value. The calculated and echo sounder values normally within 2 metres of each other.

One other problem was the failure of our only printer, which until the printer failure was diagnosed, caused the SNIFFER program to run extremely slowly. Fortunately, we were able to use one of the spare printers while our printer was being repaired.

NON GEOCHEMICAL SYSTEMS

GPS navigation was used for 98.24% of the survey, 88% of this in differential mode.
Navigation was acquired using:
GPS System - Magnavox T-Set GPS navigator

Primary Transit System

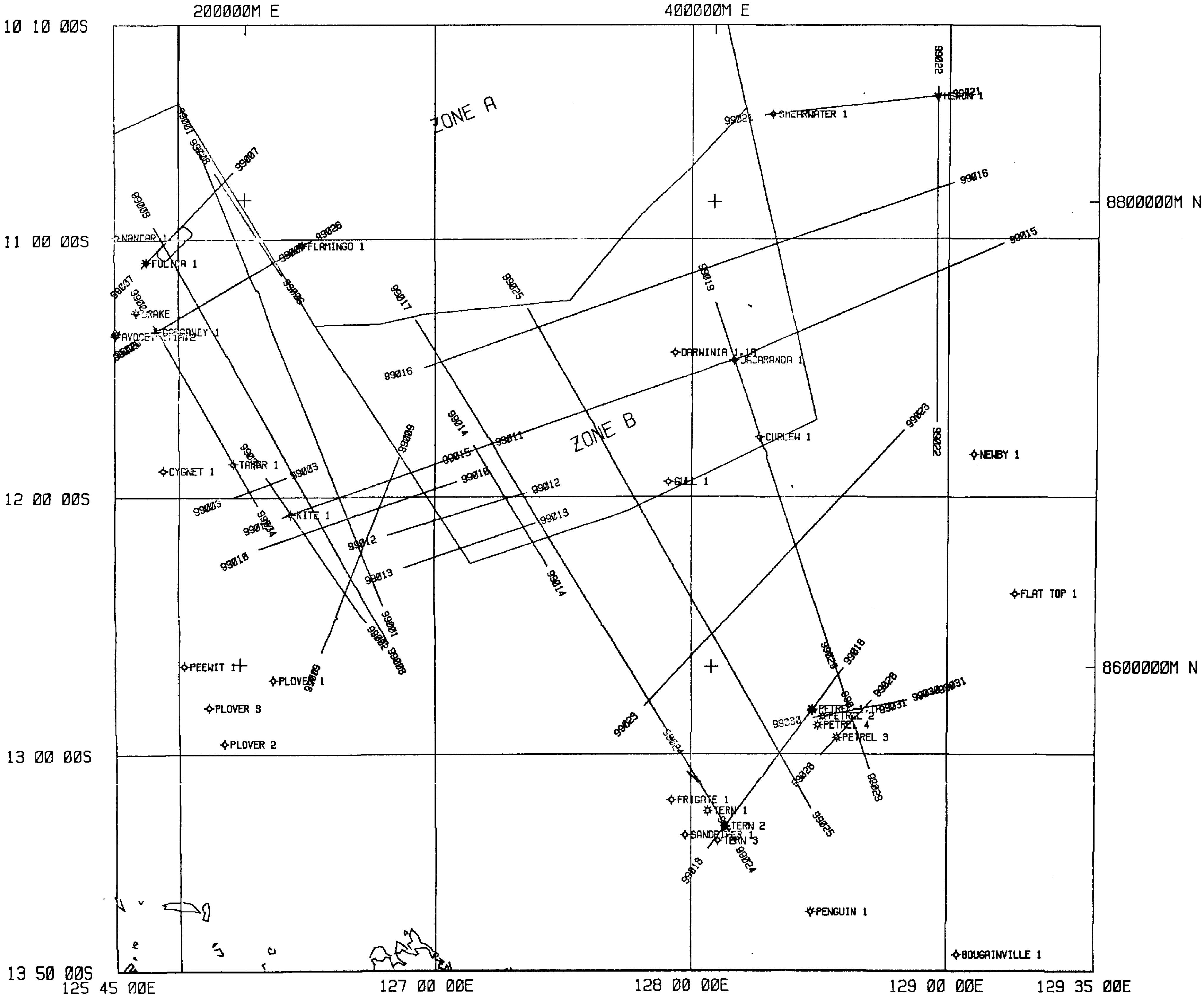
Magnavox MX1107RS dual channel satellite receiver
Magnavox MX610D dual-axis sonar doppler speed log
Sperry gyro-compass

Secondary Transit System

Magnavox MX1142 single channel satellite receiver
Raytheon DSN450 dual-axis sonar doppler speed log
Robertson gyro-compass

BONAPARTE BASIN

R9205004



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KILOMETRES

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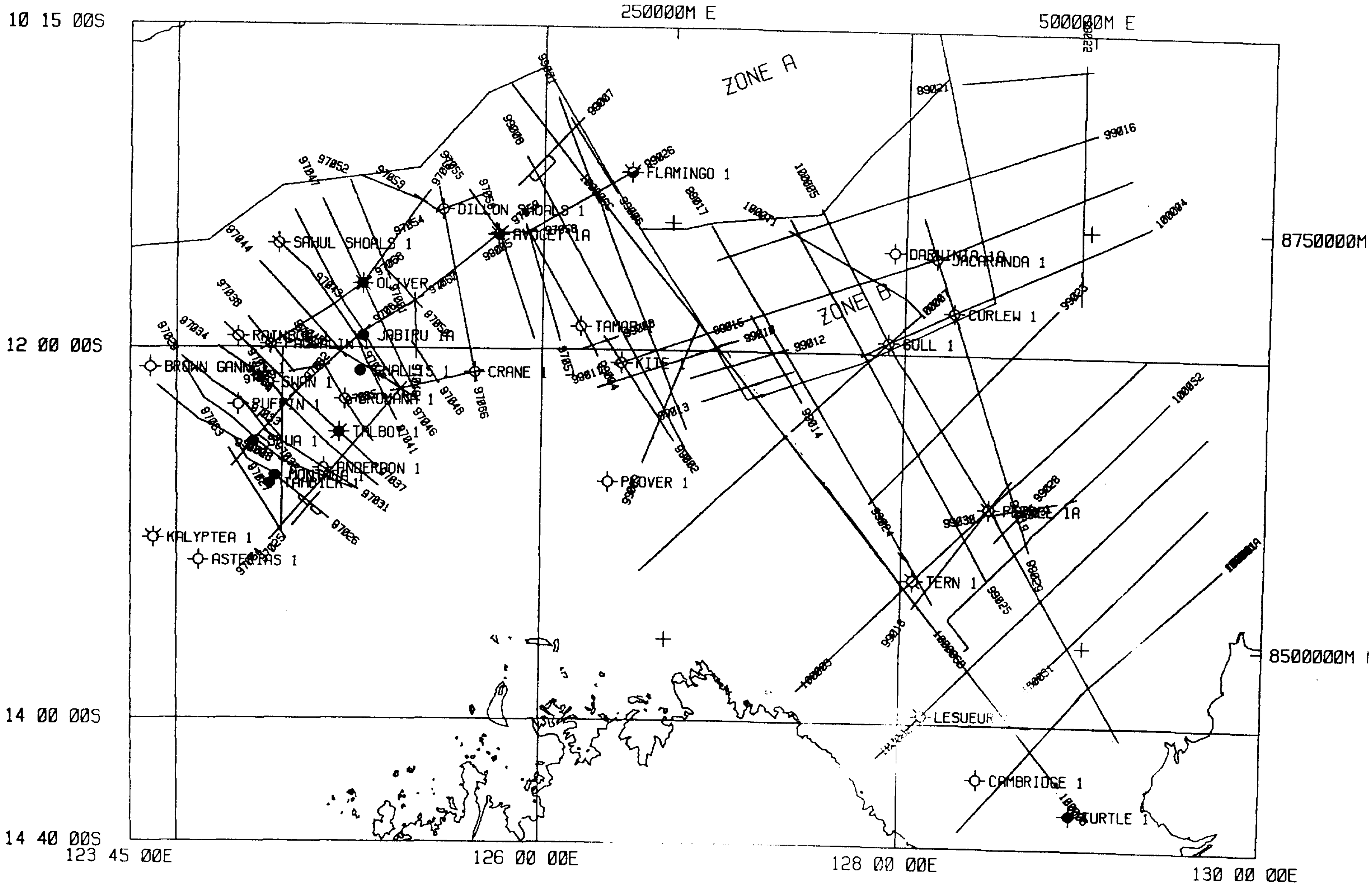
MILES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 129 00 00E

DHD SURVEY LINES
BONAPARTE BASIN SURVEY 99
S4BONA99 7/6/92 J NEEDHAM

BONAPARTE BASIN, VULCAN SUBBASIN



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KILOMETRES

0 20 40 60 80 100

MILES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 129 00 00E

DHD SURVEY LINES		
BONAPARTE BASIN & VULCAN SUB-BASIN SURVEYS 97 99 & 100		
S7VULBON	7/6/92	J NEEDHAM