BMR RECORD 1992/47
LIGHT HYDROCARBON GEOCHEMISTRY OF THE BONAPARTE BASIN, INCLUDING THE SAHUL SYNCLINE, MALITA GRABEN AND SOUTHERN PETREL SUB-BASIN: *RIG SEISMIC* SURVEY 100.

PROJECT 121.22

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Executive Summary

During April and May 1991 the Bureau of Mineral Resources conducted a combined deep crustal seismic and Direct Hydrocarbon Detection (DHD) survey (*Rig Seismic* Survey 100; Figure 1a) in the Bonaparte Basin, which is located in the Timor Sea off north-western Australia. This survey is one of three combined seismic and DHD surveys (Surveys 97, 99 and 100) which have been conducted in the Timor Sea (Figure 1b). Survey 100 collected approximately 2540 line-km of DHD, together with approximately 2100 line-km of deep crustal seismic, gravity, and magnetic data. The DHD data from this survey complements that obtained in the same general area during Survey 99 (Bickford et al., 1992).

Several bottom-water light hydrocarbon anomalies were detected during the survey, mostly in the Petrel Sub-basin. The strongest anomalies were detected over the Petrel gas/condensate accumulation, in the vicinity of the Petrel-1 wellhead. Weak but aerially extensive anomalies were associated with the Tern gas/condensate accumulation.

The Petrel anomalies differed in character from those found over Tern, in that they were strong, up to two orders of magnitude above background, and were confined to a small area. In contrast, the Tern anomalies were weak, generally less than two-fold above background, but extended over a large area.

A cross-plot model of percent hydrocarbon wetness versus methane has been used as a tool to predict the potential 'source' (oil prone, gas/condensate or dry gas) of bottom-water anomalies. The data from the anomalies detected over the Petrel and Tern gas/condensate accumulations show wetness trends from background (less than 1%) to levels of about 3.4%, with increasing methane concentrations up to 272 ppm (over Petrel). The crossplot model trends are consistent with the hydrocarbon compositions in these gas/condensate accumulations.

Several other hydrocarbon anomalies were detected away from exploration wells. These anomalies were typically weak, and usually of gas or gas/condensate 'source' (according to the crossplot model). However, one strong anomaly, detected in the southern Petrel Sub-basin, had a maximum percent hydrocarbon wetness value greater than 16%, and an oil-prone 'source' according to the crossplot model.

Even though the data base is limited, the observation that the stronger anomalies show gas/condensate trends in the southern to northern Petrel Sub-basin and oil-prone trends in the far southern Petrel Sub-basin is consistent with the fact that the far southern Petrel Sub-basin is more oil-prone (e.g. the Turtle and Barnett oil accumulations) than the more northerly areas (e.g. Petrel and Tern). This suggests that the DHD technique is useful on a regional scale of discriminating between gas and oil-prone regions. At a prospect level, the DHD technique detected the Tern gas accumulation. The anomaly over Petrel is more problematical. The Petrel-1 well blew-out during drilling in 1969 and the very sharp and strong nature of the anomaly over the well location may be the result of a leaking well-head or casing. Nevertheless, the survey results show that the DHD technique can detect large gas accumulations in the Timor Sea.

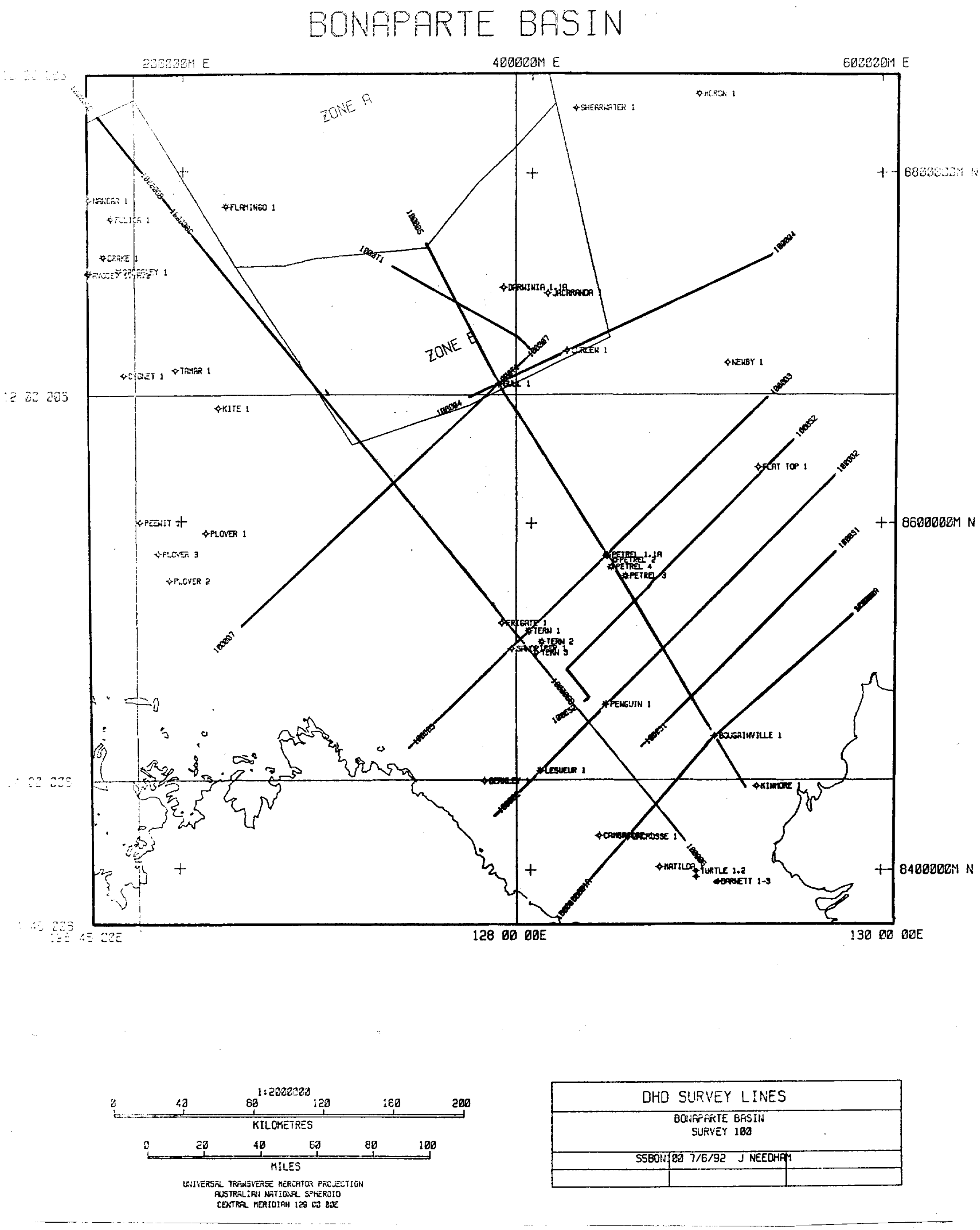

Figure 1a. Map of the Bonaparte Basin area showing the DHD survey lines and selected well locations for BMR Survey 100.

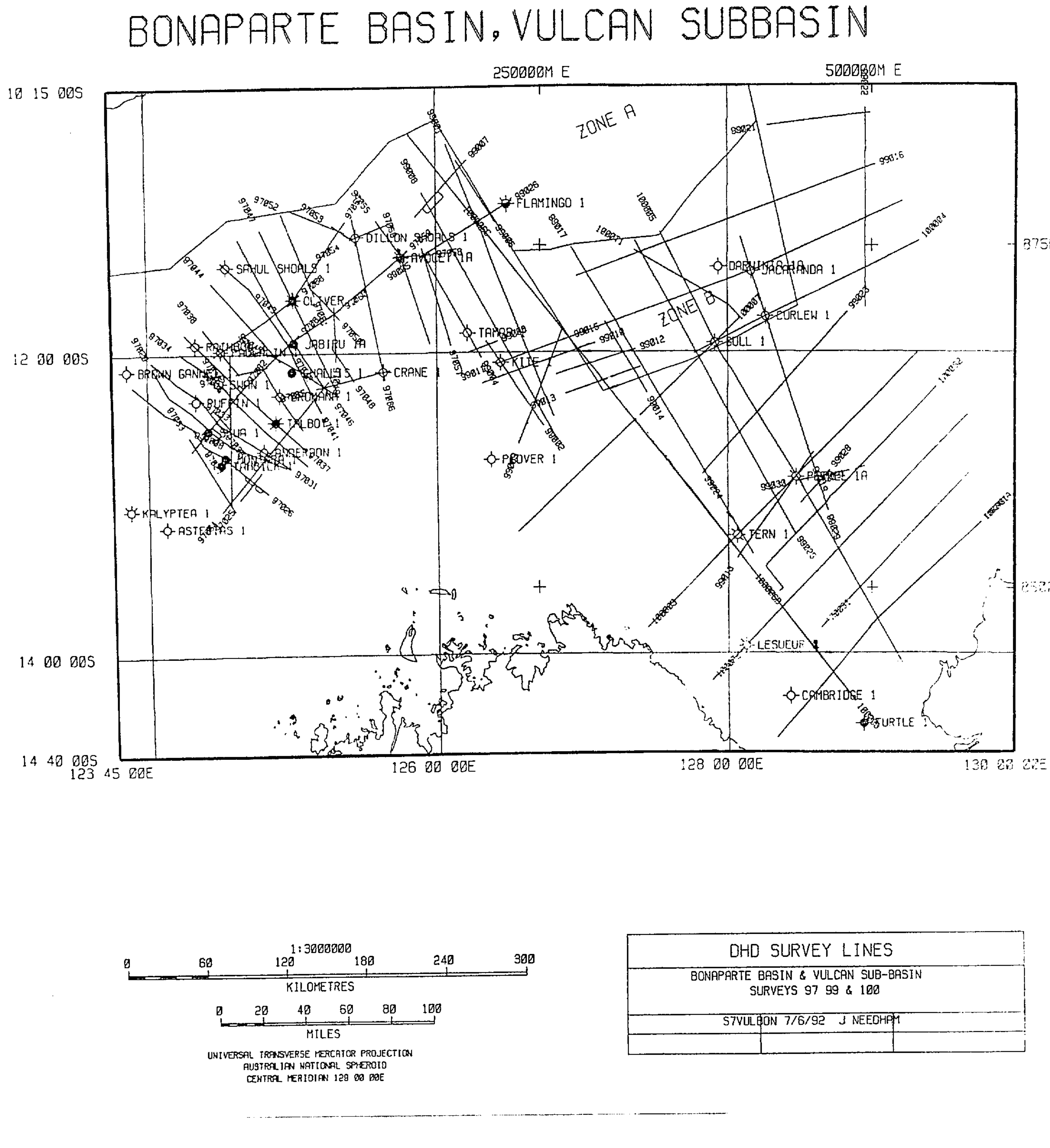

Figure 1b. Map of the Timor Sea showing the DHD survey lines and selected well locations for BMR Surveys 97, 99 and 100.

Introduction

Surface geochemistry and offshore exploration for hydrocarbons

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

Within Australia, the 'sniffer' has been a relatively under-utilised tool in offshore hydrocarbon exploration, with only four surveys being carried out prior to 1988. Those surveys were all located in 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, and a joint Agreement with Transglobal Exploration and 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 program: overall objectives

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

- To collect, via reconnaissance surveys, new information on the thermal generation of hydrocarbons in under-explored Australian basins.
- To test the application of both bottom-water DHD and sediment geochemical techniques to hydrocarbon prospect ('target') evaluations in both known hydrocarbon provinces and frontier basins.
- To test, develop and refine criteria to recognise thermally generated migrated hydrocarbons from background biogenic hydrocarbons in both seawater and sediments.
- To examine the relationship between hydrocarbon generation and migration by relating the surface and sub-seafloor expressions of hydrocarbon seeps to the sub-seafloor geology and probable locations and type(s) of source rocks.
- To relate the chemical and isotopic compositions of seeps to 'source' characteristics, i.e. gas, condensate, liquids, and to predictions from geohistory and maturation modelling of different source rock types.
- To test bottom-water DHD and sediment geochemistry techniques in the search for hydrocarbons sealed by stratigraphic traps.
- To examine the biogenic processes influencing the concentrations, distributions and chemical compositions of hydrocarbon seeps in bottom-waters and the near surface sediments.
- To examine oceanographic dispersal processes of seeps.

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

The geochemical analysis system (Direct Hydrocarbon Detection or DHD) that has been installed aboard the *Rig Seismic* as part of the Agreement is shown schematically in Figure II-1 of Appendix II. The laboratory system analyses a variety of gases extracted from seawater, including 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 Record presents the surface geochemical (DHD) data obtained during *Rig Seismic* survey 100 in the Bonaparte Basin (Figure 1a) during April and early May of 1991. This report presents the DHD data and a preliminary interpretation of the results; other aspects, such as the deep seismic, gravity and magnetics are not dealt with.

Bonaparte Basin: Background And Objectives

Objectives

The geological structures within the Bonaparte Basin reflect multiple periods of rifting and extension which relate to the formation of an initial Palaeozoic rift, later Mesozoic extension, and finally, continental margin formation (Willcox and Ramsey, 1991). In addition, in the northern Bonaparte Basin, geologically recent structural reactivation, due to the interaction of the basin fabric with compressional and strike-slip stresses created by collision between the northern margin of Australia and the Indonesian plate, was probably instrumental in reactivating Mesozoic structural traps and, importantly, facilitating hydrocarbon migration ("spilling") from reservoirs,

The principal objectives of the DHD component of Survey 100 were:

- To investigate hydrocarbon seepage from the Petrel Sub-basin, Malita Graben and Sahul Syncline.

- To conduct DHD calibration surveys over known hydrocarbon accumulations, for example, the Petrel and Tern gas-condensate discoveries.

- To test whether or not surface geochemistry (DHD) could distinguish gas-prone hydrocarbon sources from oil-prone sources, by making comparisons between the southern oil-prone part of the Petrel Sub-basin (around Barnett-1 and -2; Turtle-1 and -2) and the northern gas-prone area (around the Petrel and Tern gas-condensate discoveries).

The Direct Hydrocarbon Detection (DHD) data was collected simultaneously with the deep crustal seismic data, thereby allowing geochemical anomalies to be related to sub-seafloor geology. In view of the possibility of flushing oil from reservoirs along the margins of the Sahul Syncline and Malita Graben with gas generated from source rocks which are now overmature, it was hoped that the DHD data would help to establish the nature and migration pathways of the hydrocarbon charge emanating from the Sahul Syncline and Malita Graben at the present day.

DHD Results

Overview

Survey 100 was carried out in the Bonaparte Basin during April and early May 1991 using the R.V. *Rig Seismic*. During the survey, a total of approximately 2540 km of DHD data was acquired. Of this, 2090 km were collected concurrently with deep-seismic and gravity data along seven lines (100/001 to 100/007). An additional 350 km of DHD data were acquired along two 'DHD-only' lines run in the southern Petrel Sub-basin (Lines 100/S1 and S2), and 100 km of DHD data was recorded during a seismic test line (100/T1), run across the Malita Graben. When transits were made between seismic lines and during maintenance of the seismic acquisition system, the collection of DHD, gravity and magnetic data usually continued, although the DHD data has not been reported here. Of the ten deep-seismic/DHD lines planned for the cruise, the seven lines with the highest priority (100/001 to 100/007) were completed (Willcox and Ramsey, 1991).

The following section briefly presents the results obtained during the survey on a line-by-line basis. A number of data plots, which summarise the salient points of each line, are also included. The complete set of results for the entire survey are given in Appendix I, and include:

- Line summary sheets, which summarise the light hydrocarbon statistics and characteristics of each survey line,
- Charts showing the distribution of the C_1 to C_3 hydrocarbons (and tow-fish depth) along each survey line,
- Floppy diskettes containing the survey data in an ASCII format (Enclosure 2).

Full details of the acquisition methods used and the interpretative methodologies employed are given in Appendices II and III. An explanation of the classification scheme used in describing the anomalies is given in Appendix III.

In the following discussion the line summary plots have been grouped and discussed as follows:

1. Southern Petrel Sub-basin: survey lines 100/001 through 100/003, including 100/S1 and 100/S2 (Figures 2a-m).

2. Northern Petrel Sub-basin, near the boundary with the Malita Graben: survey lines 100/004, 100/007 and 100/T1 (Figures 3a-m).
3. Strike lines linking the Malita Graben with the southern Petrel Sub-basin (100/005), and the Sahul Syncline with the southern Petrel Sub-basin (100/006) (Figures 4a-m).

Background values for hydrocarbons were very similar to those measured on Cruises 97 and 99 (Vulcan-1 and Bonaparte-1), with total hydrocarbons (THC) around 8 to 10 ppm, methane around 3 to 5 ppm, and C_2 and C_3 hydrocarbons in the range 0.01 to 0.1 ppm. Butane levels were generally below the detection limit of 0.005 ppm.

The anomalies found during the survey are summarised in Table 1, and show the survey line number, the light hydrocarbon maximum concentrations, and approximate location (e.g. proximity to exploration well location, etc.).

Line	THC	Methane	Ethane	Propane	Butanes	Wetness	Notes
100/001A	11.82	3.31	0.014	0.067	0.563	16.3%	
100/003	~10.00	~5.00	~0.035	~0.015	<0.010	~1.00%	Regional anomaly over Tern
100/003	40.33	24.89	0.522	0.101	0.061	2.66%	Petrel-1
100/004	19.78	8.54	~0.015	~0.012	<0.010	~0.50%	East of Curlew-1
100/005	14.06	6.68	0.116	0.032	<0.010	2.27%	North of Gull-1
100/005	393.81	272.82	6.852	1.049	0.385	3.40%	Petrel-1
100/006	~15.00	~9.00	0.113	~0.025	~0.015	1.54%	Regional anomaly west of Tern
100/007	13.67	7.72	0.079	0.023	<0.010	1.37%	
100/007	~11.00	~6.00	~0.020	0.028	0.050	1.55%	
100/T1	~11.00	~6.00	~0.025	~0.012	<0.010	~0.60%	
B'ground	8 to 10	3 to 5	~0.020	~0.010	<0.010	~1.00%	

Table 1. Summary tables of survey 100 DHD bottom-water anomalies and typical background hydrocarbon concentrations in parts per million (ppm). Values prefixed by '~' are average values, indicating that no well-defined maximum concentrations were observed. Butane concentrations prefixed by '<' indicate values below the detection threshold of 0.005 ppm per component.

Southern Petrel Sub-basin (Lines 100/001 through 100/003)

Several light hydrocarbon anomalies were detected on these survey lines. The most distinctive anomaly in total hydrocarbons (THC) and sum C_1-C_4 hydrocarbons was found on survey Line 100/003 which corresponds with the transit over Petrel-1. This anomaly had THC, sum C_1-C_4 and methane concentrations about five-fold above background (Figures 2a-c). Ethane (Figure 2d), and propane (Figure 2f), showed about an order of magnitude increases above background, while total butanes (iso-butane plus normal-butane, Figure 2h), showed a small increase above background. The anomaly over Petrel-1 was also evident in the ratio of C_1/C_2 (Figure 2j), the ratio C_2/C_3 (Figure 2k), and the Bernard parameter (Figure 2l), and a small increase in percent hydrocarbon wetness (from background values of <1%) to values approaching 3% (Figure 2m).

Another very weak anomaly in sum C_1-C_4 hydrocarbons, methane and ethane was detected on Line 100/003, almost insignificant relative to other typical variations in these hydrocarbons, but the anomaly is associated with Tern-1 and the Tern gas-condensate accumulation. While weak this anomaly could be detected over approximately 50 line-km (Figures 2a-d).

A significant anomaly was detected on survey Line 100/001A. This anomaly was composed of significant increases in butane (up to about fifty-fold background concentrations, Figure 2h), with moderate increases in propane (Figure 2f). These significant increases in concentration were detectable over about 5 km, approximately half-way between Bougainville-1 and Lacrosse-1 (Figure 1b). This anomaly showed a marked increase in wetness values up to 16% (Figure 2m).

The locations of the light hydrocarbon anomalies mentioned above are associated with regional minima in the ratio of C_1/C_2 (Figure 2j), regional highs in C_2/C_3 (Figure 2k) and regional minima in the Bernard parameter (Figure 2l). The most prominent anomaly in the C_1-C_3 hydrocarbons produced the most distinct variation in these parameters, but the most prominent anomaly in C_3 and C_4 hydrocarbons produced the most distinct variation in wetness values (Figure 2m).

A brief description of the individual survey lines is presented below.

Line 100/001:
High levels of total hydrocarbons (THC) were recorded at the start of the line. These values decreased gradually during the line, and were probably caused by minor contamination from reterminating the tow-fish prior to the start of the survey. No anomalies were recorded over either the Bougainville-1 or Lacrosse-1 wells, although between the two wells, a weak butane anomaly was recorded, approximately 3 times typical background concentration.

Line 100/001A (re-shoot of Line 100/001):
The results obtained on this line were broadly similar to the results recorded on Line 100/001, however a strong butane anomaly, with moderate propane, was recorded in the same area as the weak butane anomaly on Line 100/001. Normal-butane concentration reached 0.387 ppm, approximately 80 times background, iso-butane reached 0.176 ppm, approximately 35 times background, and propane reached 0.067 ppm, approximately 7 times background (Figure 2m).

Line 100/S1 (DHD-only line):
No anomalies were detected on this line.

Line 100/002:
Slightly anomalous (just above background) concentrations of methane and ethane were detected between the Lesueur-1 and Penguin-1 wells. Slightly anomalous concentrations of ethane also occur before the Lesueur-1 well.

Line 100/S2 (DHD-only line):
A very weak THC, methane, ethane, propane and sum C_1-C_4 anomaly was detected towards the western end of the line (concentrations of sum C_1-C_4 hydrocarbons increase from less than 6 ppm background to greater than 7 ppm).

Line 100/003:
A moderate to strong C_1-C_4 anomaly was detected over Petrel-1. The maximum recorded values were: THC 40 ppm (4 times background), methane 25 ppm (6 times background), ethane 0.52 ppm (16 times background), propane 0.101 ppm (7 times background), and normal-butane 0.04 ppm (8 times background).

In addition, a very weak increase in methane concentration (from 4 ppm background to 5 ppm) was observed from shotpoint 100 to shotpoint 300 (approximately), immediately to the west of Tern-1.

Northern Petrel Sub-basin, near the boundary with the Malita Graben (Lines 100/004, 100/T1 and 100/007)

On these three survey lines, four weak anomalies were detected. A weak THC and sum C_1-C_4 anomaly (predominantly methane), with traces of ethane and propane was found on Line 100/004 (Figures 3a-3h). One very weak sum C_1-C_4 (predominantly methane) anomaly was detected on Line 100/T1. Two weak anomalies were detected on Line 100/007. The first anomaly on Line 100/007 was detected 15 km to the southwest of the Gull-1 exploration well, and continued southwest over a distance of 60 km. This anomaly comprised methane increasing from background levels of less than 5 ppm to greater than 7 ppm, accompanied by significant (approximately four-fold) increases in ethane and trace amounts of propane; no butanes were detected (Figures 3a-3h). This anomaly was reflected in minima in the C_1/C_2 ratio (Figure 3j), an increasing C_2/C_3 ratio (greater than 3, Figure 3k), a decreasing Bernard Parameter (less than 100, Figure 3l), and increases in wetness from background levels of less than 0.5% to greater than 1.0% (Figure 3m). The second anomaly on Line 100/007 was detected further to the southwest, with trace increases in methane, approximately 2-3 fold increase in propane, and significant, but scattered increases in butanes (Figures 3a-h). This anomaly was not aerially extensive, but showed significant increase in wetness values above background (Figure 3m).

A brief description of the individual survey lines is presented below.

Line 100/004:
A weak THC and methane anomaly (2 times background) was observed to the east of the Curlew-1 well, although no anomaly occurred over the well itself. No anomaly was observed over the Gull-1 well.

Line 100/T1 (seismic test line) :
A very weak sum C1-C4 anomaly detected during first half of line.

Line 100/007:
A weak but extensive THC, methane, ethane and propane anomaly was detected over 200 shotpoints (approximately 60 kilometres), starting 15 km southwest of the Gull-1 well. Ethane values reached 3.5 times background, and THC, methane and propane values were about 2 times background. Further to the south-west, a weak propane and butane anomaly was detected: propane reached 2 to 3 times background, and normal-butane 3 times background.

Strike lines linking the Malita Graben and the Sahul Syncline with the southern Petrel Sub-basin (Lines 100/005 and 100/006)

On these two survey lines two significant anomalies were detected. One of these (on survey Line 100/005) was found over the Petrel-1 well location. This anomaly had THC, sum C_1-C_4 hydrocarbons, and individual C_1-C_4 concentrations increase between 30 to 220 times background (Figures 4a-h).

The other significant anomaly was found on survey Line 100/006 and was associated with the Tern gas-condensate accumulation. In this anomaly THC, sum C_1-C_4 hydrocarbons and methane concentrations increased about two-fold above background, ethane about five-fold, together with trace increases in propane (Figures 4a-h).

The anomalies on both of these Lines are reflected in significant decreases in the C_1/C_2 ratio (Figure 4j), increases in the C_2/C_3 ratio (Figure 4k), and decreases in the Bernard Parameter (Figure 4l). The strong anomaly over Petrel-1 was associated with increase in percent hydrocarbon wetness from background levels of 0.5% to values greater than 3%. The weak, but aerially extensive anomaly associated with Tern showed only minor increase in percent hydrocarbon wetness (Figure 4m).

A brief description of the individual survey lines is presented below.

Line 100/005:
A very strong anomaly over Petrel-1. Maximum recorded values were: THC 400 ppm (33 times background), methane 272 ppm (45 times background), ethane 6.85 ppm (220 times background), propane 1.05 ppm (70 times background), and normal-butane 0.22 ppm (40 times background).

A weak to moderate, aerially restricted (3 shotpoints), ethane and propane anomaly (5 times and 2 times background respectively) was detected about 13 km north-west of the Gull-1 well.

Line 100/006:
A weak but extensive regional THC, methane, ethane and propane anomaly extends from south-west of the Tern field, north-west to the central Malita Graben, for about 800 shotpoints, equivalent to a distance of about 250 km. Ethane values are about 4 times background, other hydrocarbons are about 2 times background. In addition, a localised

moderate strength ethane anomaly, about 8 times background (2 times greater than the regional anomaly) was detected in the vicinity of the Frigate-1 well.

Vertical Profile 100/007

A vertical profile was conducted at the end of Line 100/007 to examine the hydrocarbon distribution through the water column and determine the position of the thermocline and halocline. Figures 5a and 5b are plots of conductivity and methane concentration versus tow-fish depth respectively. The hydrographic data indicate a two-layer water column with a halocline between about 35m to 45m water depth. Methane concentrations are lowest in the surface waters (less than 3 ppm), and are slightly higher in the bottom waters (approximately 4 ppm).

Hydrocarbon 'Source'

To investigate possible 'source' of the observed bottom water anomalies, cross-plots of methane concentration versus percent hydrocarbon wetness, and other selected crossplots of the anomalies were constructed (Figures 6a-e, 7a-e and 8a-e). The rationale for these plots is discussed in Appendix III, and Figure III-I (Appendix III).

Figure 6a is a crossplot of methane versus percent hydrocarbon wetness for Lines 100/001 to 100/003 (southern Petrel Sub-basin). Two clear trends can be seen.

- One trend shows small increases in percent hydrocarbon wetness, from background values of about 1%, to anomalous values of about 2%, with a significant (approximately 5-fold) increase in methane concentrations. The crossplot model indicates that this anomaly trend is derived from a gas/condensate source.

- The second trend visible in Figure 6a shows significant increases in percent hydrocarbon wetness, from background values of about 1% to anomalous values of more than 16%, with no increase in methane concentrations. The crossplot model indicates that this anomaly trend is derived from a liquid hydrocarbon source.

Figures 6c (methane v. propane), 6d (methane v. butanes) and 6e (ethane v. propane) also show two clear trends, confirming the independent sources of these anomalies. The first trend is the anomaly detected over the Petrel accumulation on Line 100/003, a known gas/condensate field (Lavering and Ozimic, 1988). The second trend is the propane/butane anomaly detected on Line 100/001A. This anomaly was situated well away from any known hydrocarbon accumulations, approximately half-way between the Bougainville-1 and Lacrosse-1 wells.

Figure 7a is a crossplot of methane versus percent hydrocarbon wetness for Lines 100/004, 100/T1 and 100/007 (northern Petrel Sub-basin, near the boundary with the Malita Graben). No clear, well-developed trends can be seen due to the limited range of values, although there are indications of two trends. Figure 7b (methane v. ethane) shows these two trends more clearly:

- One trend shows little or no increase in percent hydrocarbon wetness (Figure 7a) or ethane (Figure 7b), with a small increase (less than 2-fold) in methane concentrations. The crossplot model indicates that this anomaly trend is derived from a gas/condensate or dry gas source, however, the trend is not sufficiently developed for a confident interpretation to be made.

- The second trend shows a small increase in percent hydrocarbon wetness (Figure 7a) or ethane (Figure 7b) with a small increase in methane concentrations (both less than 2-fold above 'background'). The crossplot model indicates that this anomaly trend is derived from a condensate or liquid hydrocarbon source, although again, the trend is not sufficiently developed for a confident interpretation to be made.

The first trend of little or no percent hydrocarbon wetness (Figure 7a) or ethane (Figure 7b) increase, with a small methane increase, corresponds to the anomaly observed near the Curlew-1 exploration well. The second trend, of increasing percent hydrocarbon wetness (Figure 7a) and ethane (Figure 7b) with increasing methane corresponds to the first anomaly detected on Line 100/007. This anomaly is situated well away from any exploration wells. The small propane/butane anomaly detected further to the southwest along Line 100/007 has concentrations too low to develop any trends on these crossplots, although the compositional similarity between this anomaly and the propane/butane anomaly detected on Line 100/001A suggests a similar liquid-prone source.

Figure 8a is a crossplot of methane versus percent hydrocarbon wetness for Lines 100/005 and 100/006 (strike lines linking the Malita Graben and Sahul Syncline with the southern Petrel Sub-basin). A clear, well-developed trend can be seen.

- This trend shows an increase in percent hydrocarbon wetness, from background values of about 1%, to anomalous values of about 3%, with a significant (approximately 50-fold) increase in methane concentrations. The crossplot model indicates that this anomaly trend is derived from a gas/condensate source.

Figures 8b (methane v. ethane), 8c (methane v. propane), 8e (ethane v. propane), and to a lesser extent, Figure 8d (methane v. butanes), show strong correlations between the hydrocarbon types, indicating that they are derived from a common source. This trend corresponds to the strong anomaly detected over the Petrel accumulation on Line 100/005, a known gas/condensate field (Lavering and Ozimic, 1988).

Summary

During Survey 100 several bottom-water hydrocarbon anomalies were detected using the DHD system. The strongest anomalies were found over the Petrel gas/condensate accumulation. These anomalies were detected on both crossings of the Petrel field (Lines 100/003 and 100/005), were moderate to strong (hydrocarbon concentrations increasing more than an order of magnitude on Line 100/005), and aerially confined to within 5 to 8 km of the Petrel-1 and -1A well-heads. The crossplot model used to predict hydrocarbon 'source' is consistent with the known composition of the Petrel gas/condensate accumulation.

Other significant anomalies were found near the Tern gas/condensate accumulation, and while these anomalies were generally weak (hydrocarbon concentrations increasing less than 5-fold above background), they were aerially extensive and could be detected on both crossings of Tern (Lines 100/003 and 100/006) for distance of the order of 100 km. The crossplot model used to predict hydrocarbon 'source' is consistent with the known composition of the Tern gas/condensate accumulation.

Two weak anomalies were detected near exploration wells. One anomaly, predominantly methane, and less than 0.5% hydrocarbon wetness, was found to the east of the Curlew-1 well. Another anomaly, predominantly ethane and about 1.2% hydrocarbon wetness, was detected about 12 km to the north of the Gull-1 well. The low hydrocarbon concentrations of both anomalies prevent any confident prediction of their 'source' using the crossplot model.

Three other significant anomalies were detected, none of which were located near exploration wells. Two anomalies were detected to the southwest of the Gull-1 well on Line 100/007. These anomalies were both weak, but had different hydrocarbon compositions. The first anomaly on Line 100/007 was aerially extensive and comprised methane, ethane, and traces of propane. The low hydrocarbon concentrations of this anomaly prevent a confident prediction using the crossplot model, but the model suggests a gas/condensate 'source'. The second anomaly on Line 100/007 was more localised and comprised minor amounts of propane with traces of butanes. The hydrocarbon 'source' of this anomaly could not be determined by the crossplot model. A significant anomaly (moderate increases in propane and strong increases in butanes) was detected in the southern Petrel Sub-basin, approximately half-way between Bougainville-1 and Lacrosse-1. The crossplot model predicts a liquid-prone 'source' for the anomaly.

The DHD technique detected two significant bottom-water hydrocarbon anomalies over the Tern and Petrel gas accumulations. It appears that the broad, relatively subdued anomaly over Tern is the result of natural hydrocarbon seepage from this accumulation, and suggests that within the Timor Sea, DHD may be a useful technique for detection of gas or gas/condensate accumulations. Future DHD calibration surveys over the Sunrise and Troubadour accumulations, which are located immediately to the east of the Zone of Cooperation "A", would provide an additional test of this idea.

The anomaly over the Petrel Field is more problematical, because of the complicating fact that the Petrel-1 well blew out during drilling in 1969. The anomaly over Petrel is very strong, is aerially restricted, and occurs very close to the location of the Petrel-1 well-head, suggesting that this anomaly may result from a leaking well-head or casing. It must be emphasised, however, that the Survey 100 DHD data do not provide definitive evidence that the Petrel-1 well-head is leaking. The Survey 99 data (Bickford et al., 1992), also show strong anomalies over the Petrel field, but the anomalies are far more extensive, and not as "sharp" as the anomalies observed on Survey 100. Furthermore, the maxima of the Survey 99 anomalies are located away from the Petrel-1 well-head location.

The high percent hydrocarbon wetness (greater than 16%), predicted oil-sourced anomaly which was detected in the far southern Petrel Sub-Basin contrasts with the low percent hydrocarbon wetness (about 3%) anomalies which are associated with the Tern and Petrel gas/condensate accumulations. These observations are consistent with the fact that the far southern Petrel Sub-basin is significantly more oil-prone (e.g. the Turtle and Barnett oil discoveries) than the more northerly parts of the sub-basin (e.g. Tern and Petrel).

Few anomalies were detected either within or along the margins of the Sahul Syncline and the Malita Graben. It could be argued that, in view of the highly faulted nature of the Sahul Syncline in particular, the absence of anomalies may indicate that relatively little charge is presently migrating from these depocentres. If correct, this argument would indicate that the structures (located around the margins of these depocentres) with the best chance of success would be those which were charged prior to the Late Tertiary collision, but were not breached during the structural reactivation associated with the collision. Relatively young (Late Tertiary) structures would appear to have little chance of being charged according to this scenario.

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Acknowledgments

We wish to thank the Master, Bob Hardinge, and crew of the R.V. *Rig Seismic* and all BMR scientific and technical staff listed below for their skill and contributions to the success of this study.

List of BMR Survey Personnel

Cruise Leaders:	J.B Willcox, D.C. Ramsay.
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Technical Staff:	C. Tindall, G. Sparksman, P. Davis, C. Lawson, J. Kossatz, D. Pryce, T. McNamara, L. Hatch, P. Vujovic, L. Miller, C. Saroch, U. Rieke, B. Zygmunt, R. DeGraaf, B. Dickinson, D. Sewter, S. Milnes, S. Wiggins.

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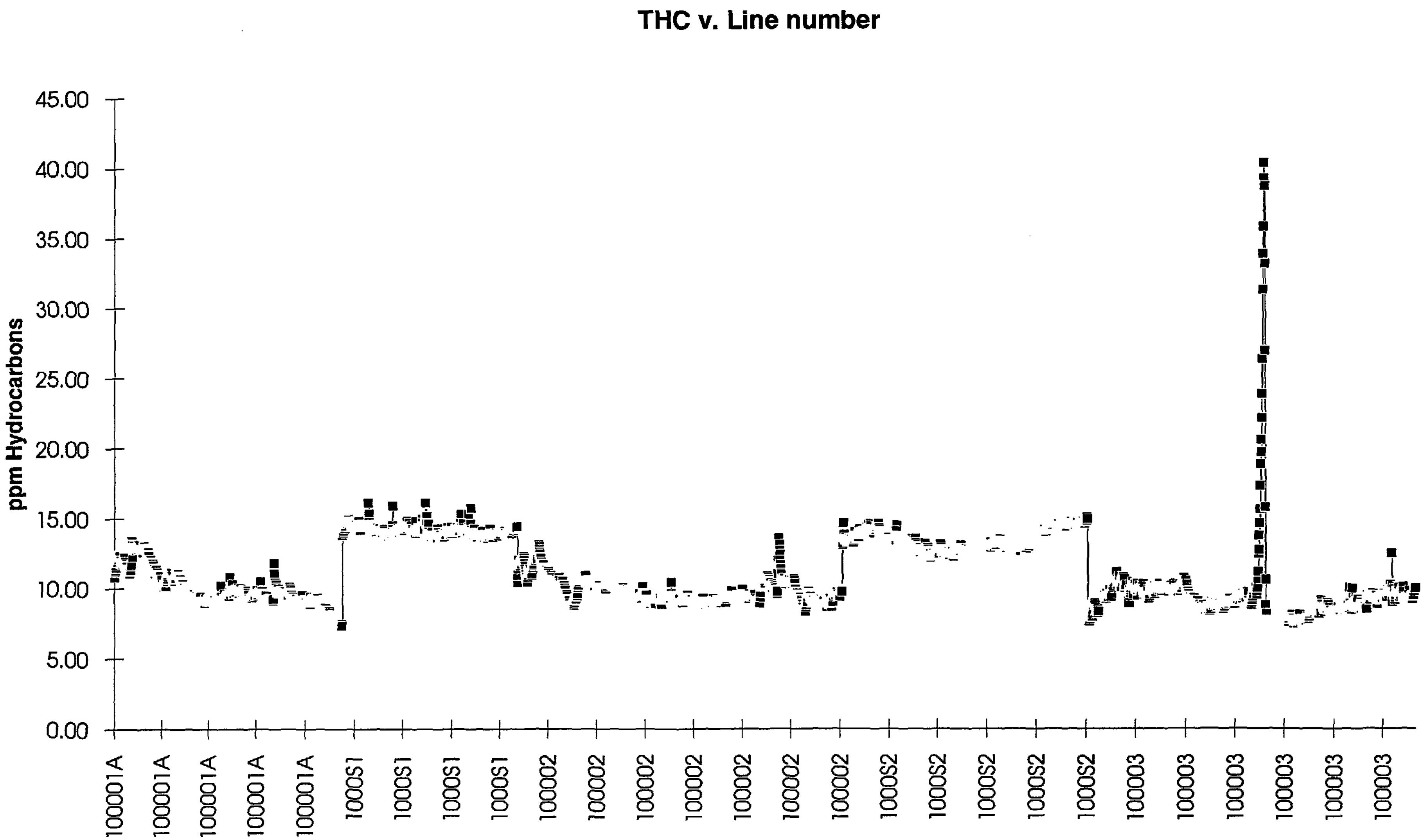

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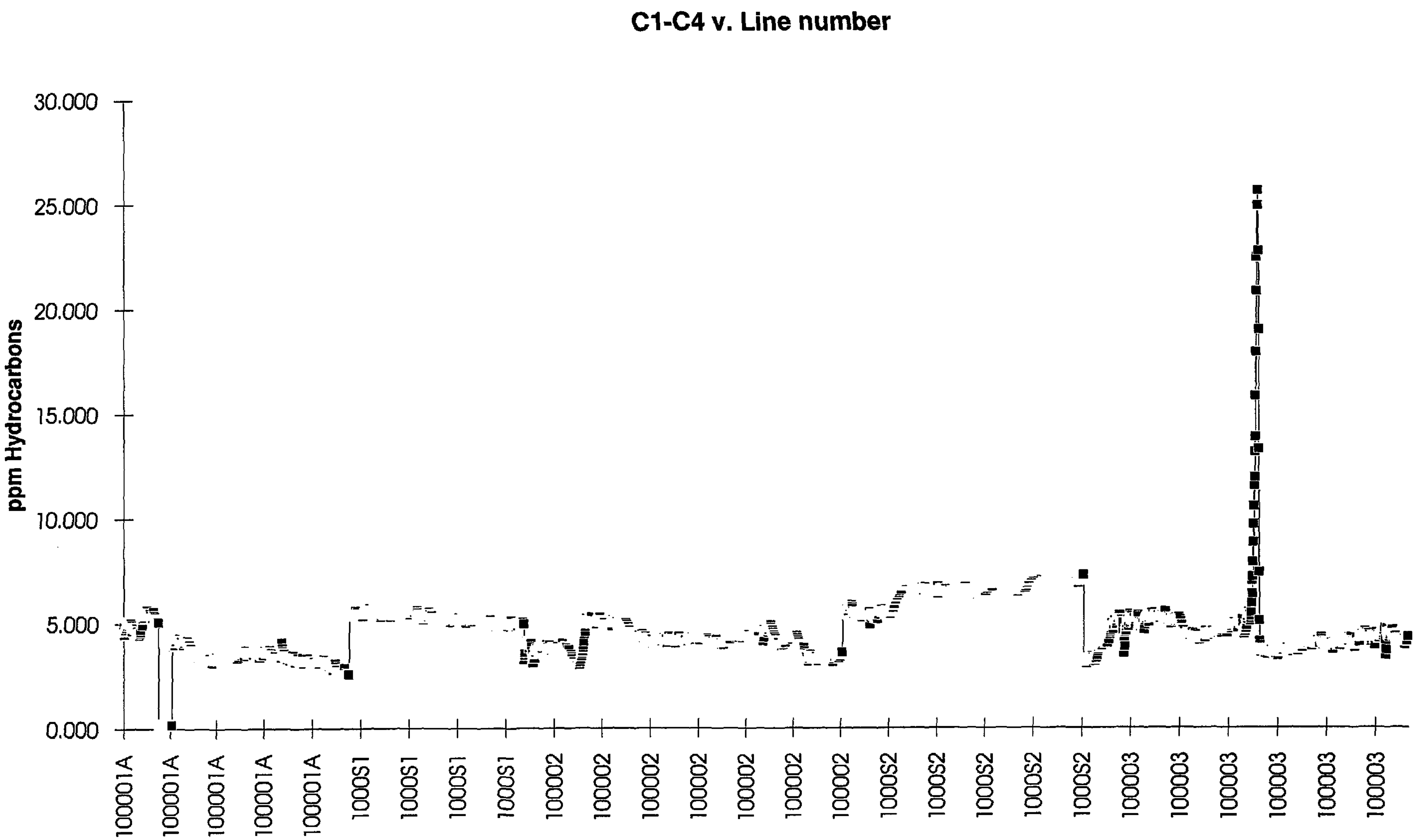

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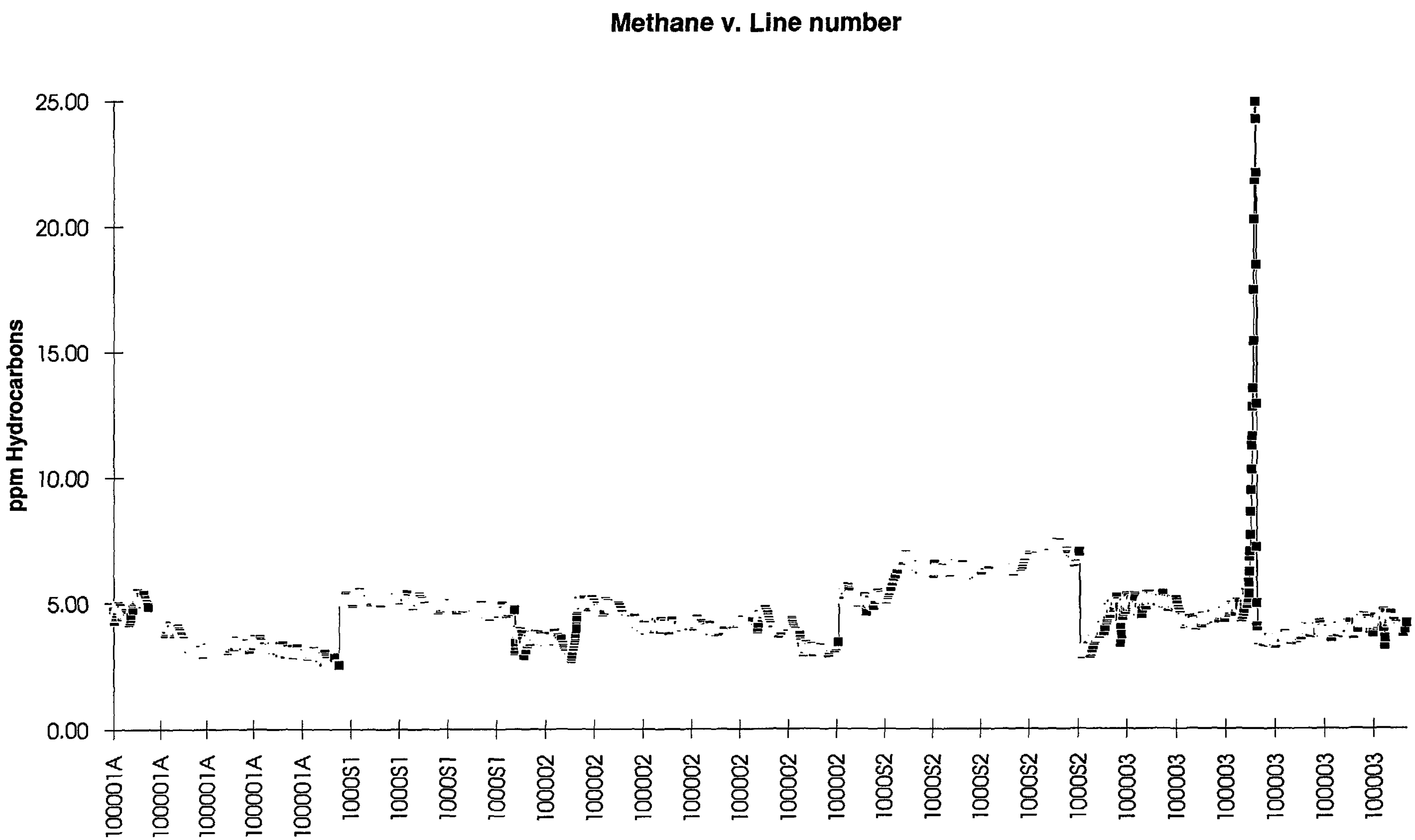

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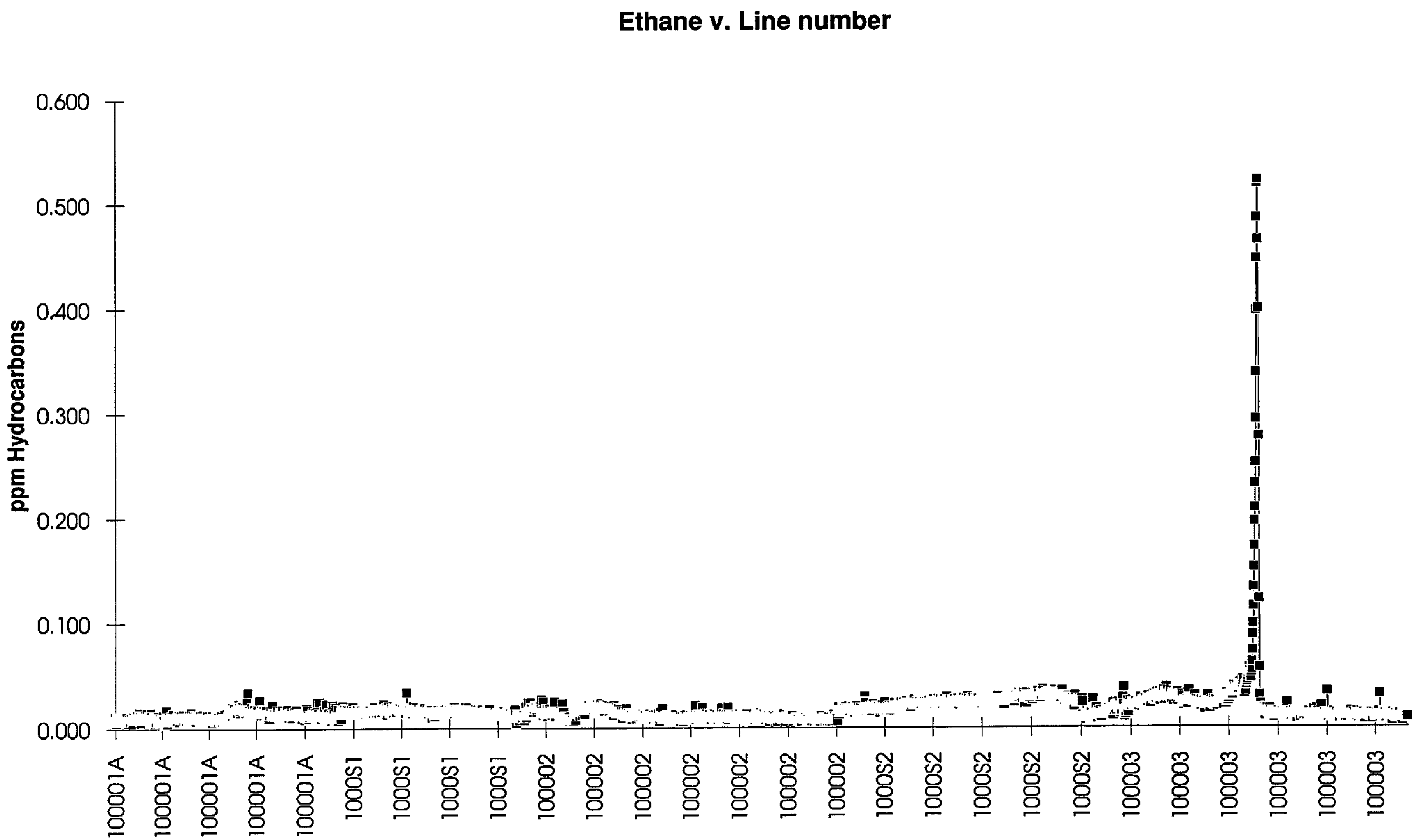

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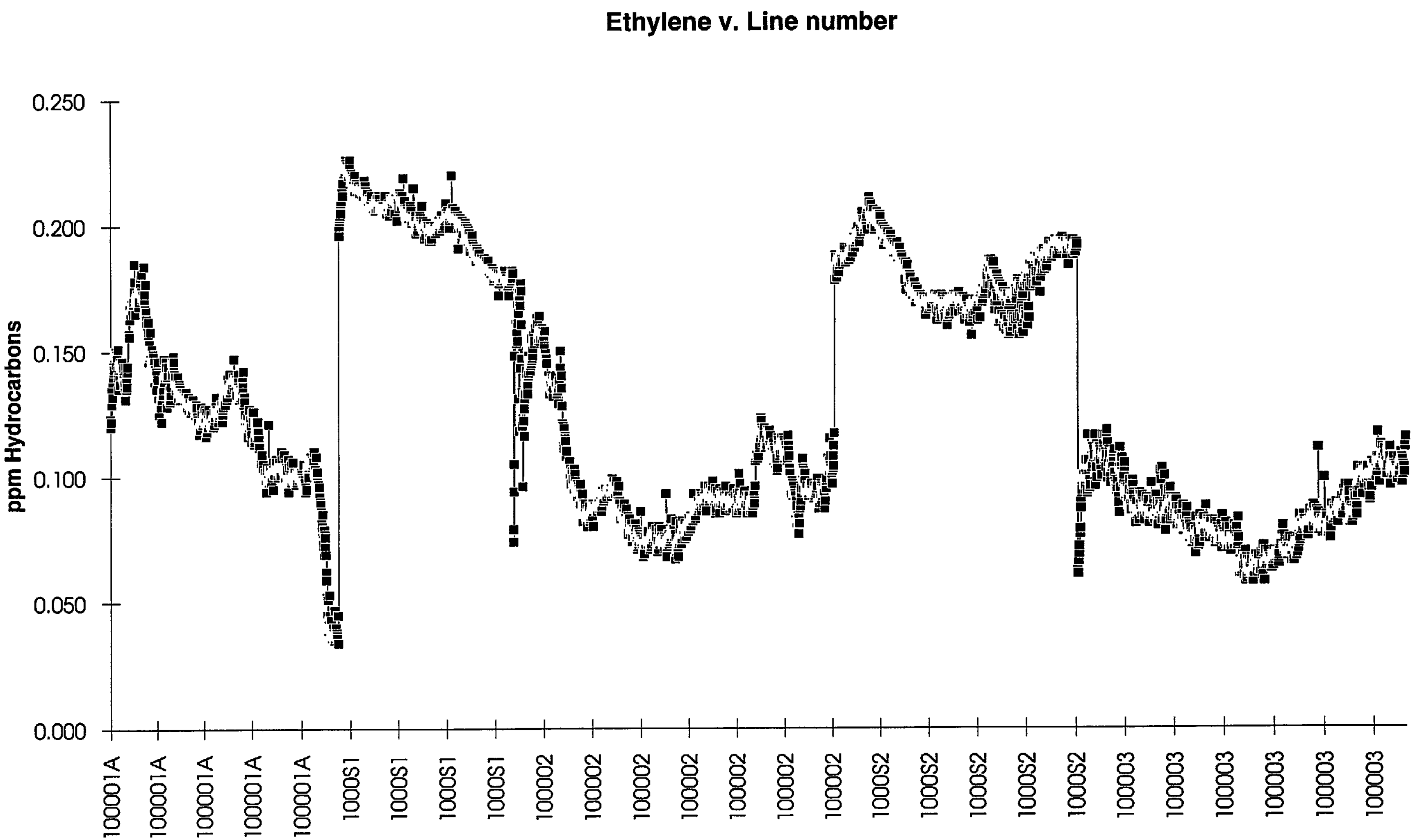

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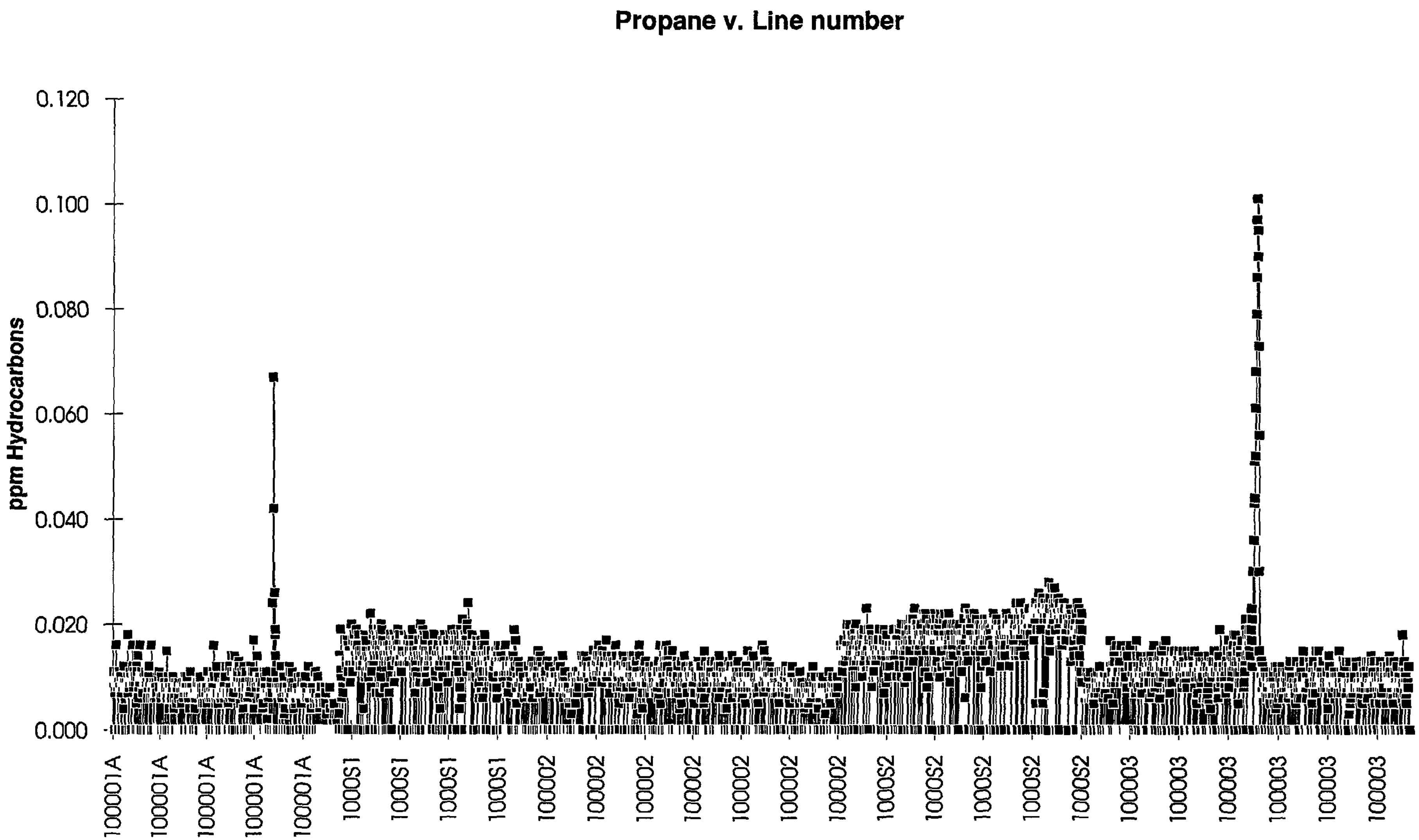

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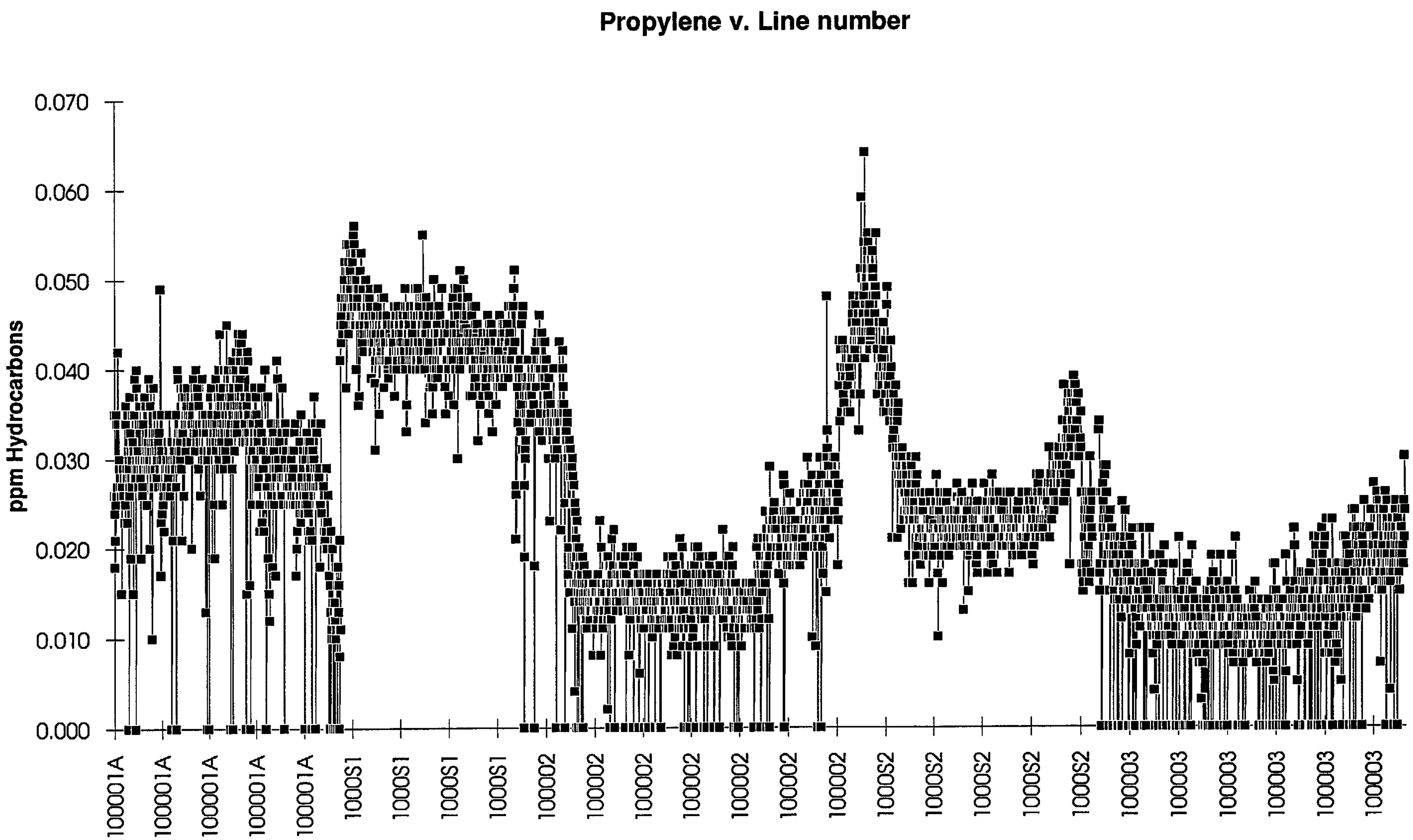

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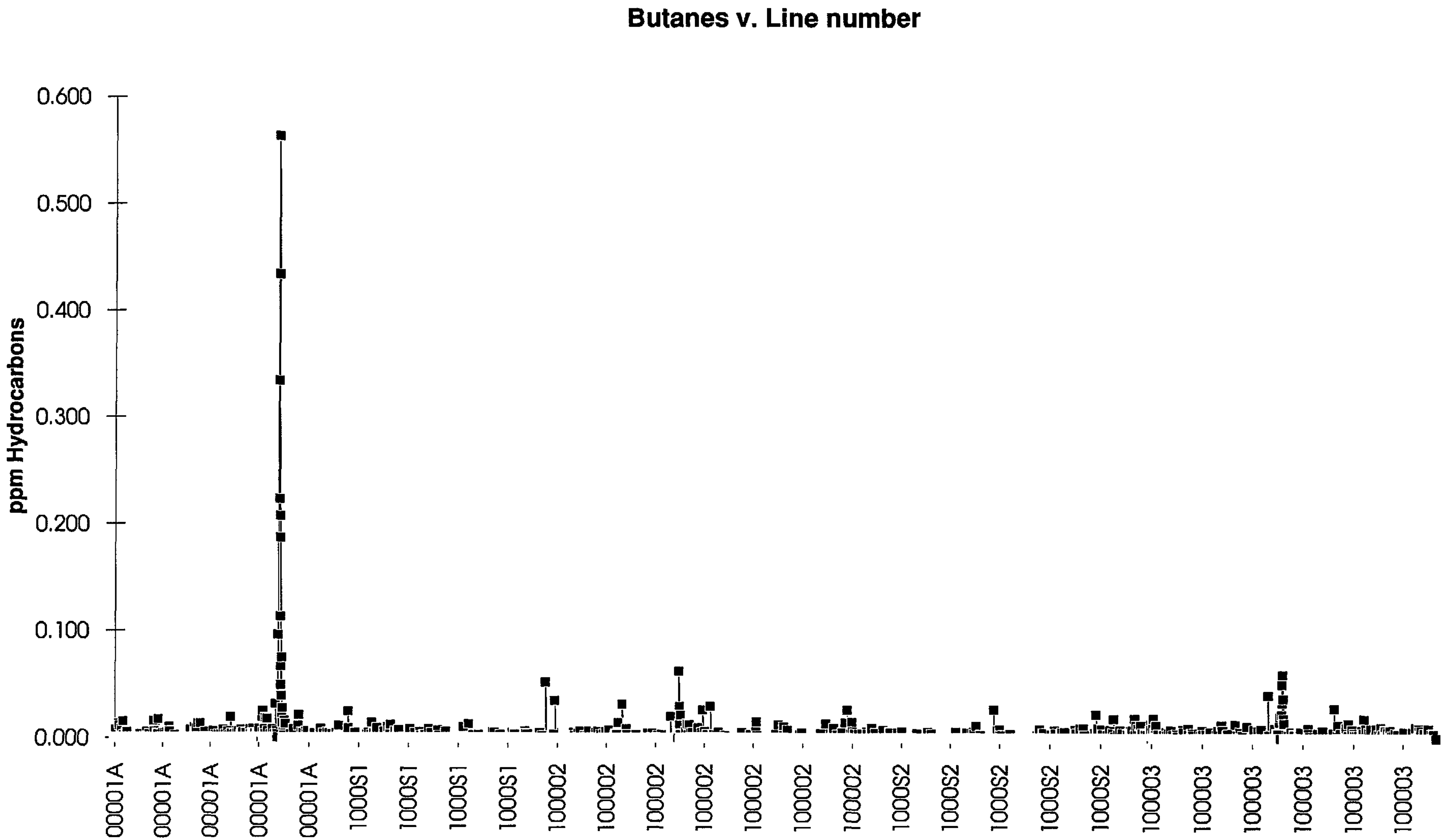

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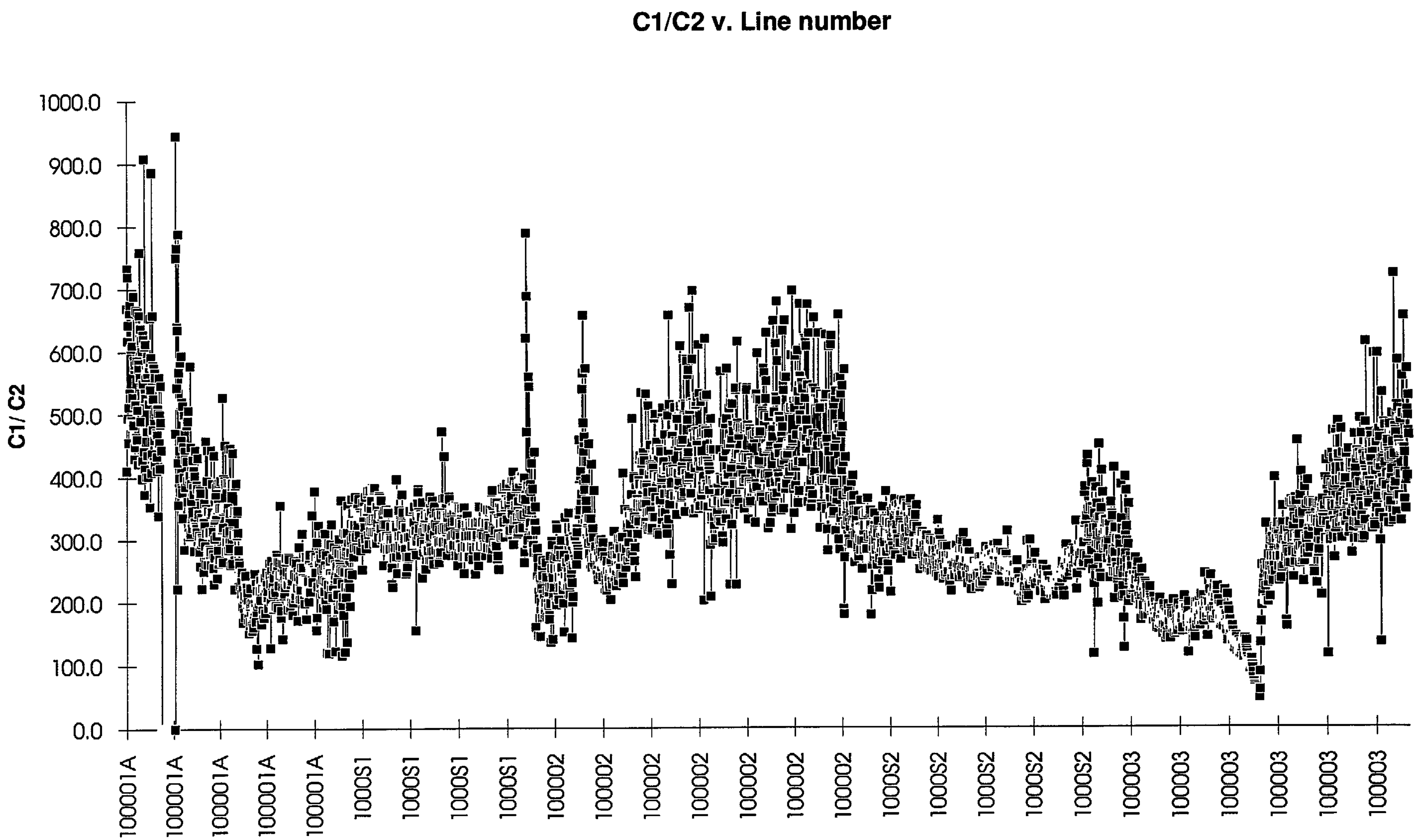

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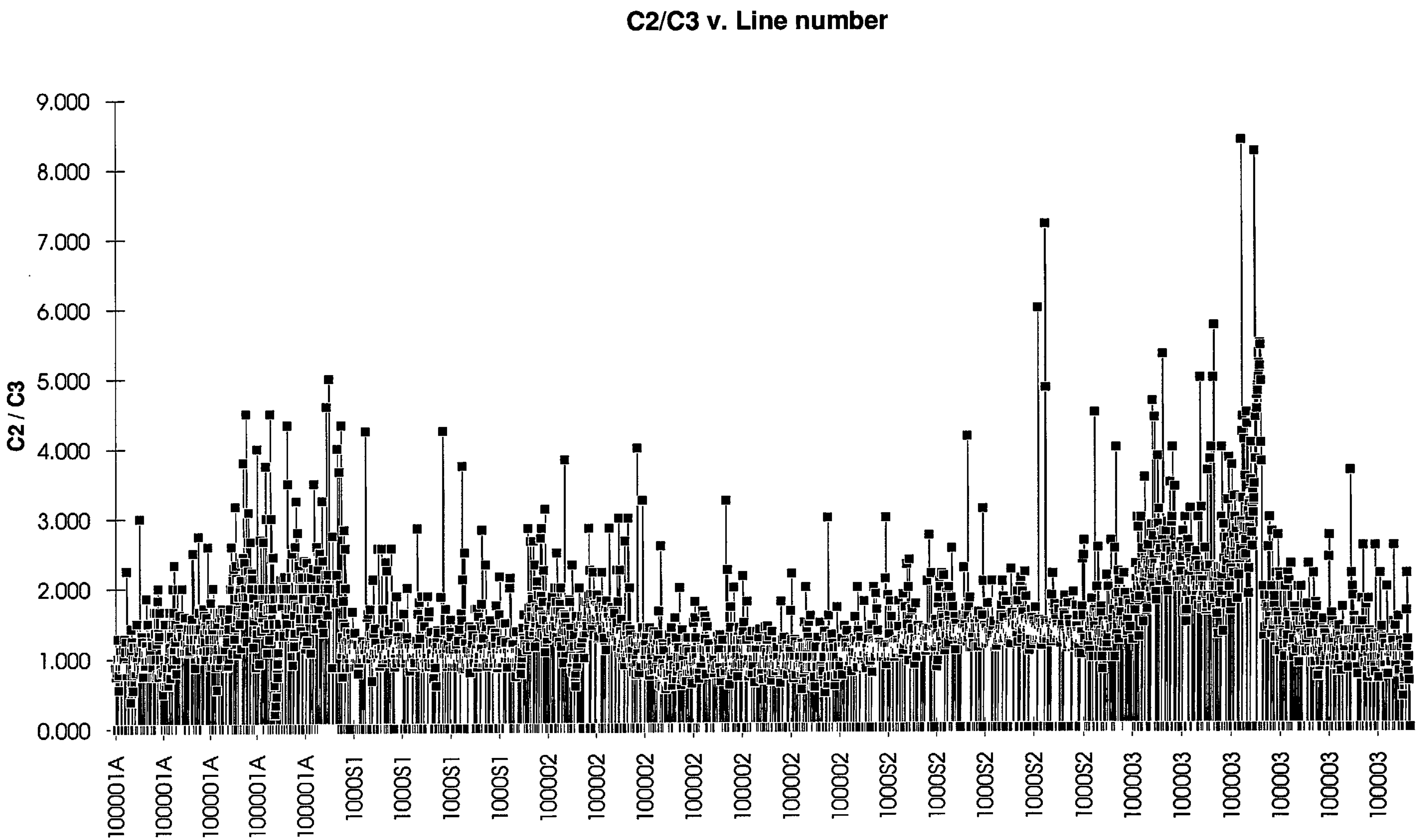

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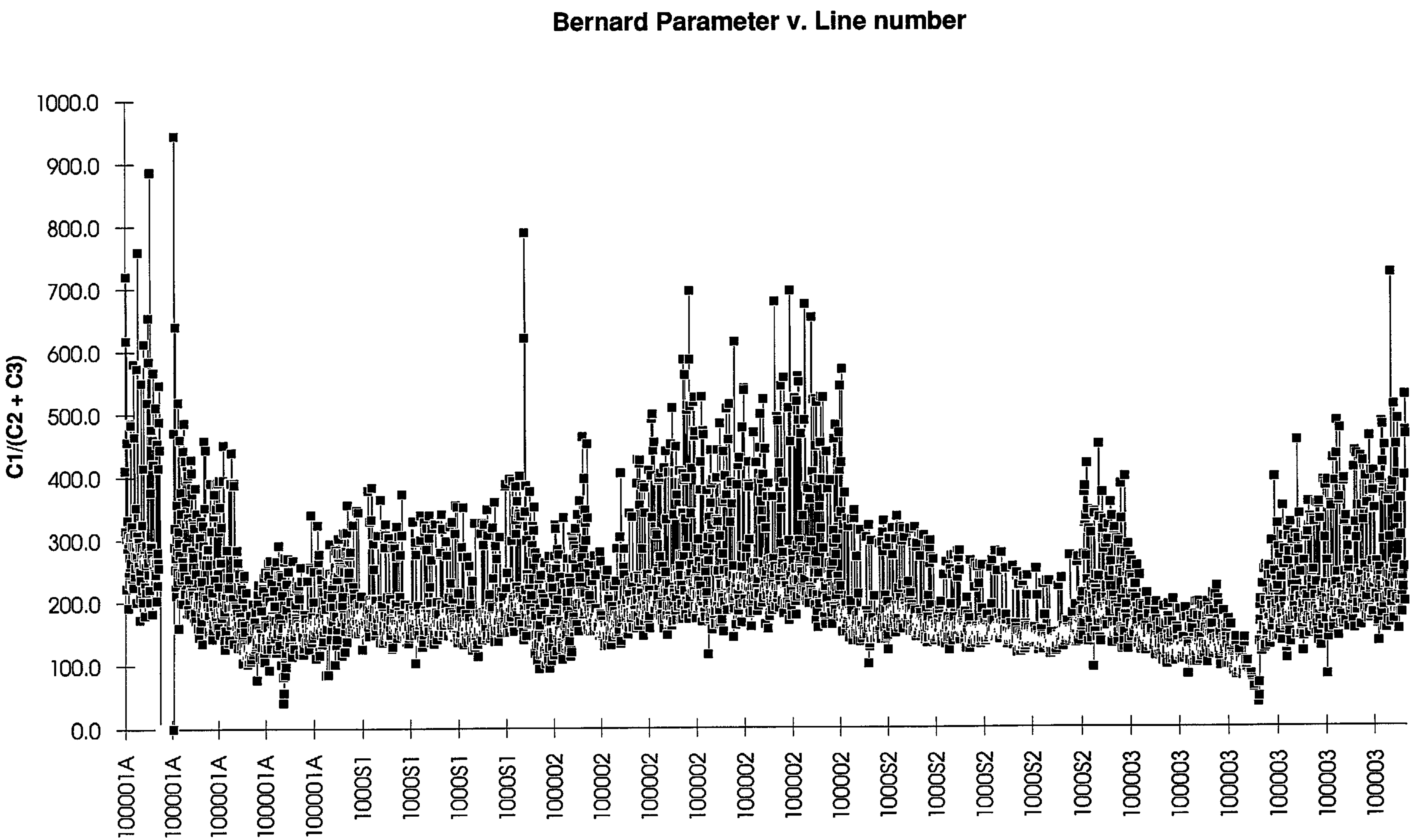

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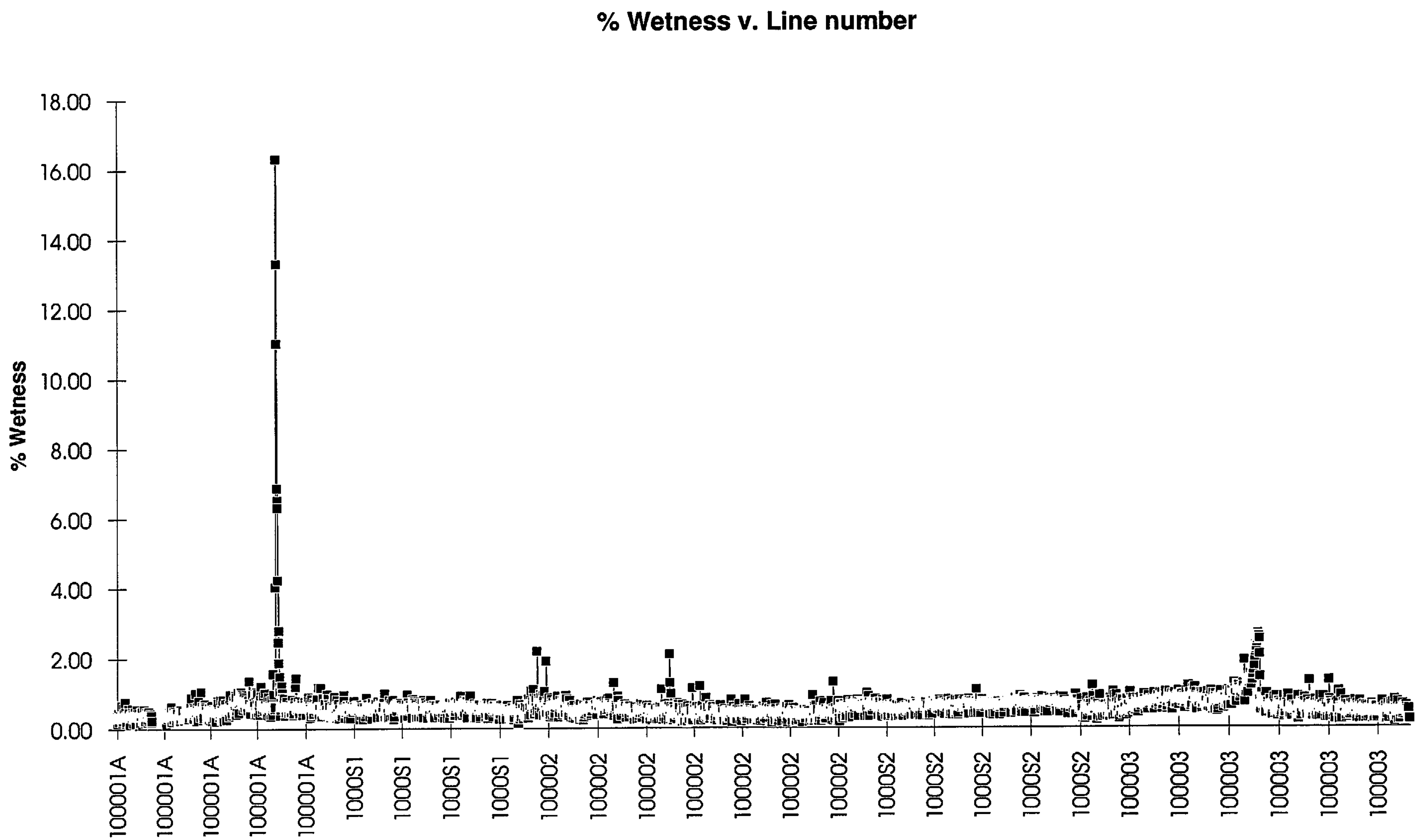

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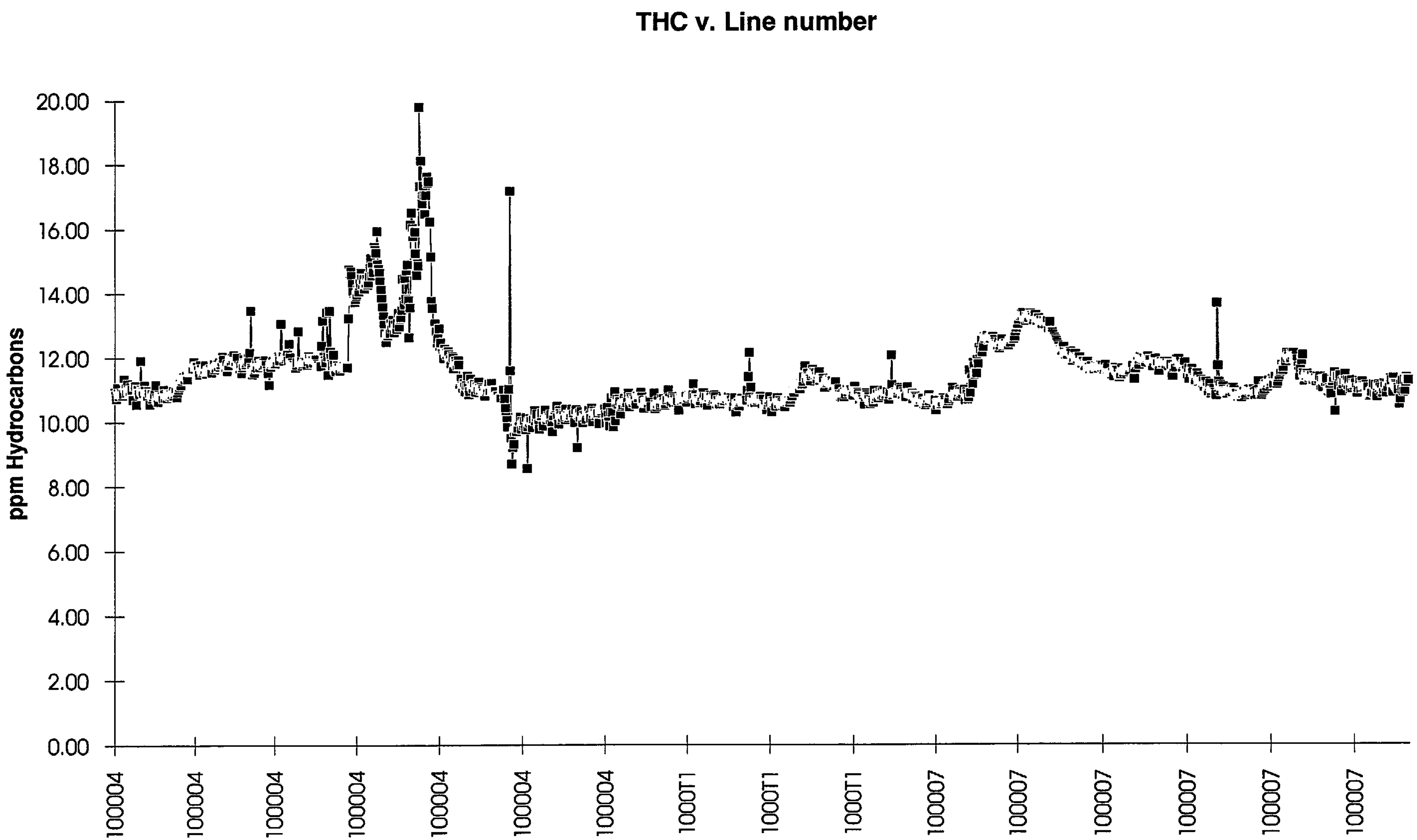

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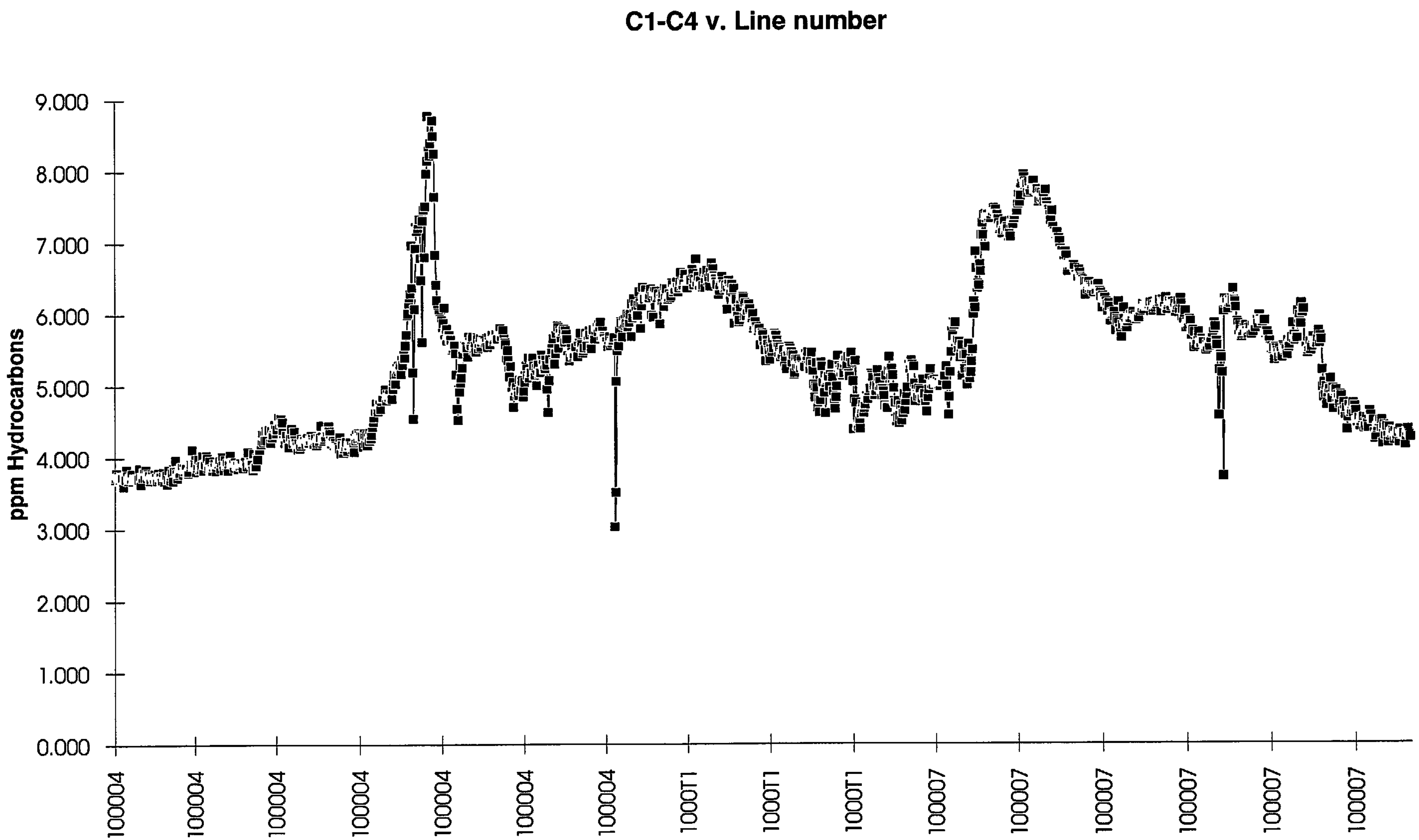

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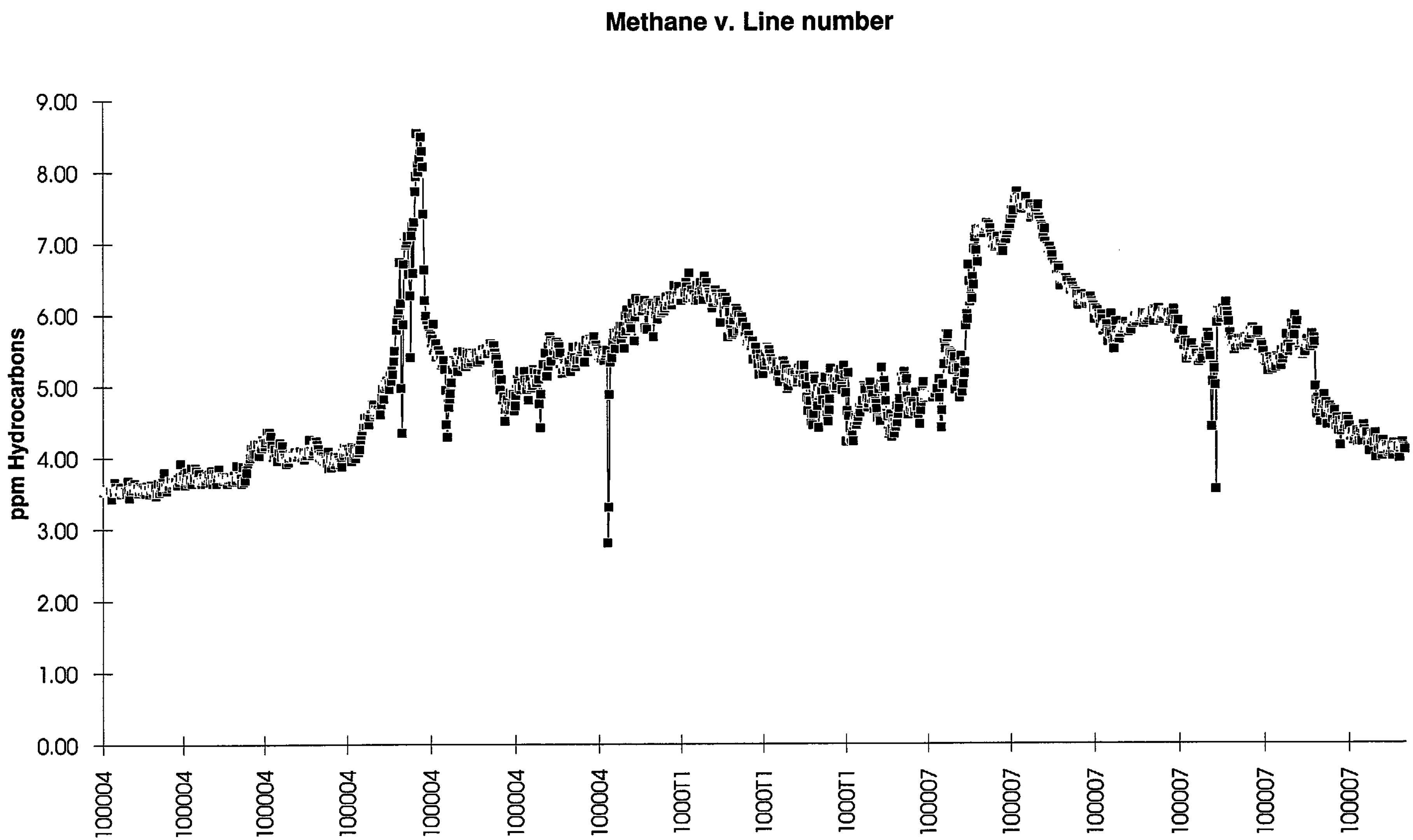

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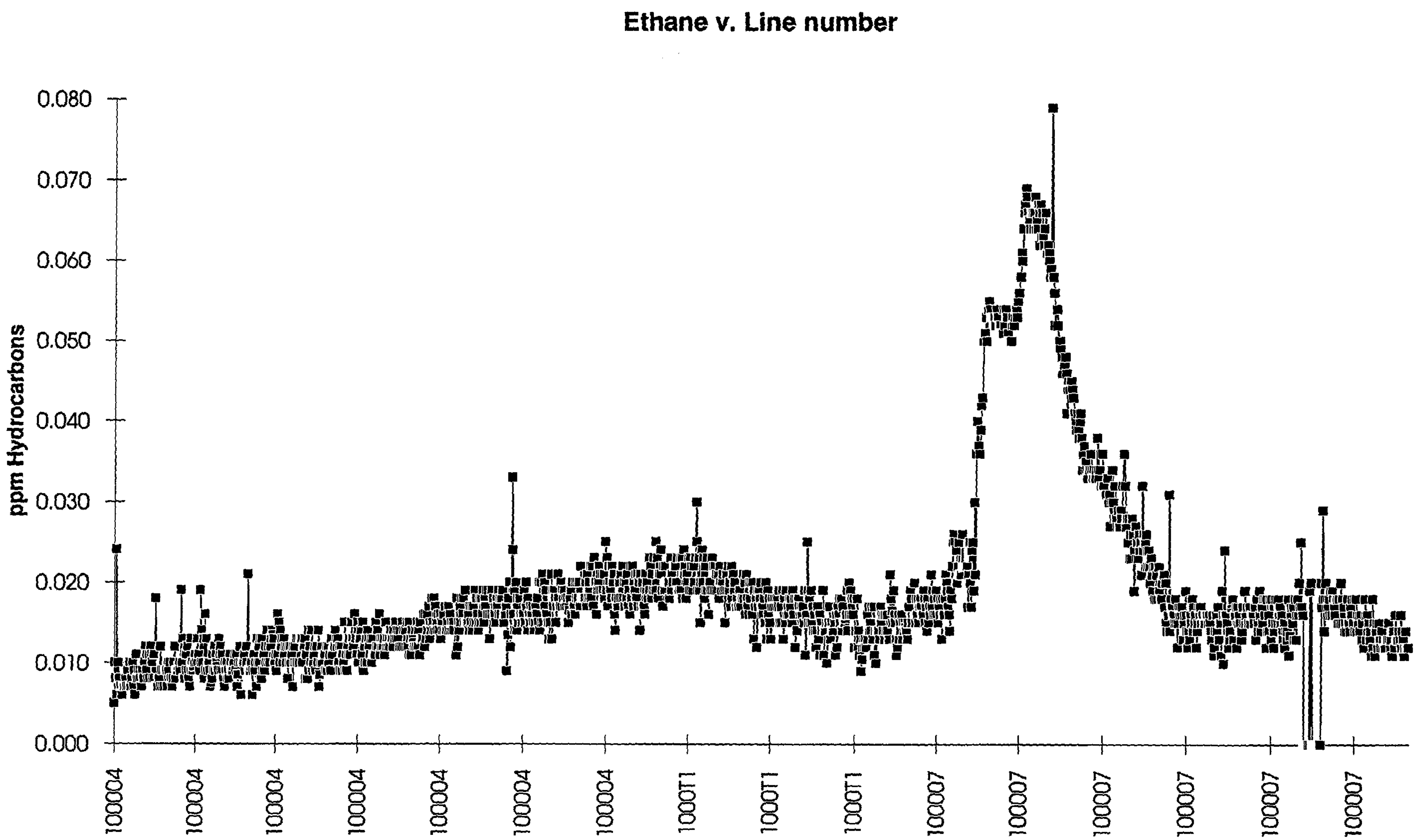

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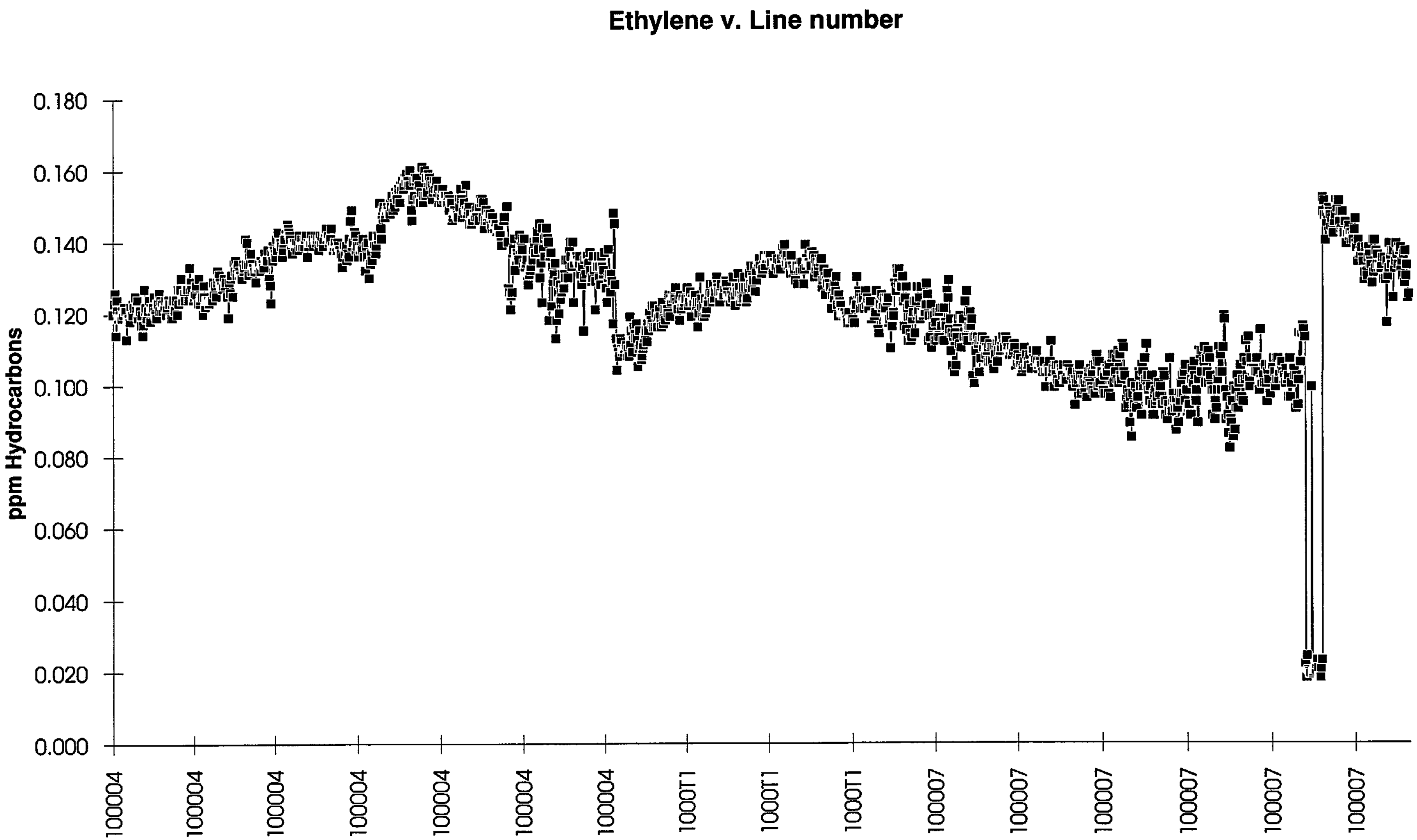

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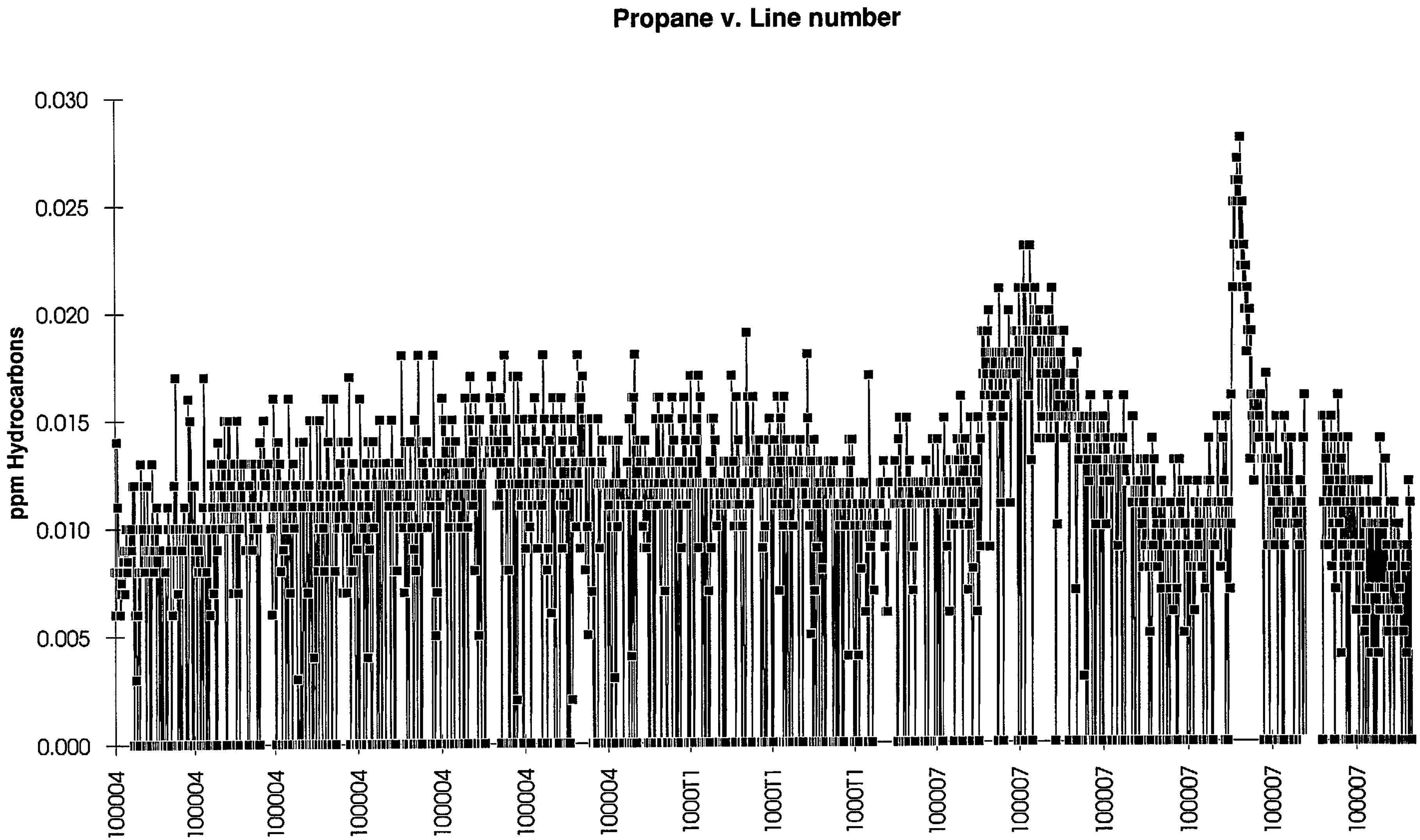

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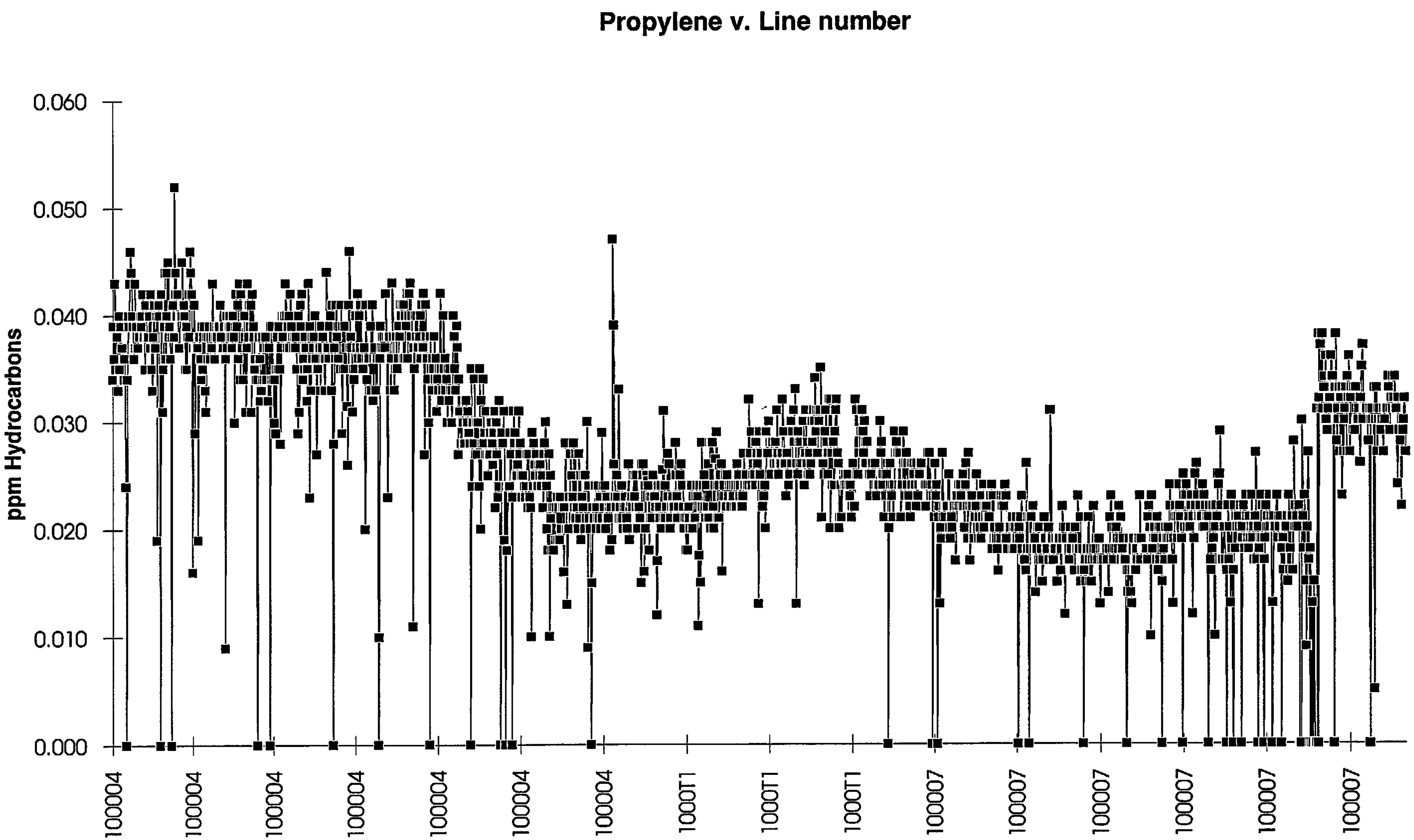

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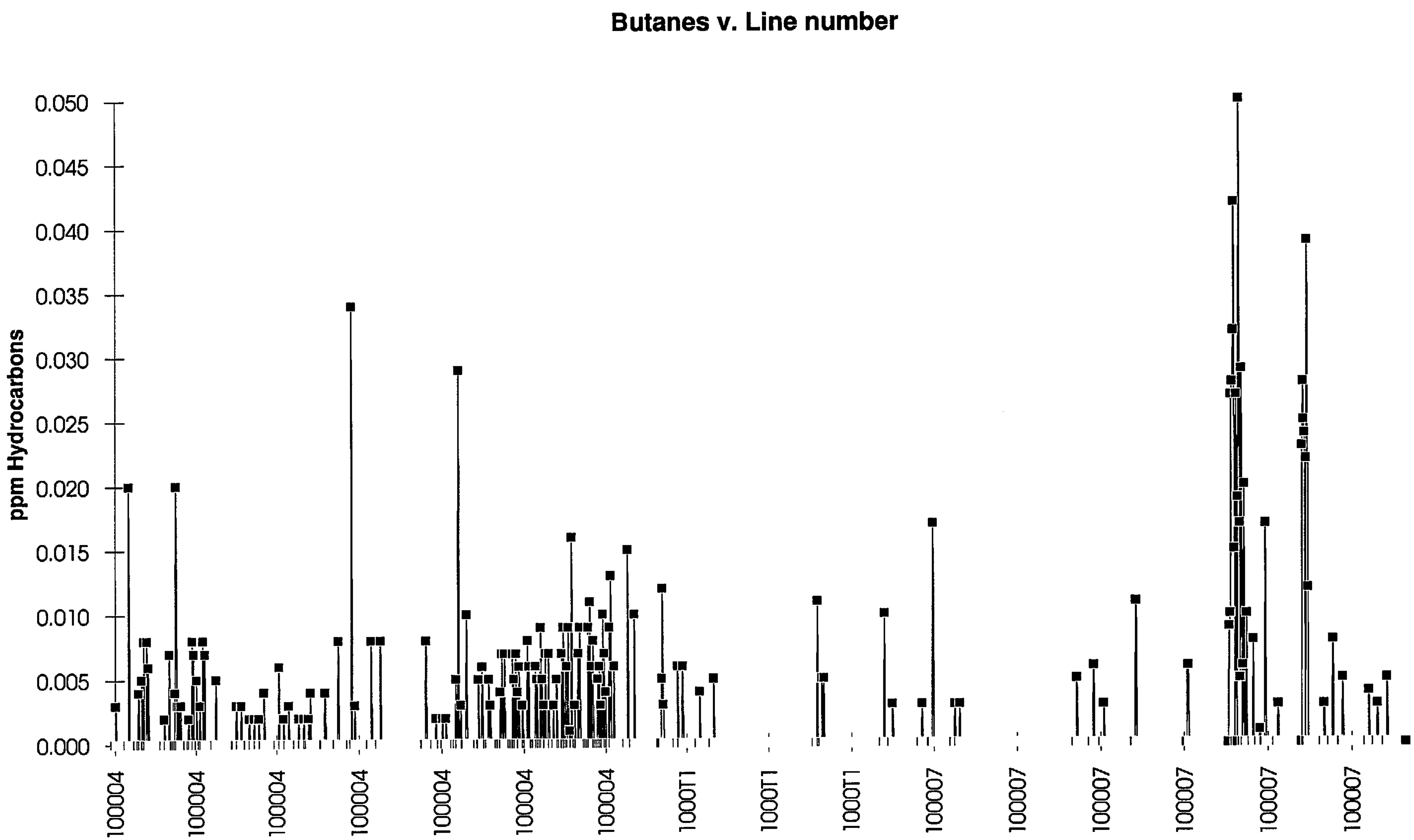

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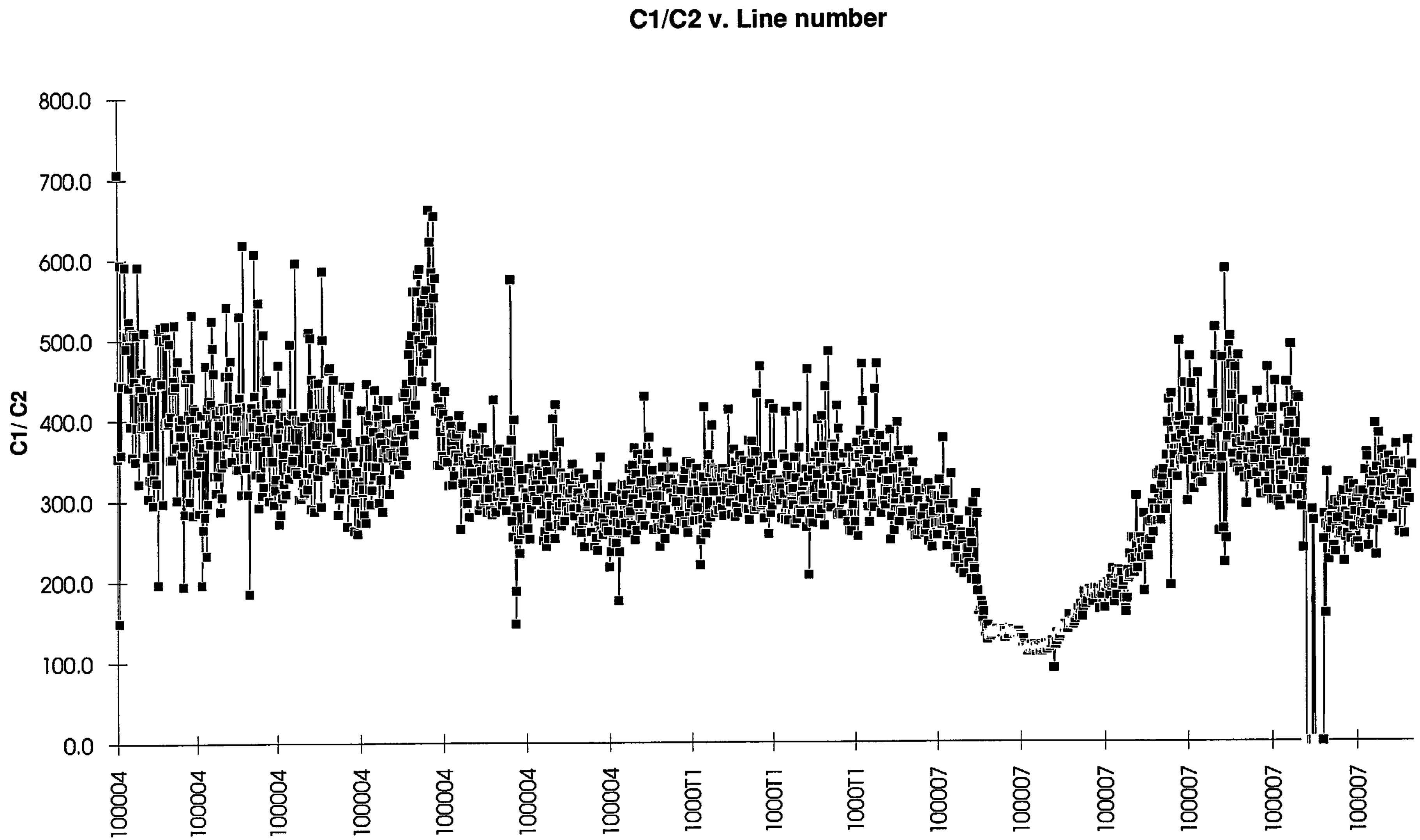

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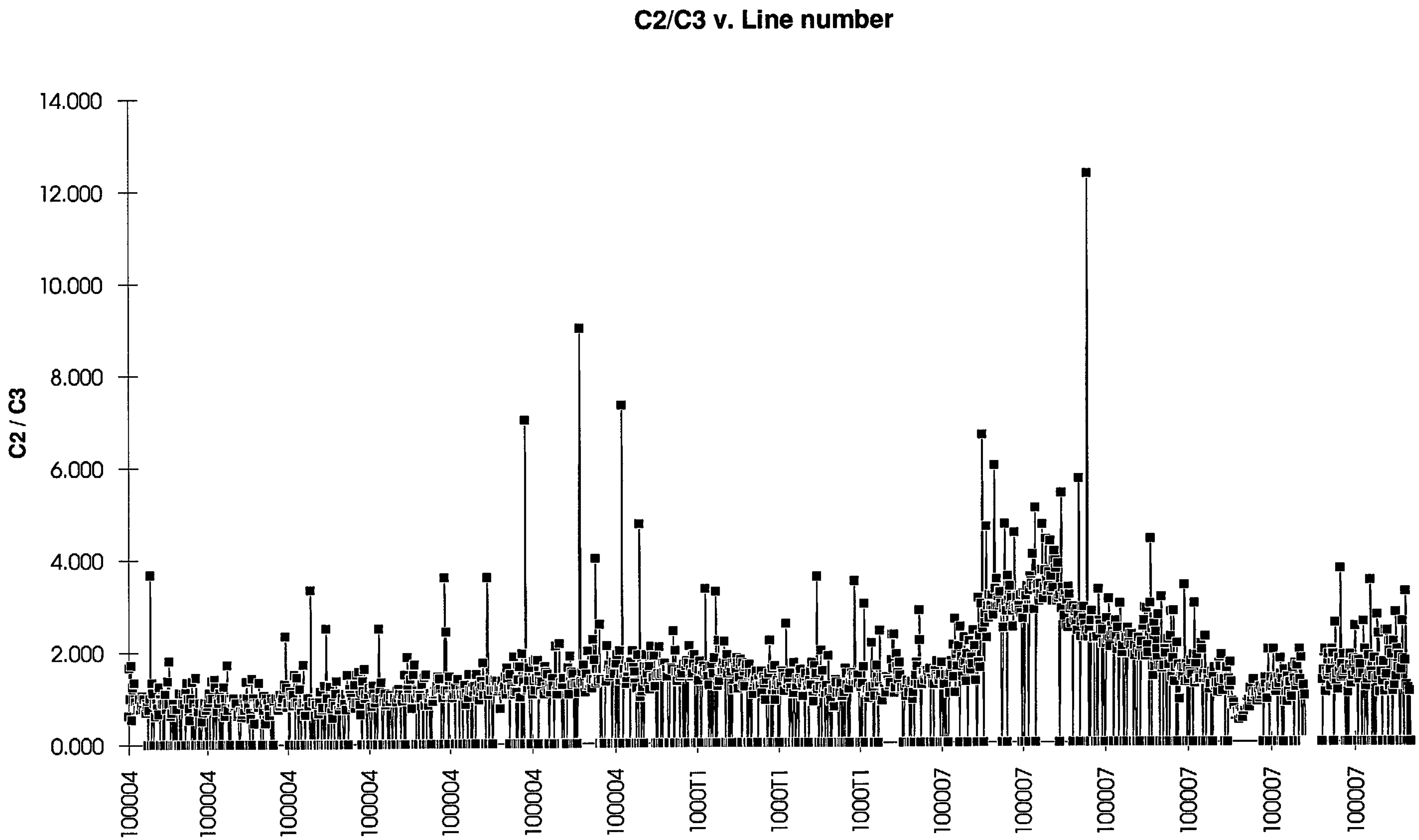

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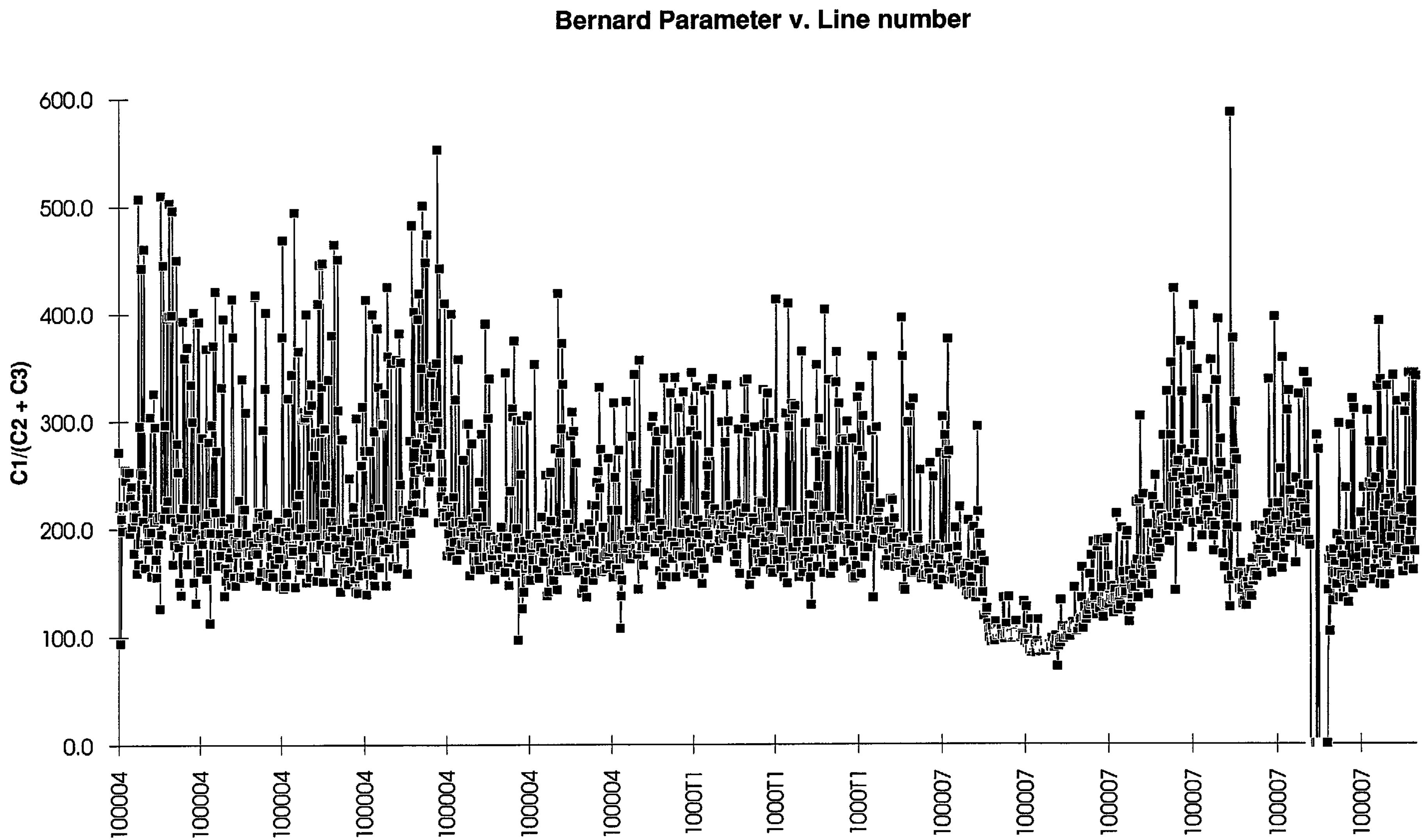

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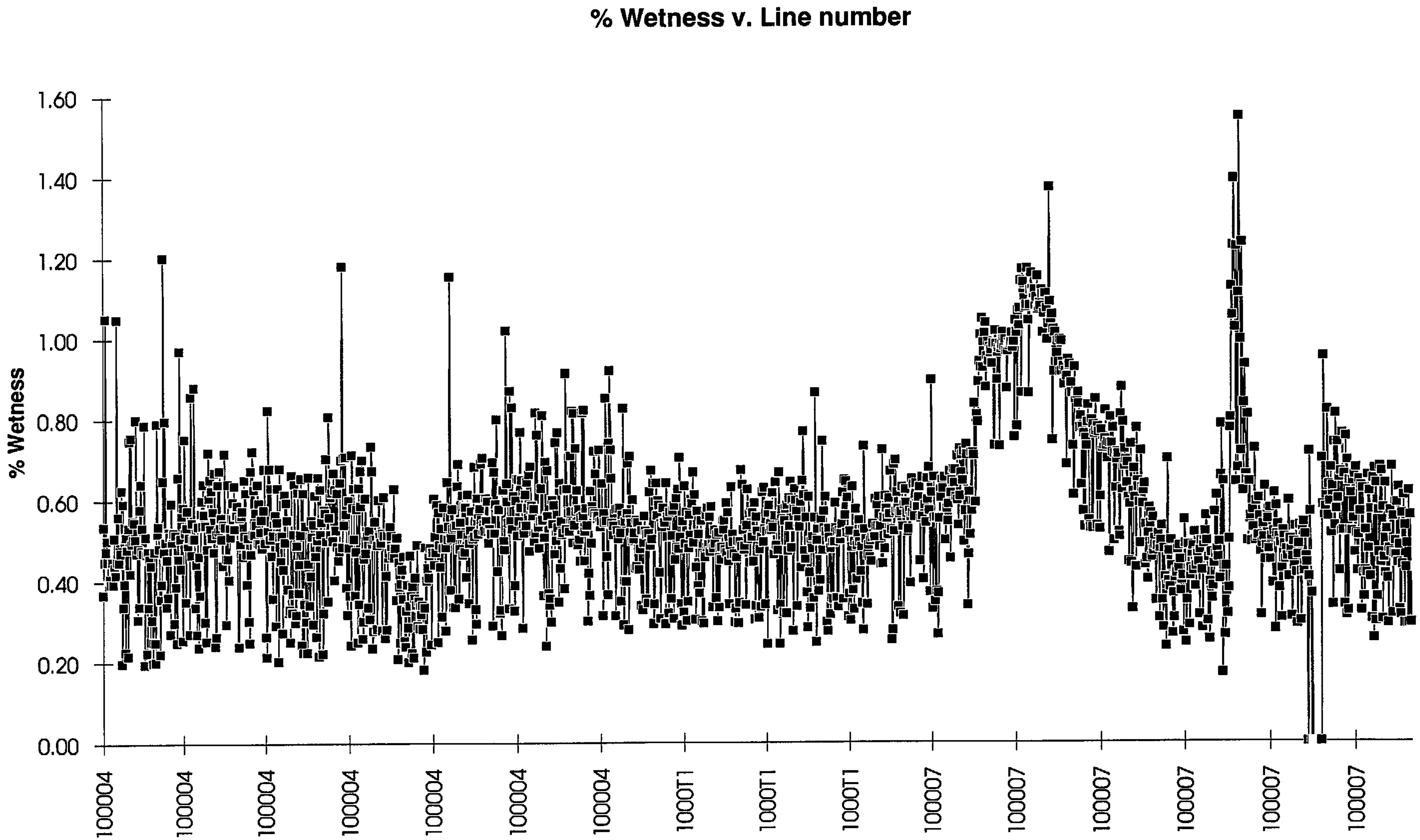

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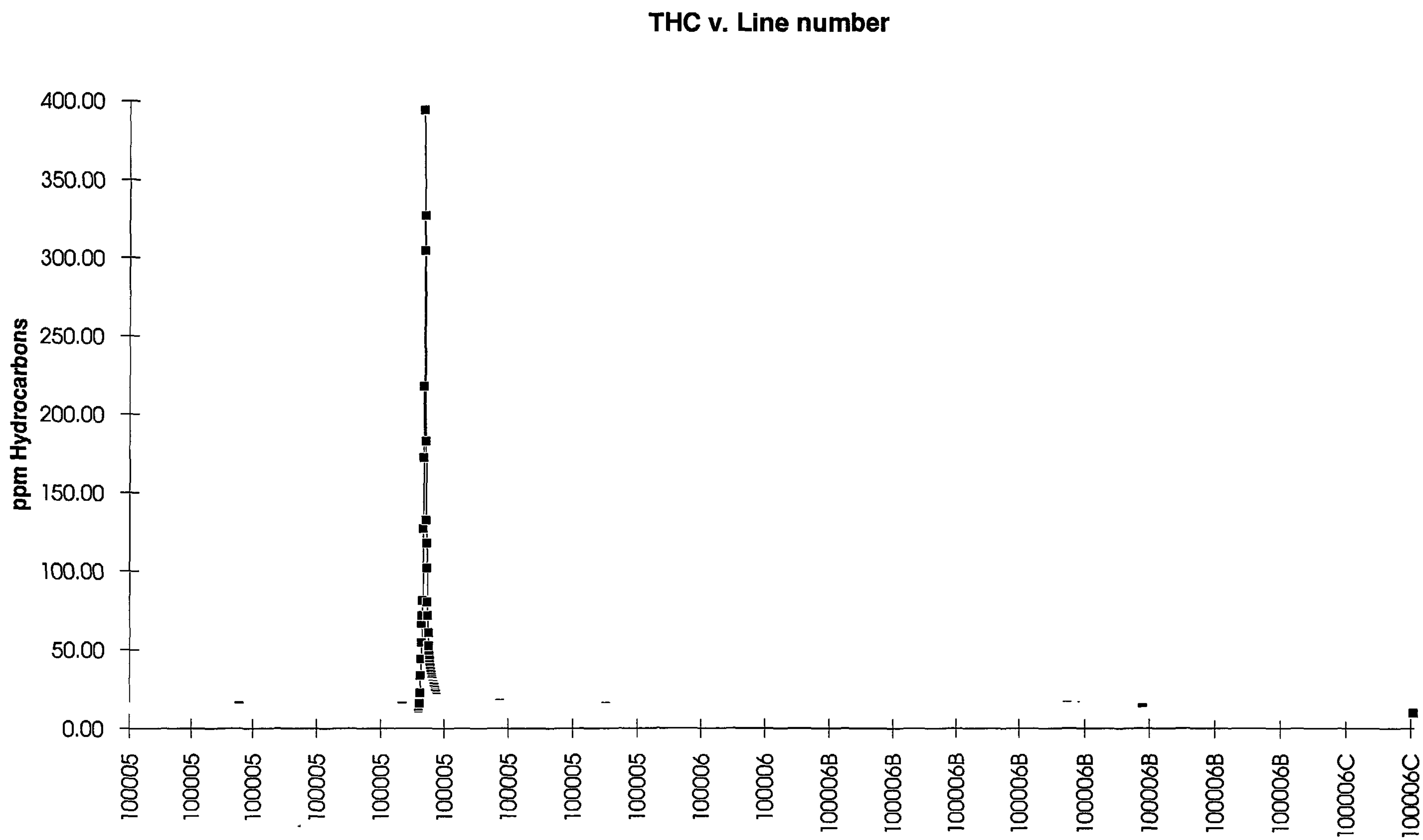

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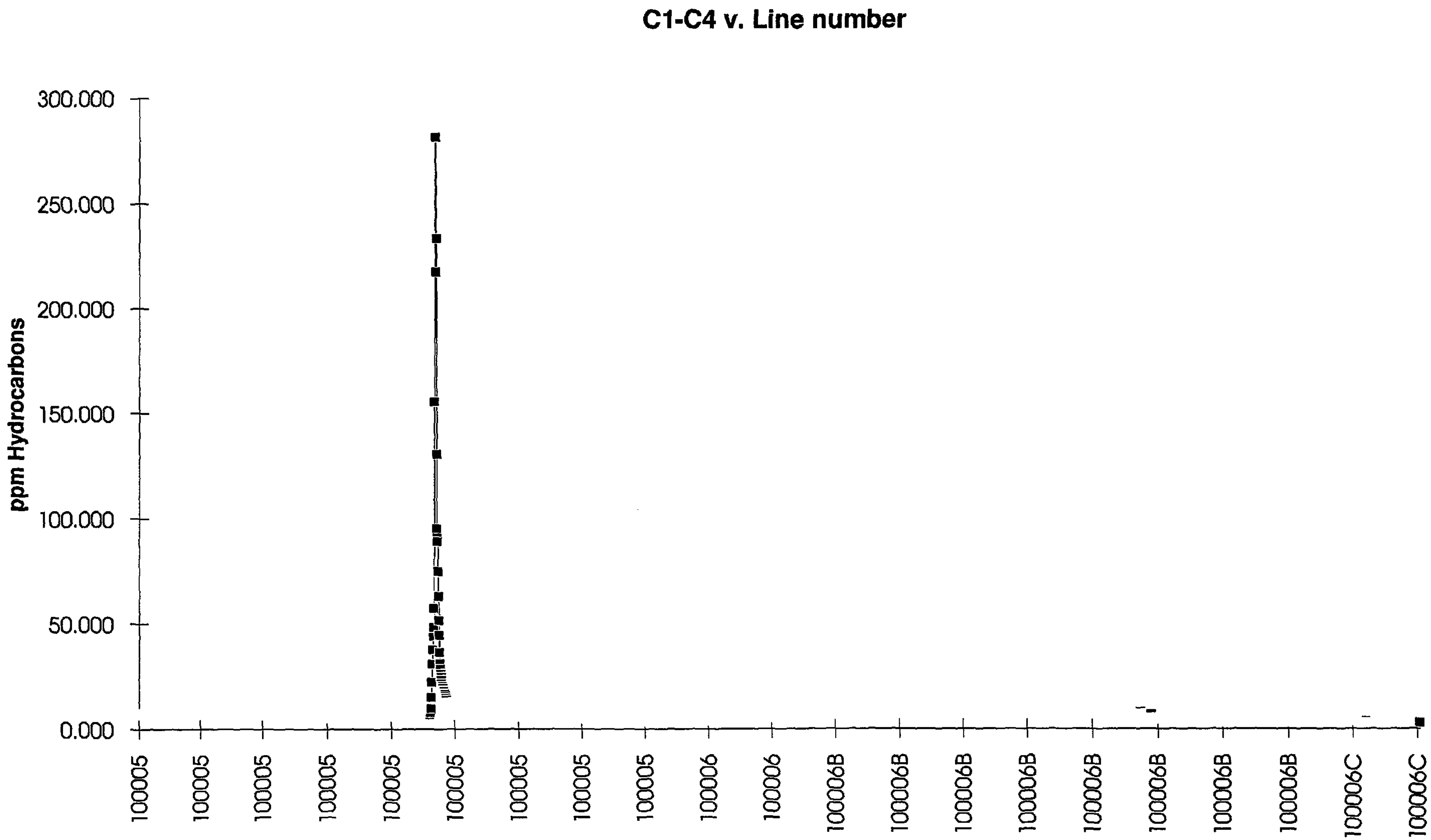

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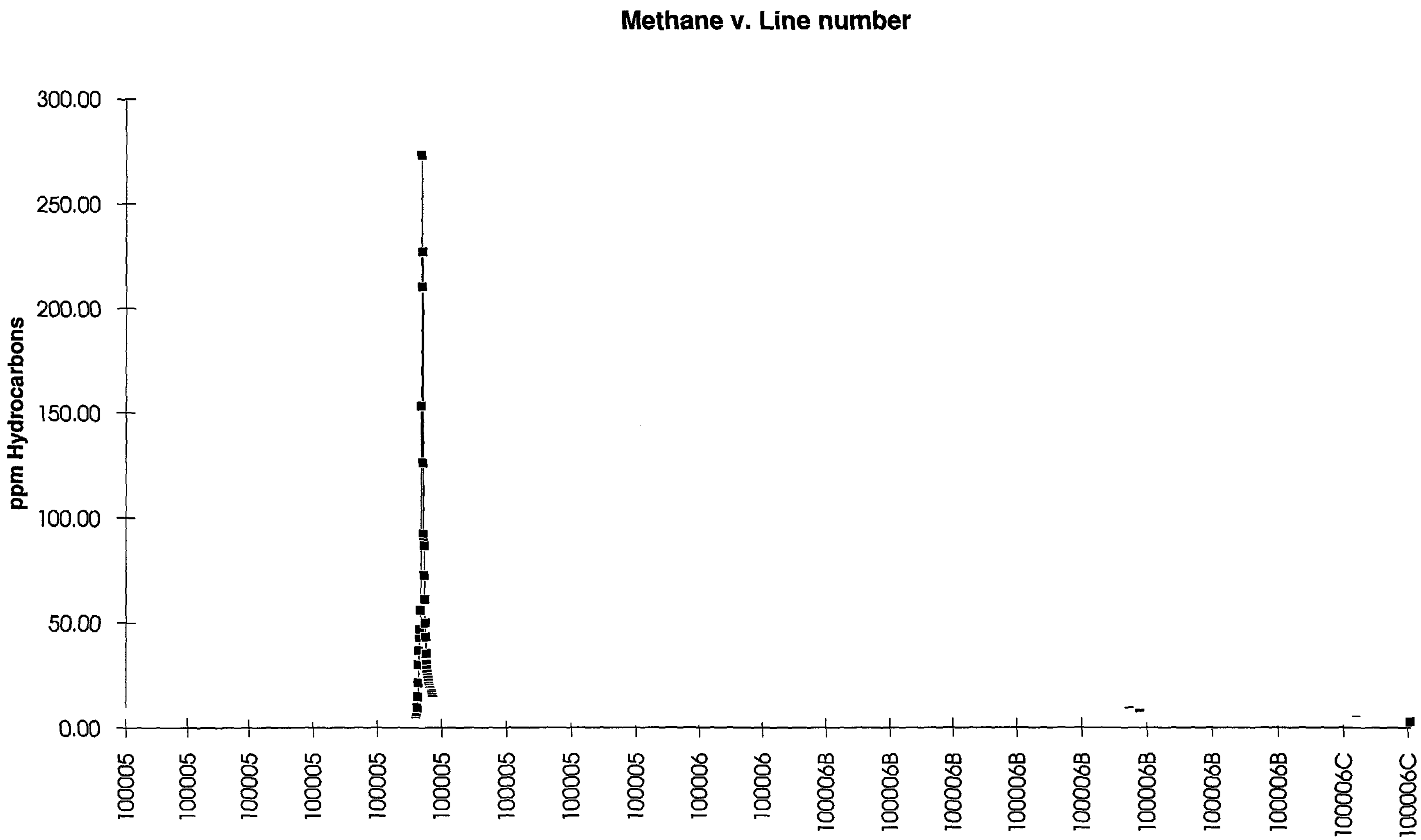

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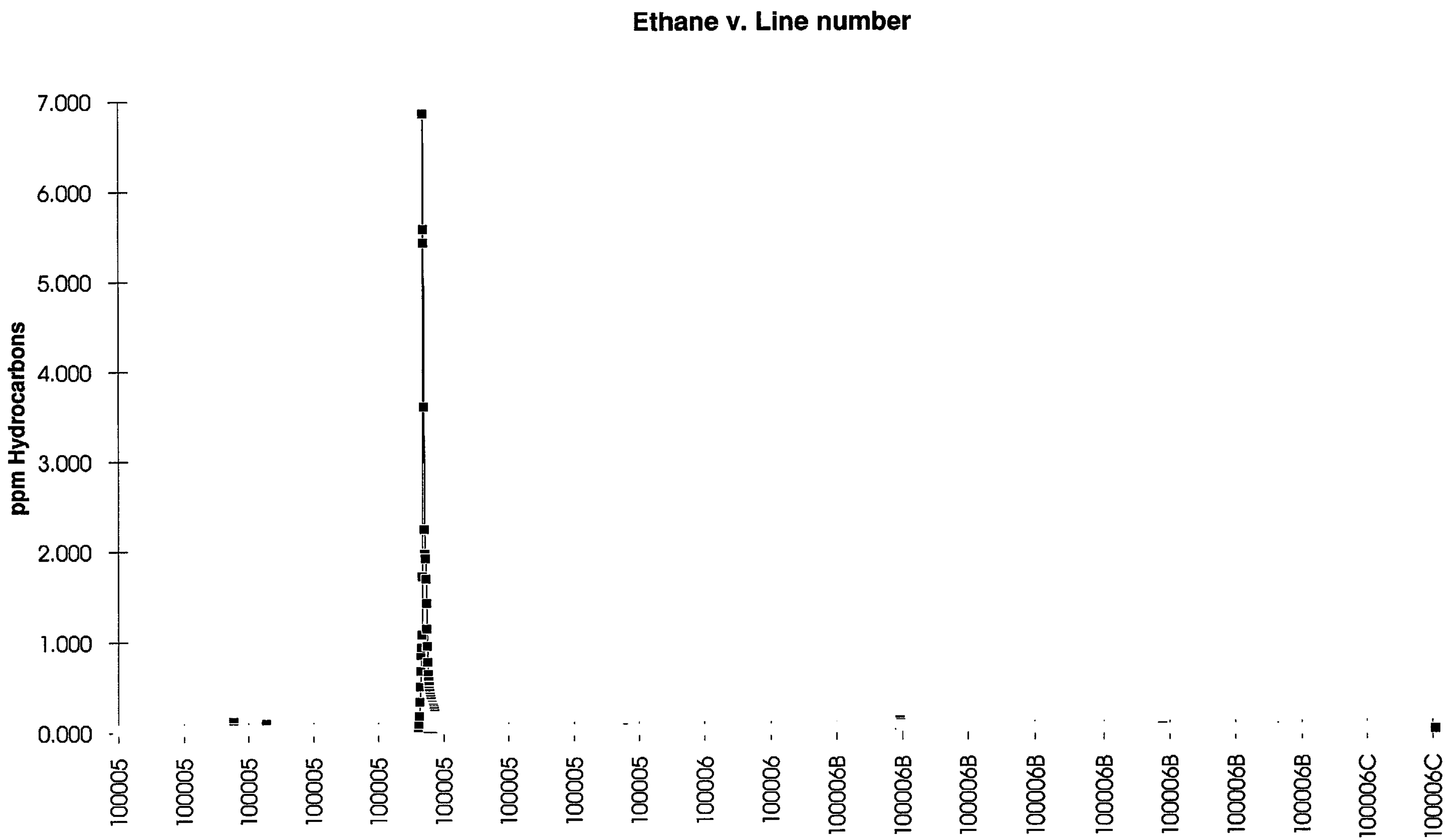

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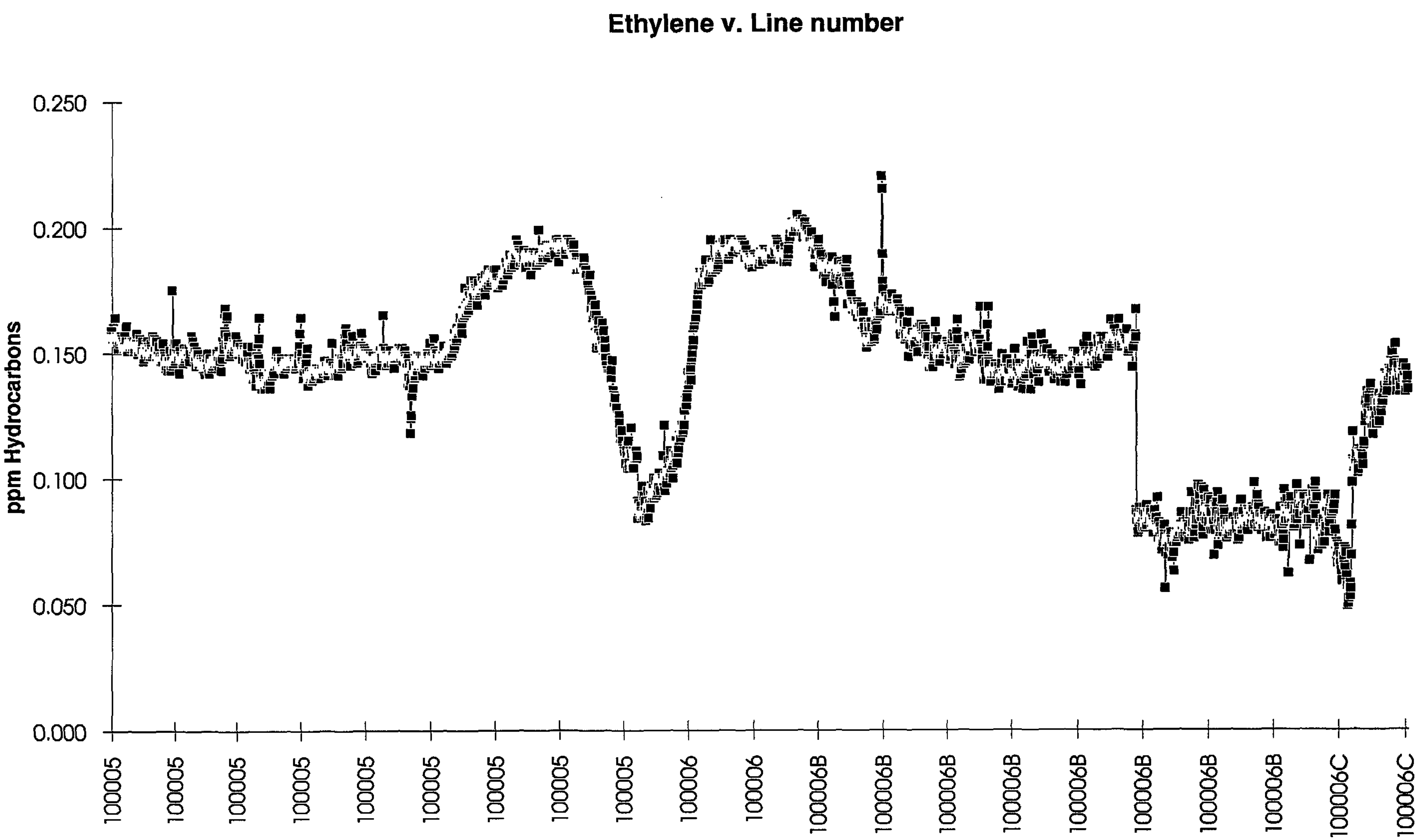

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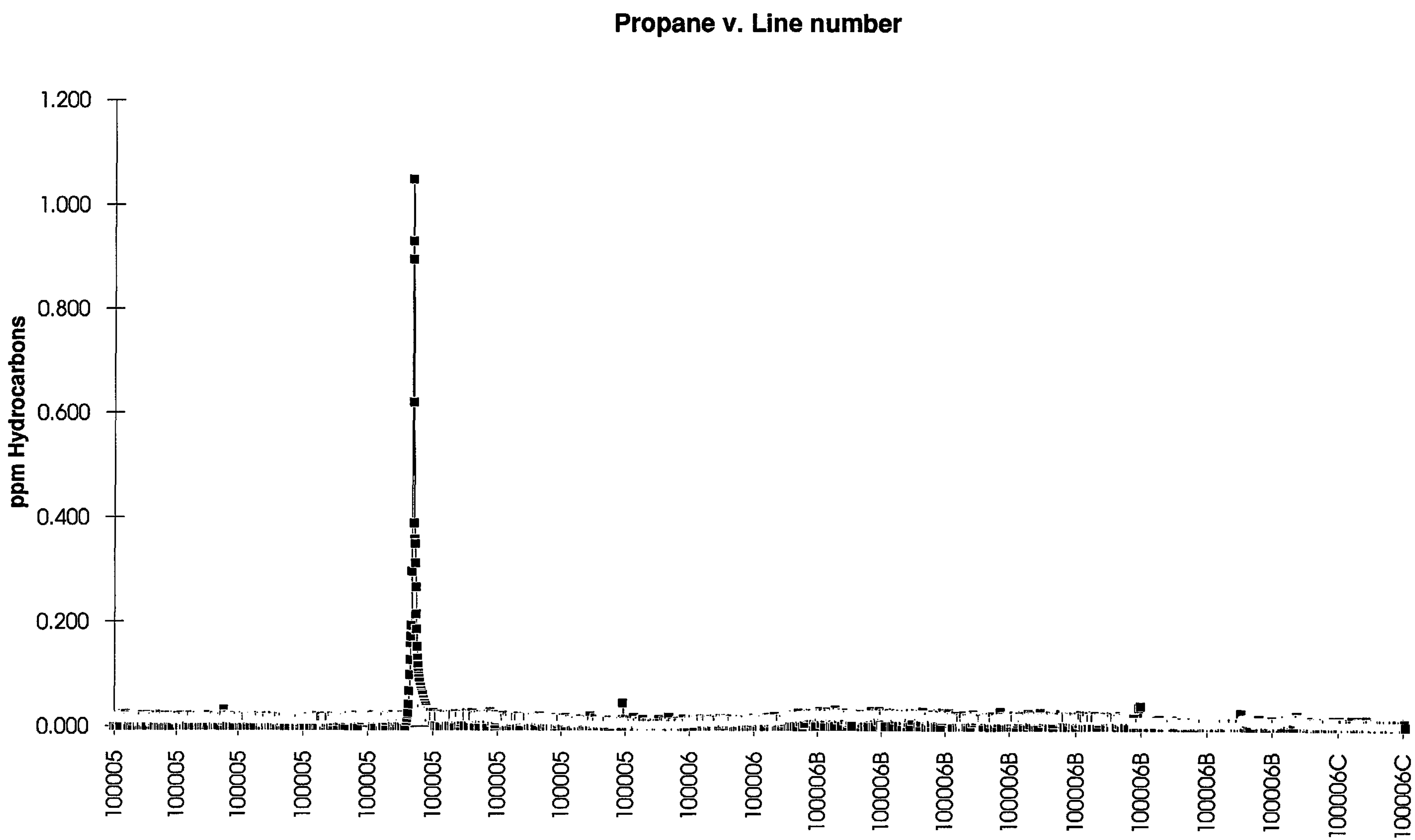

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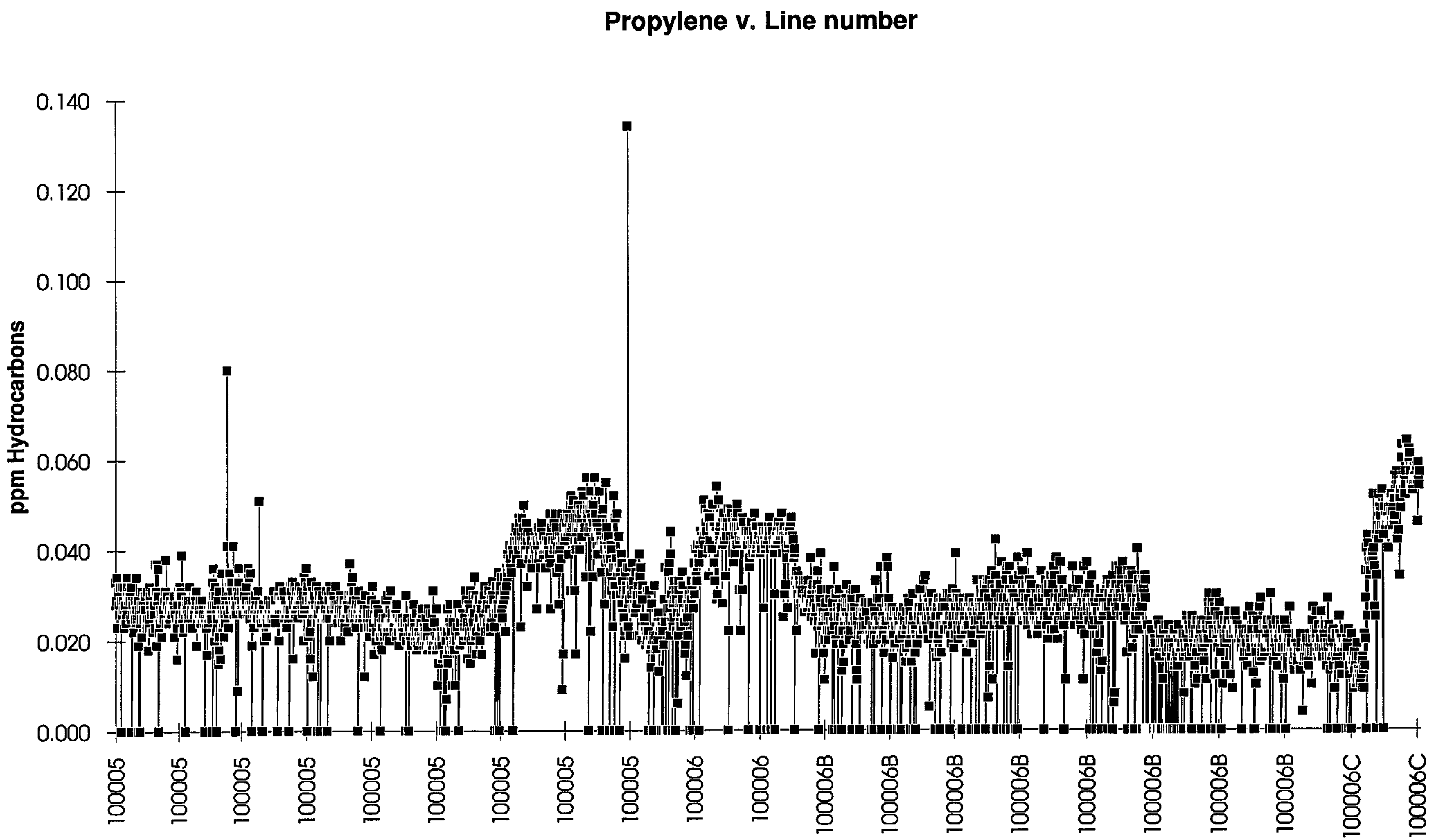

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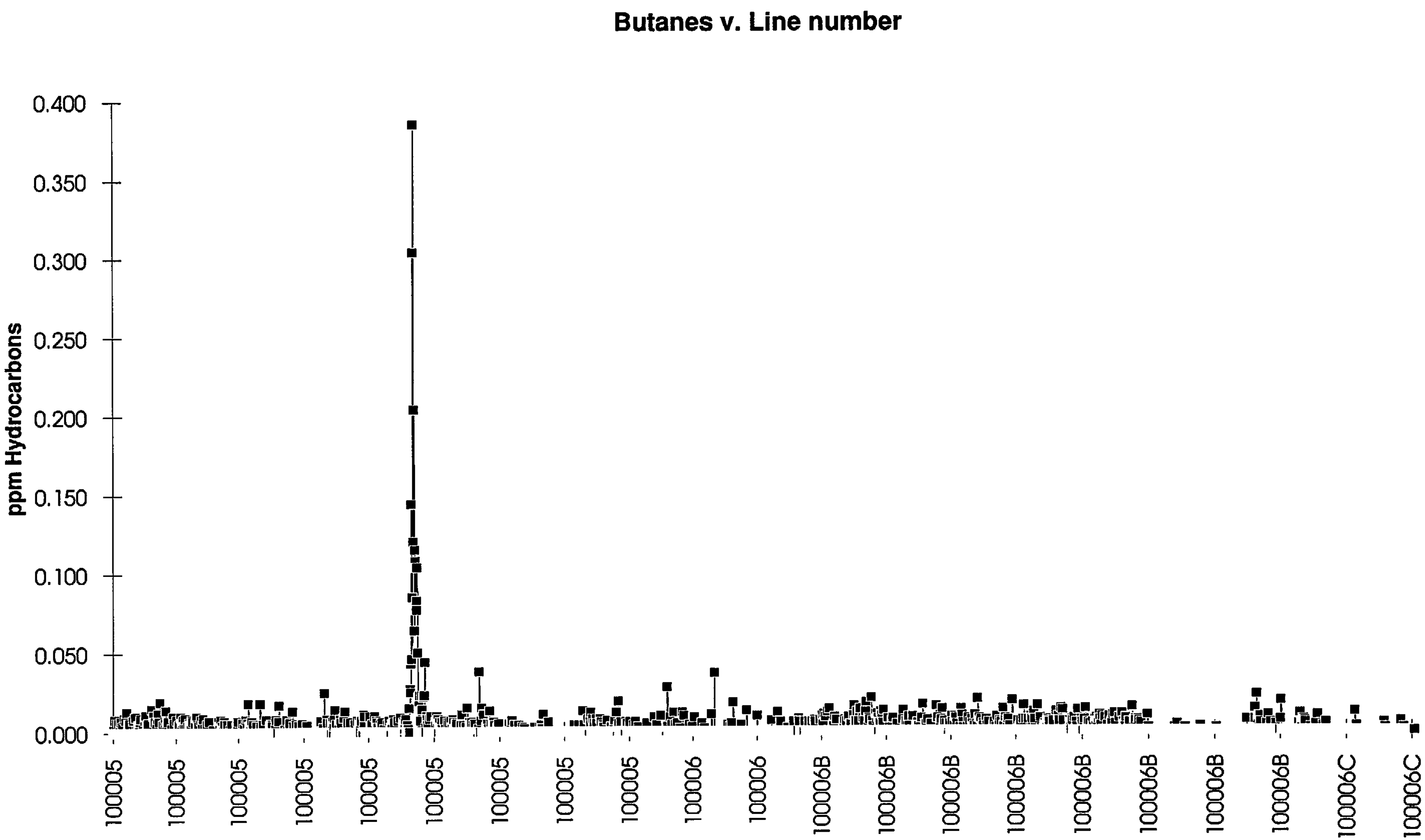

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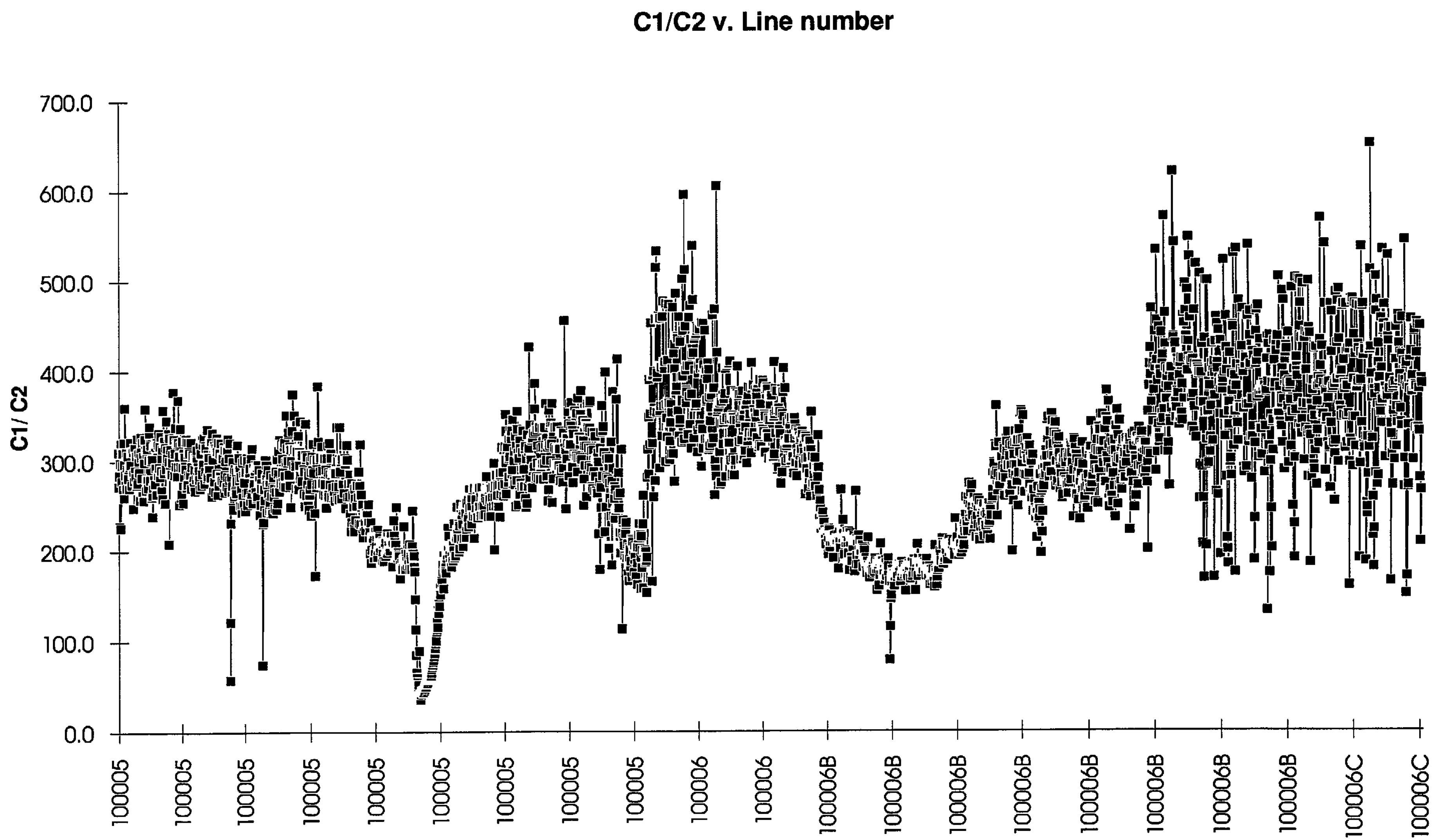

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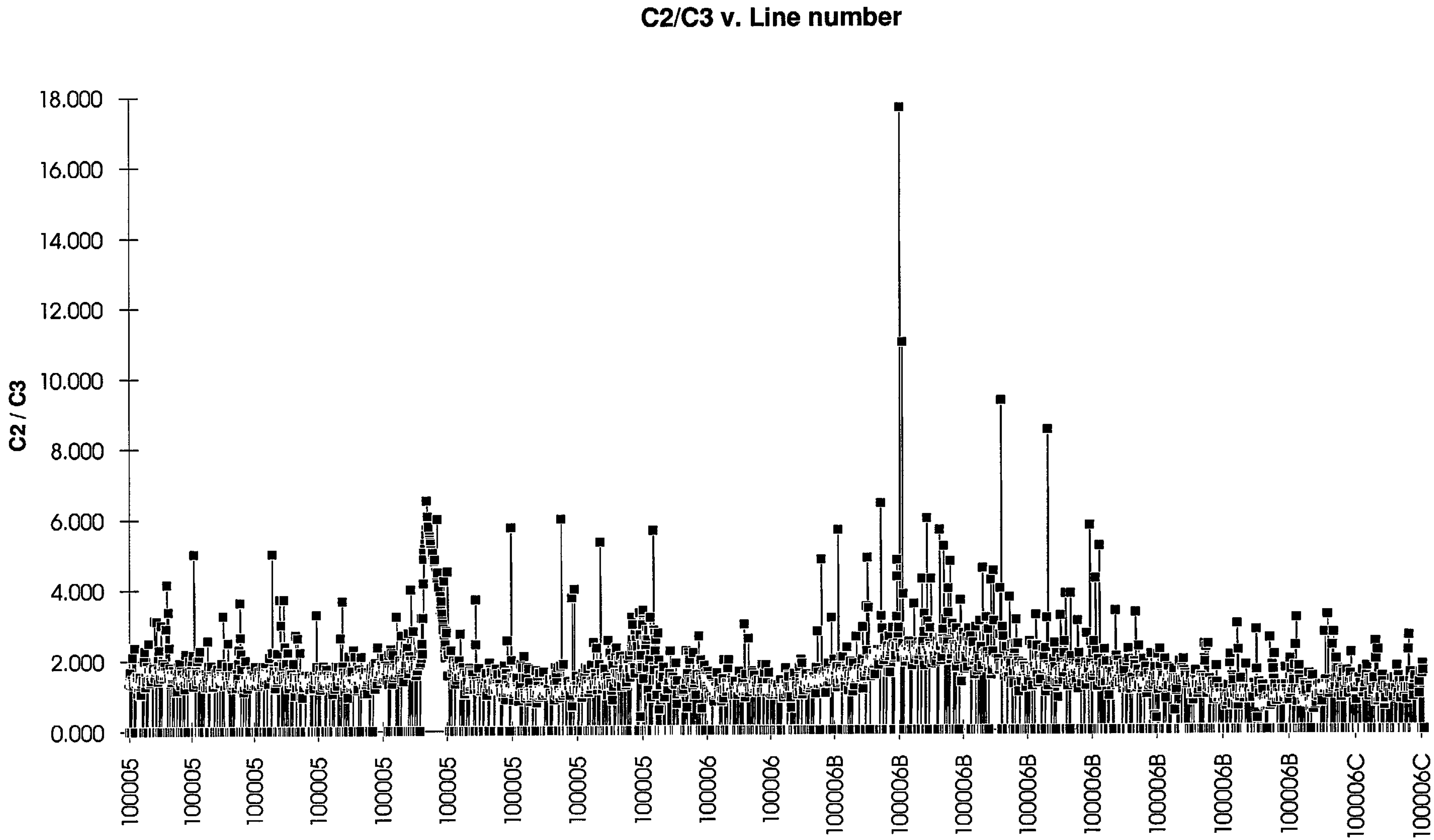

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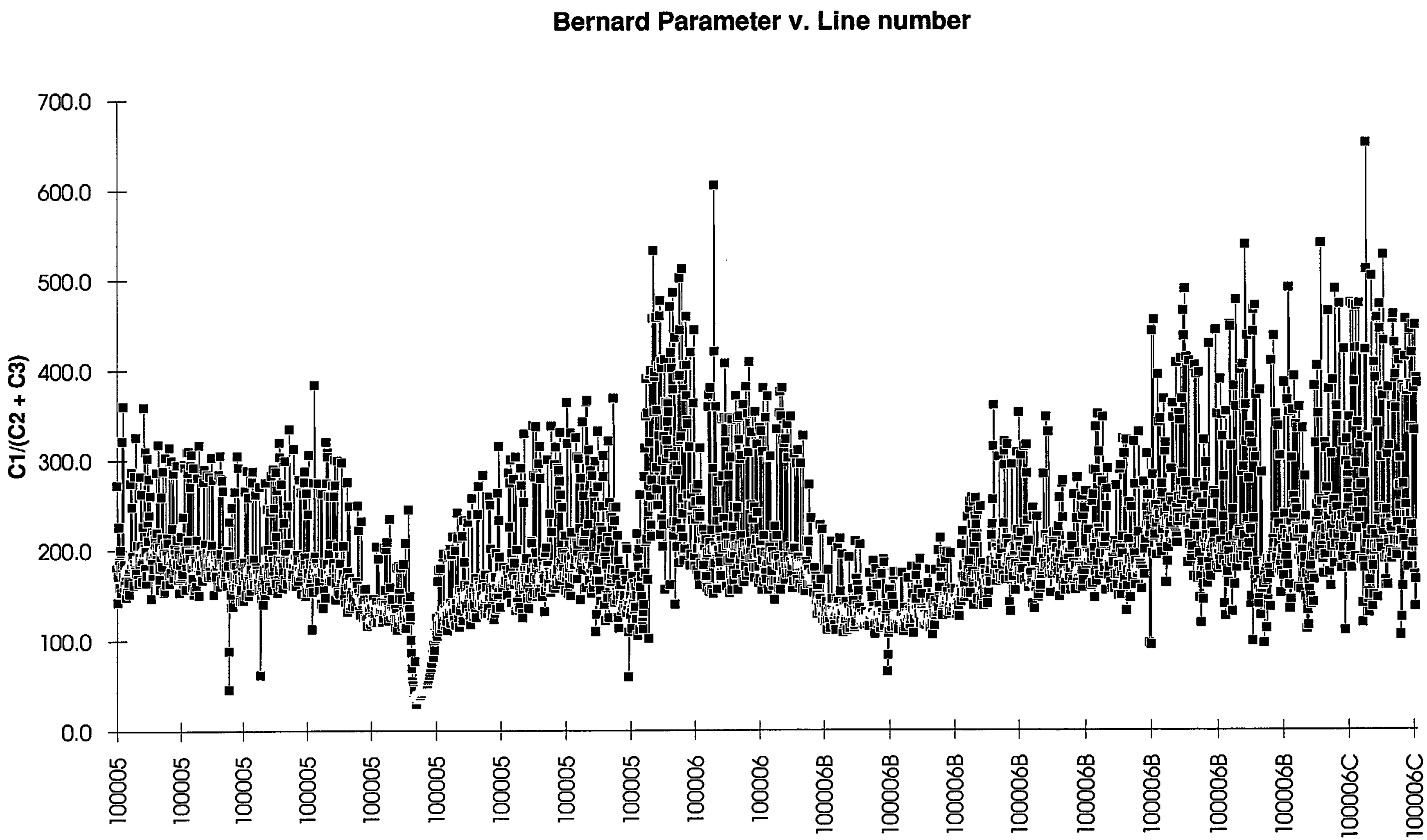

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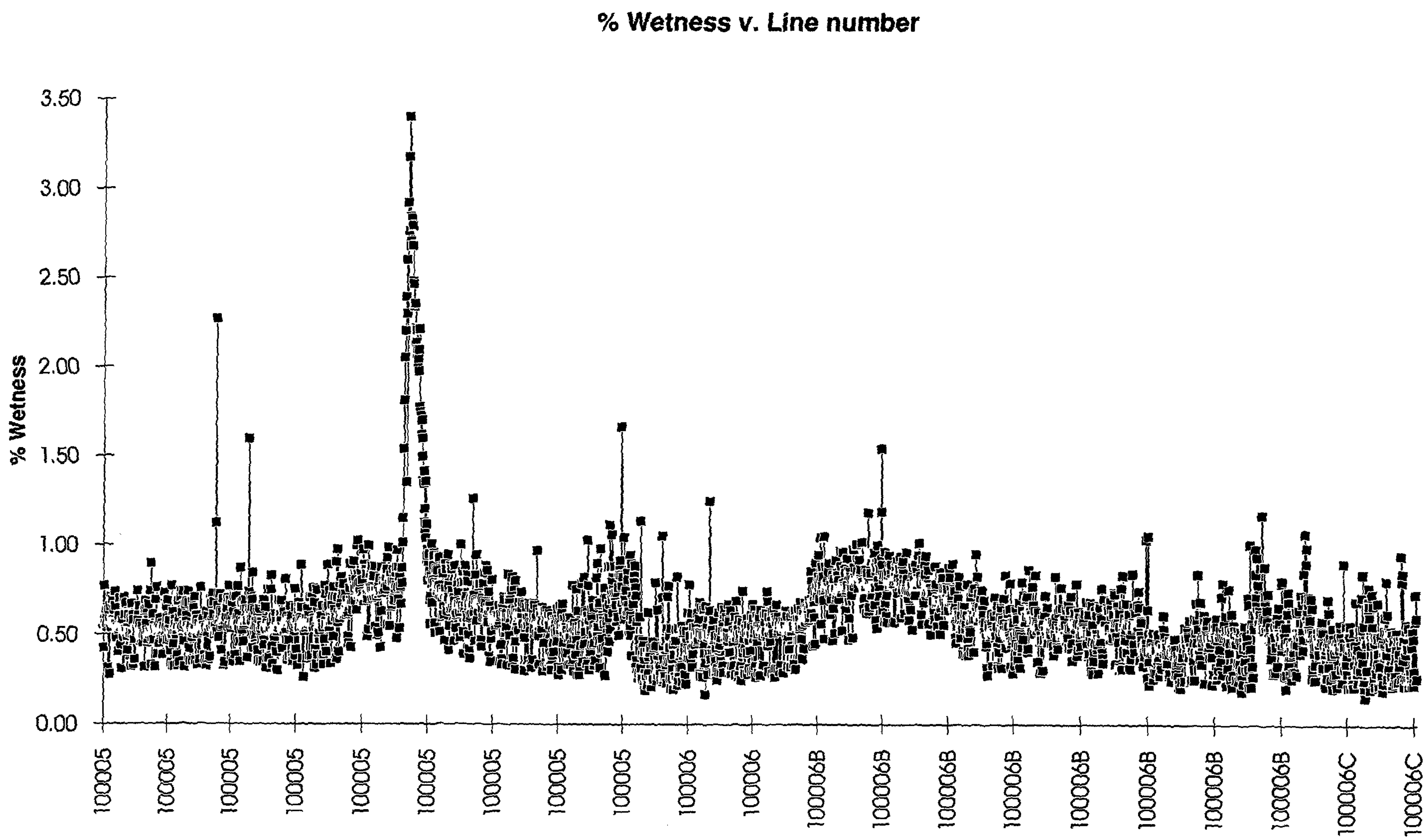

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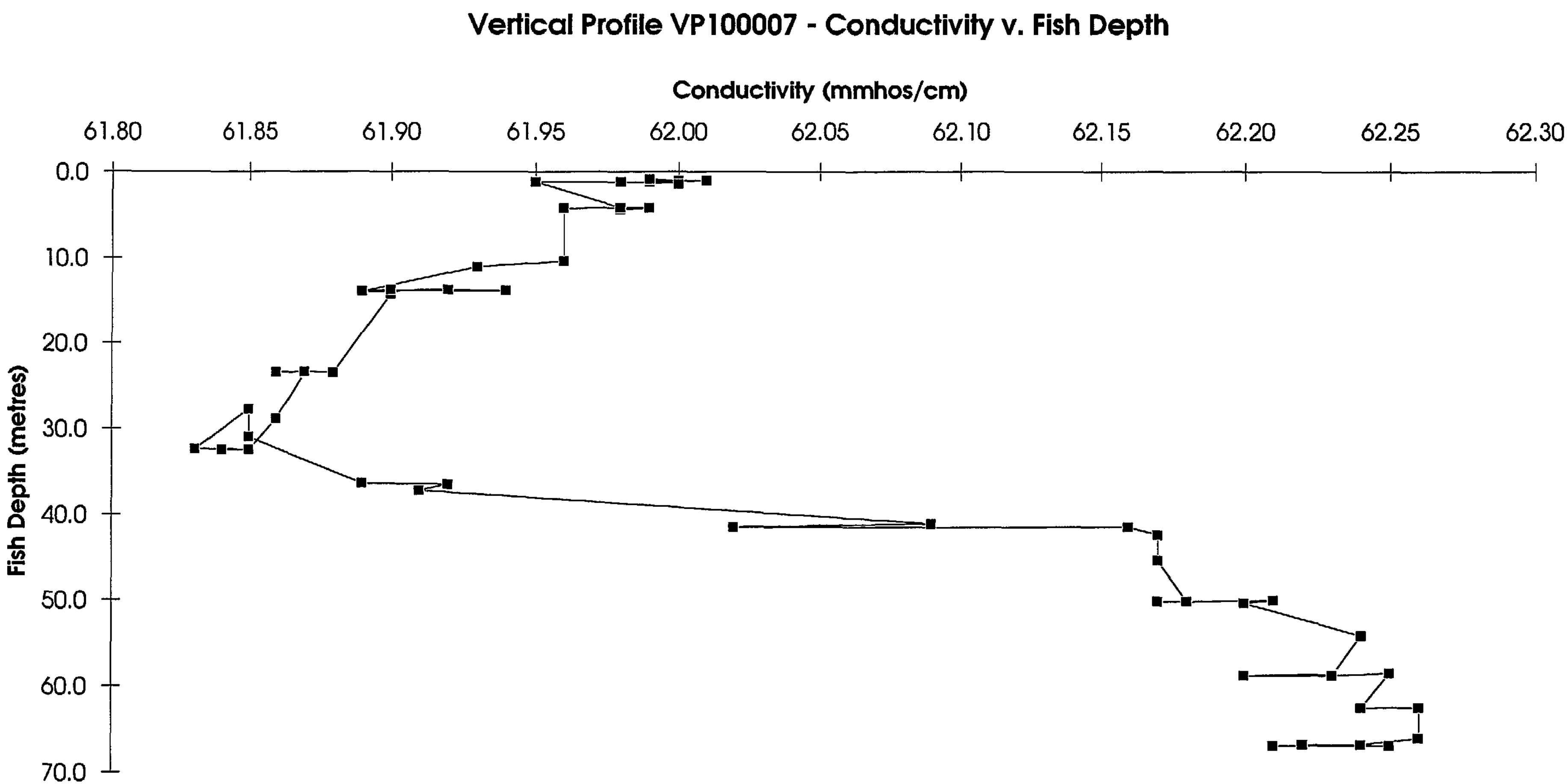

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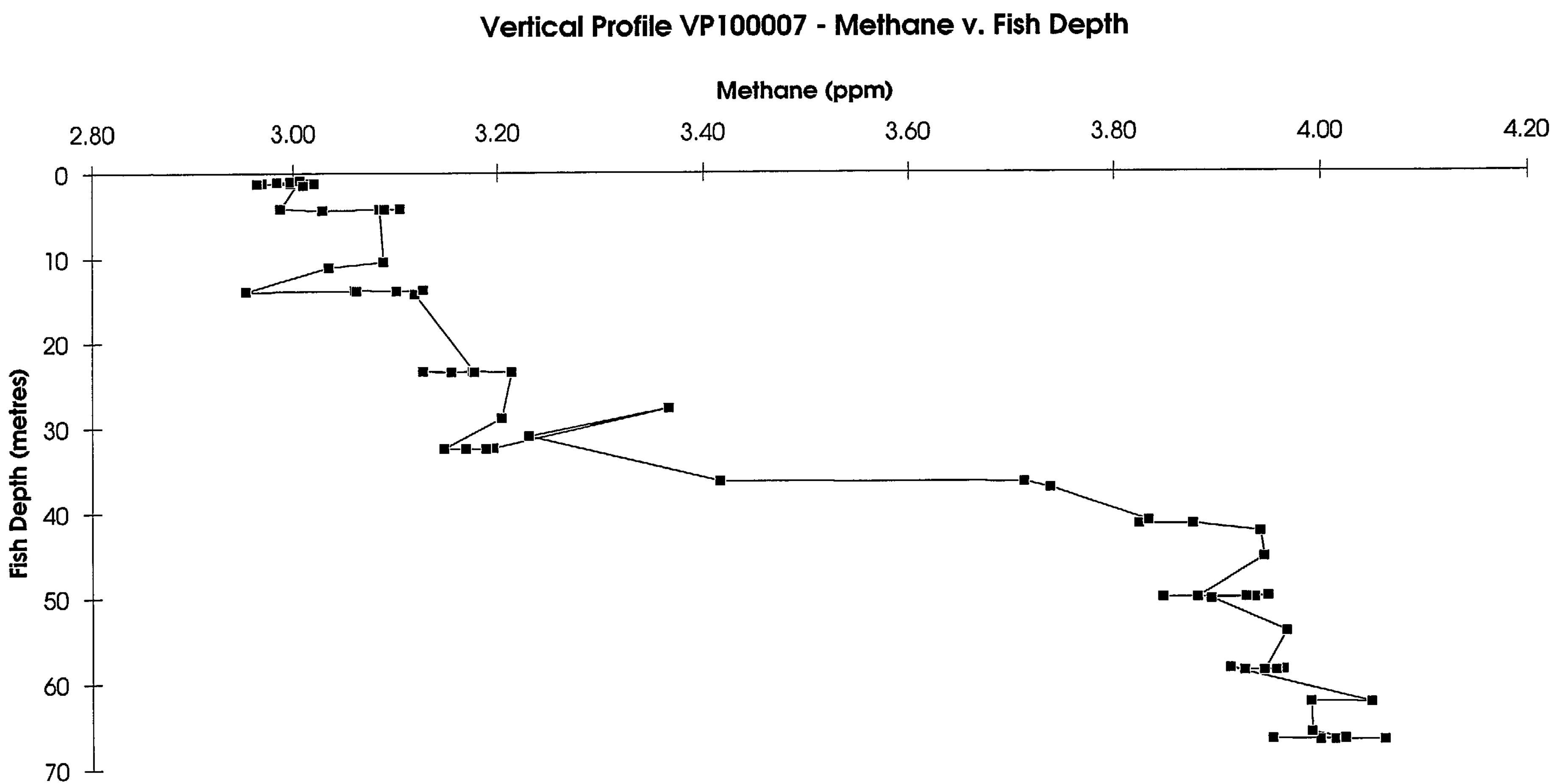

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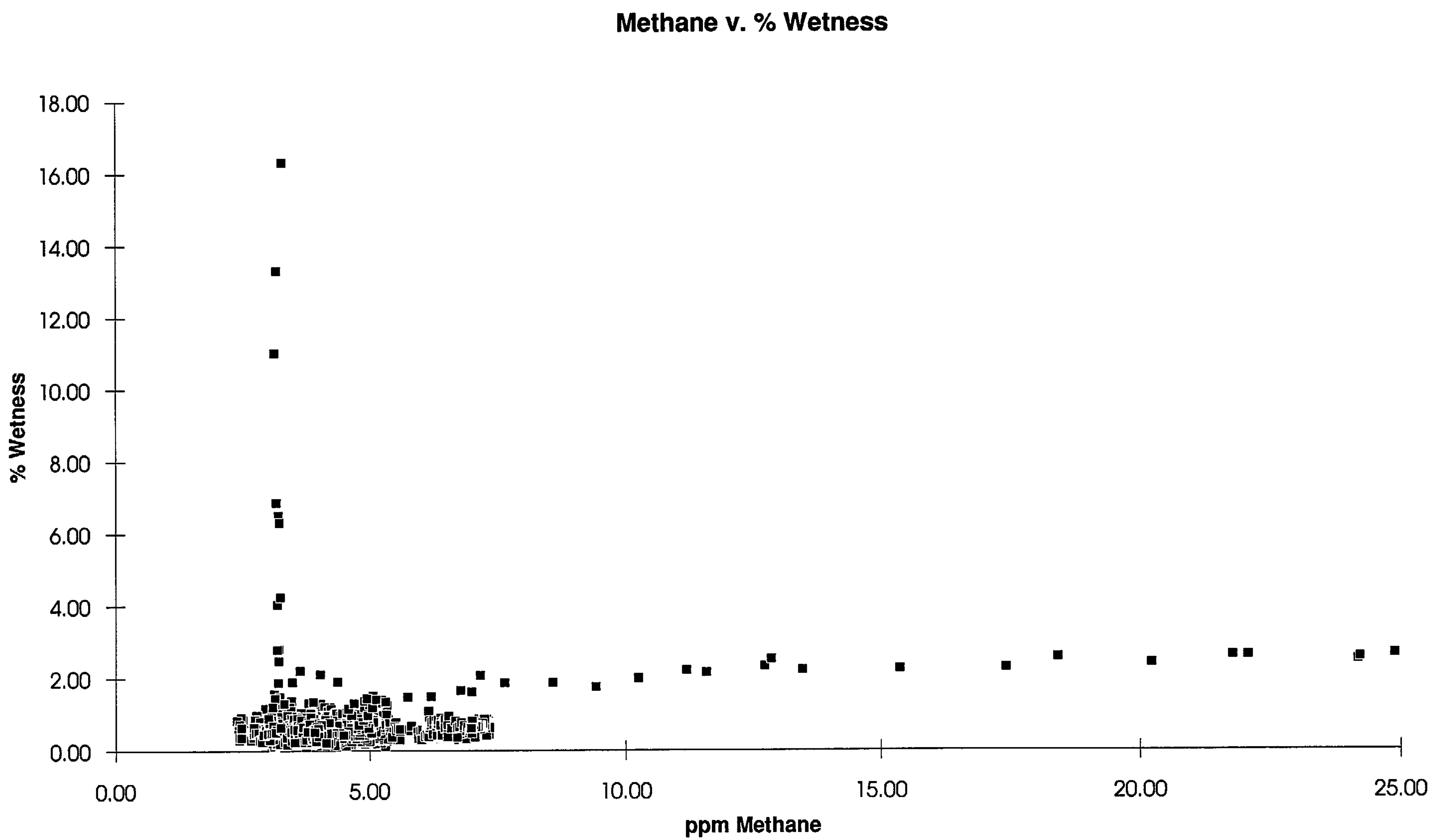

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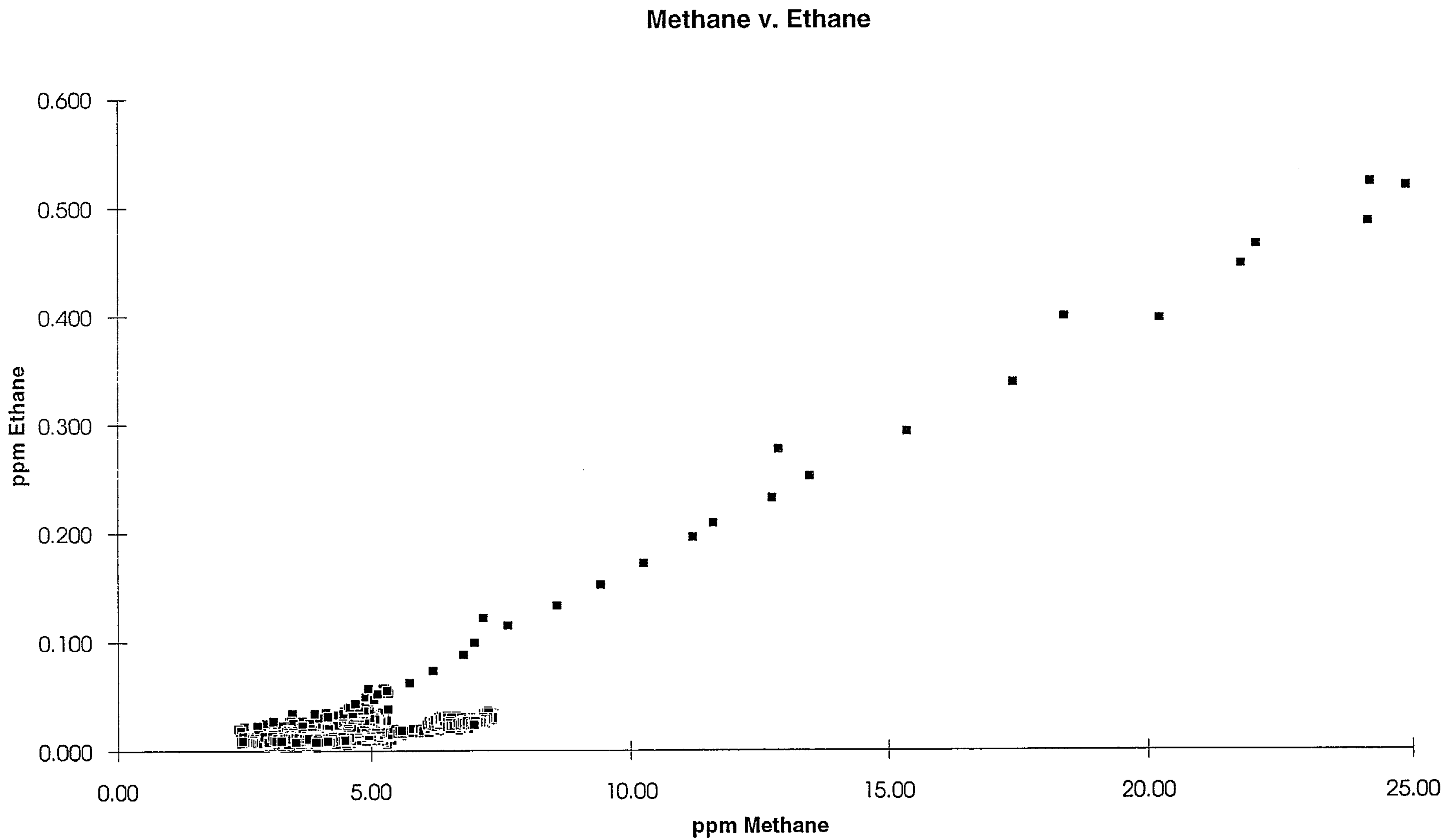

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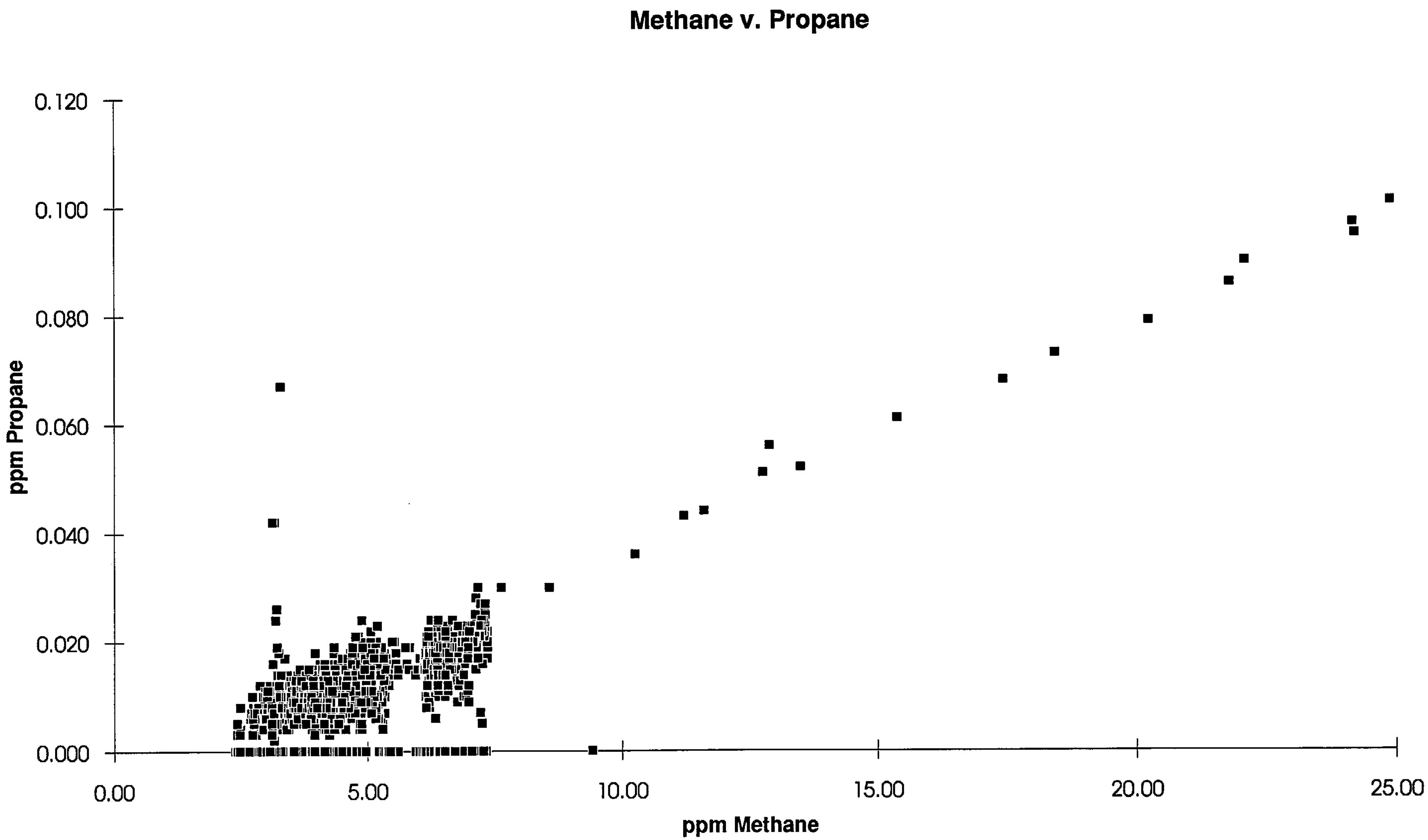

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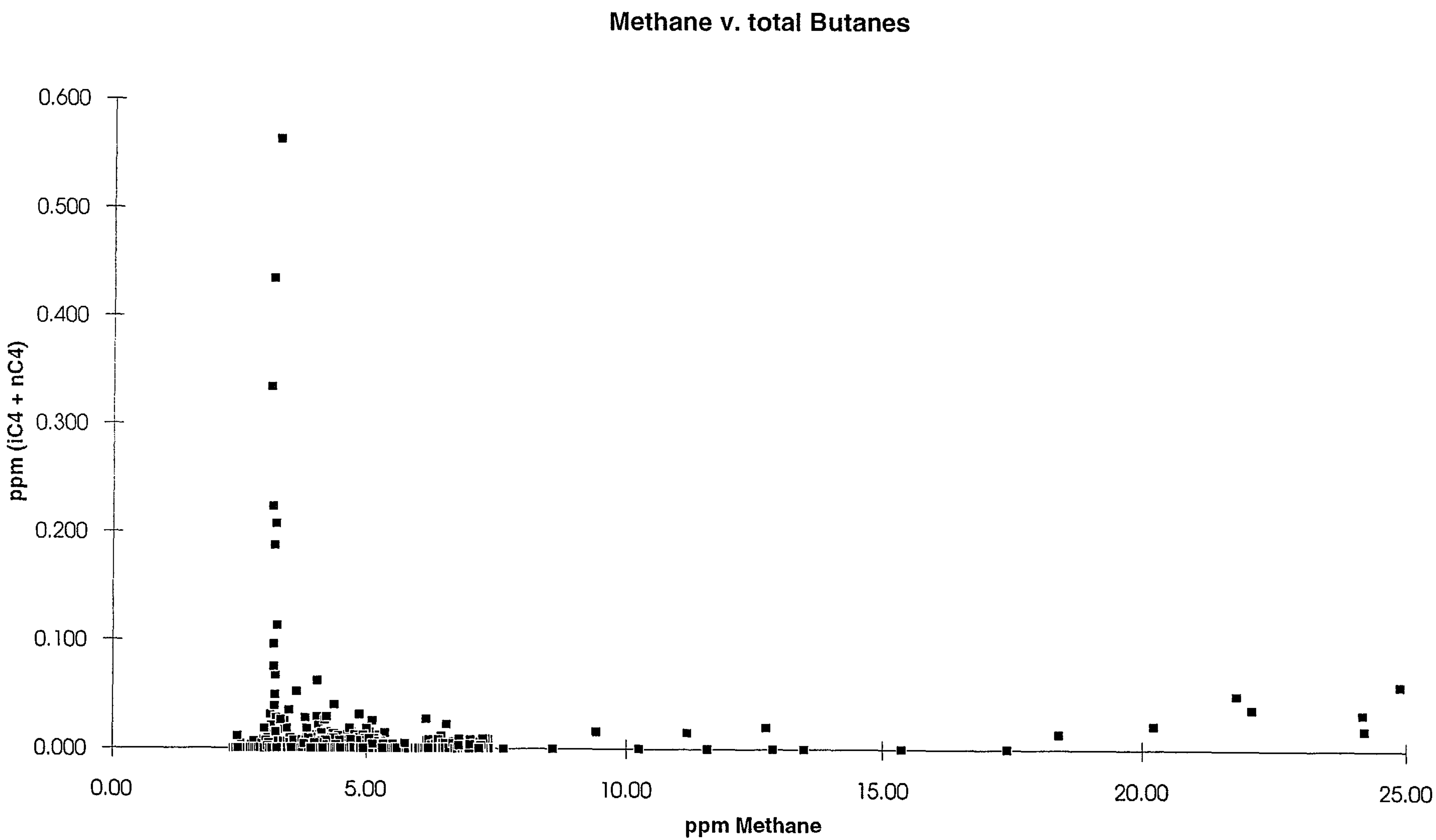

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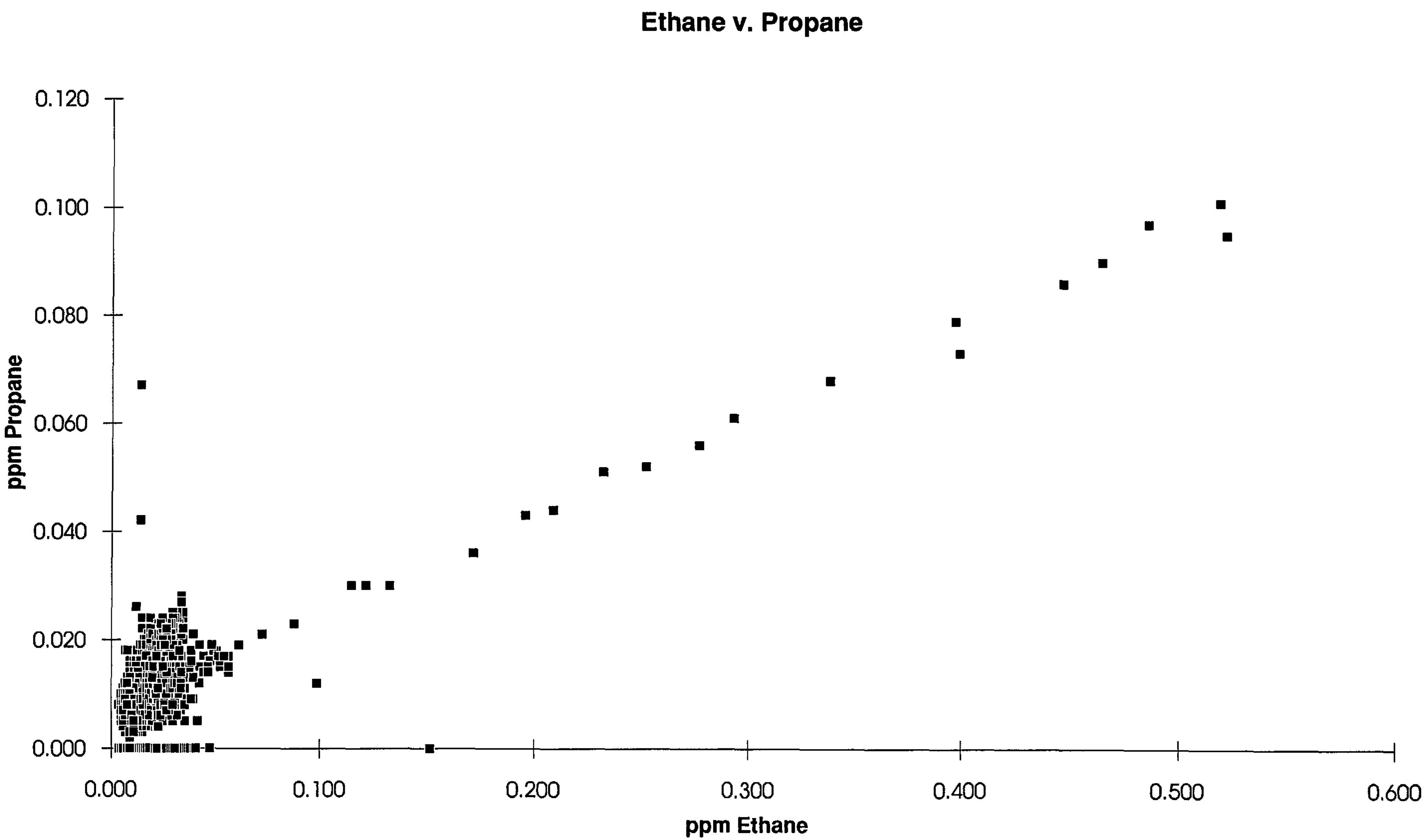

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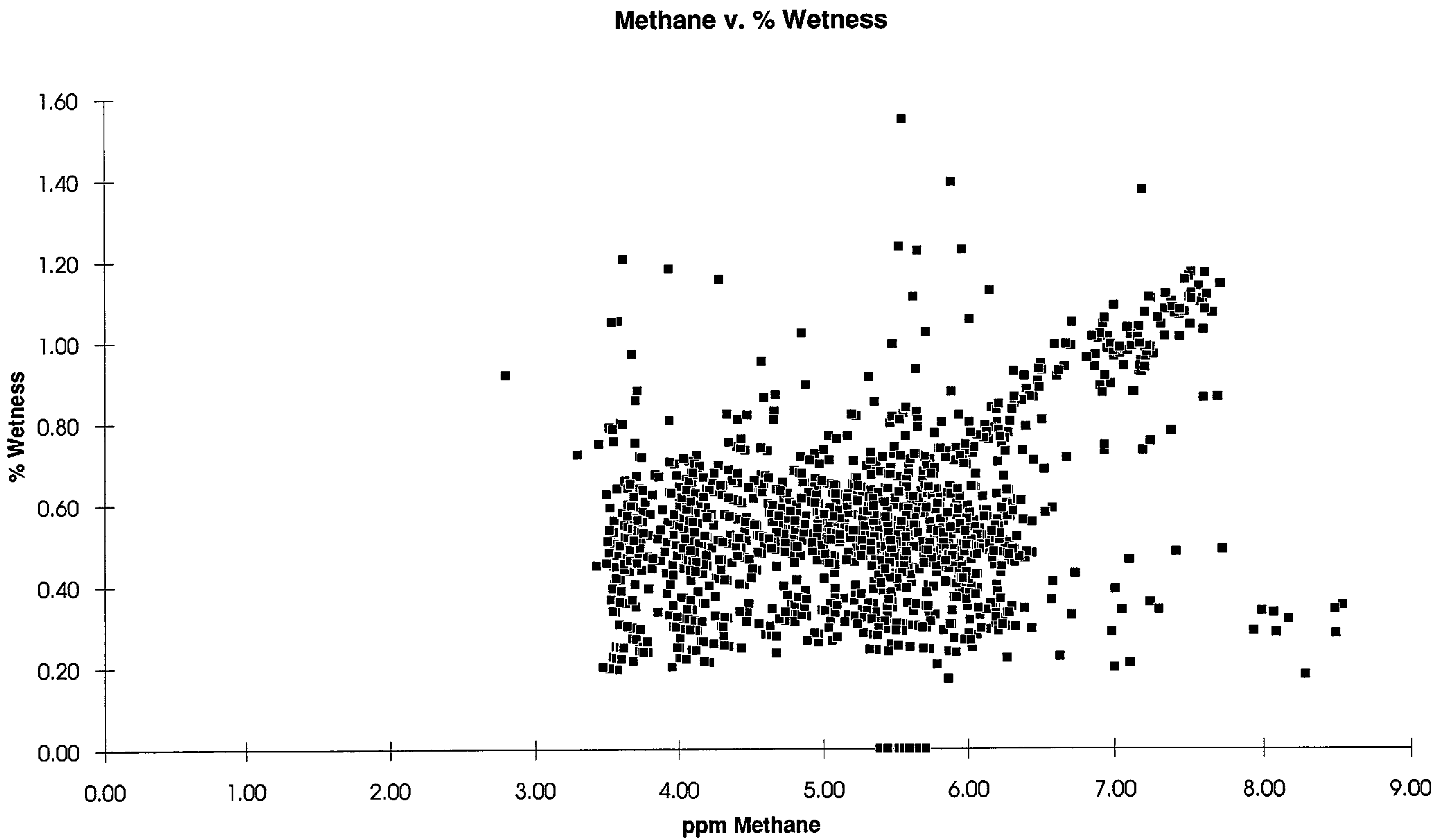

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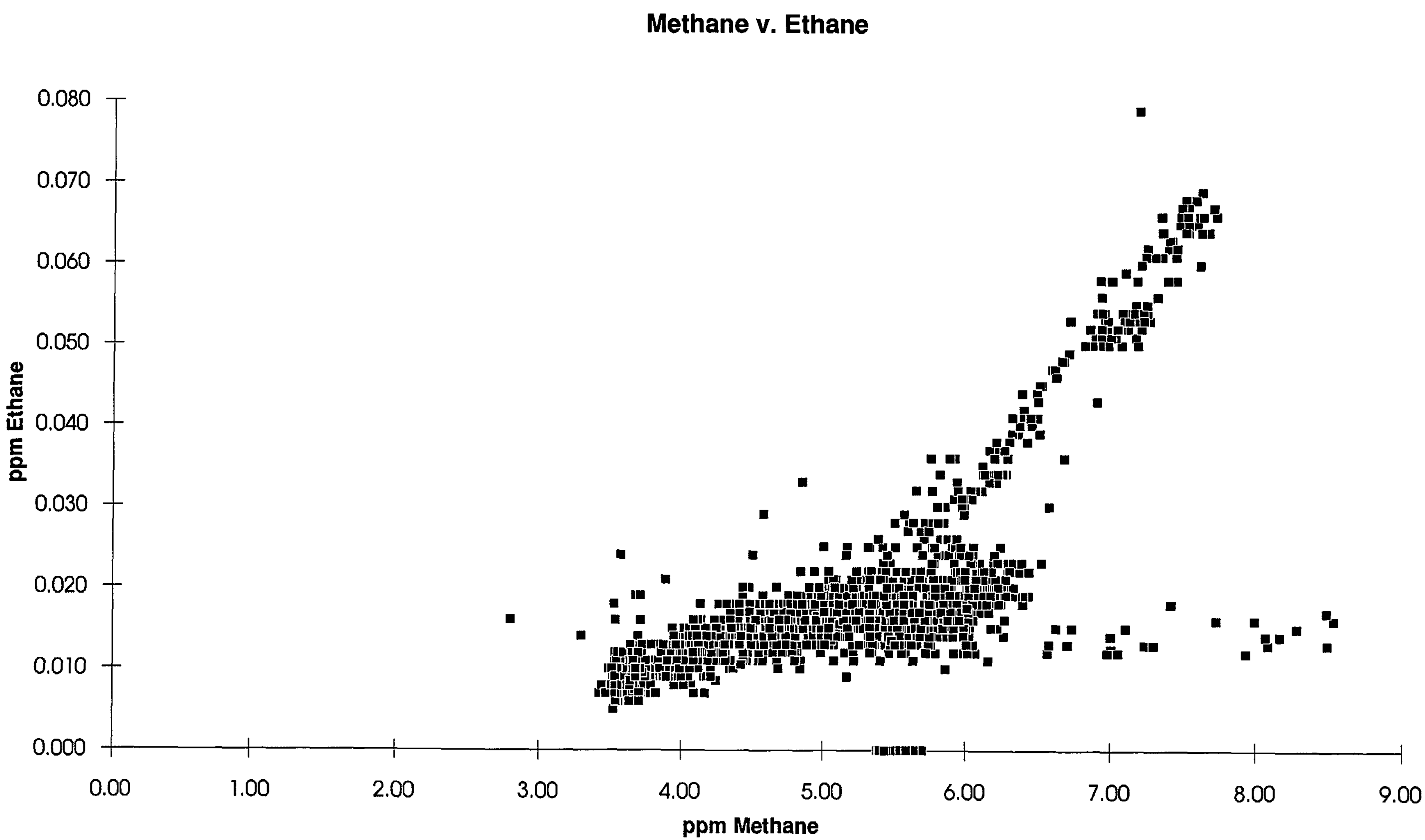

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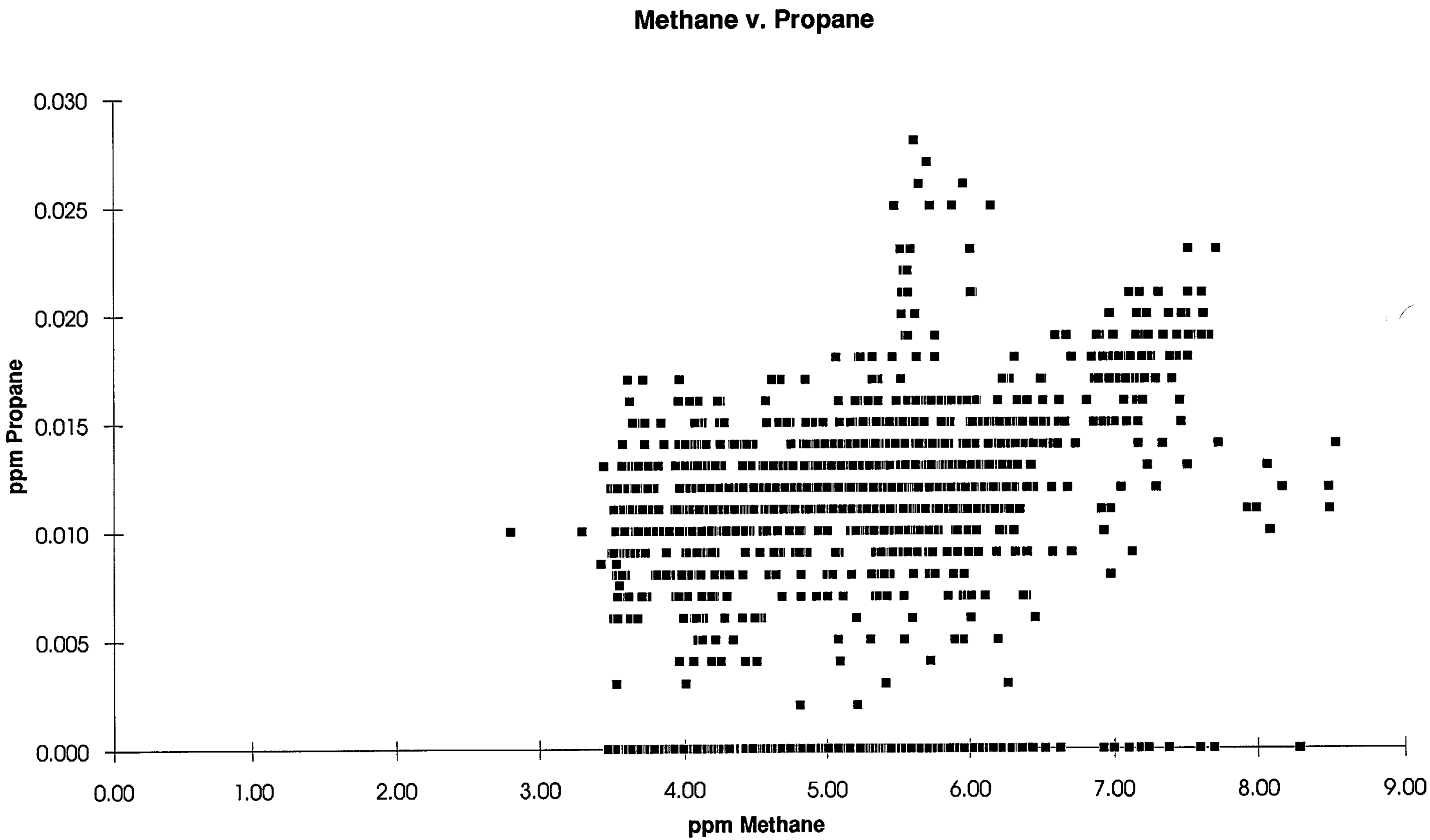

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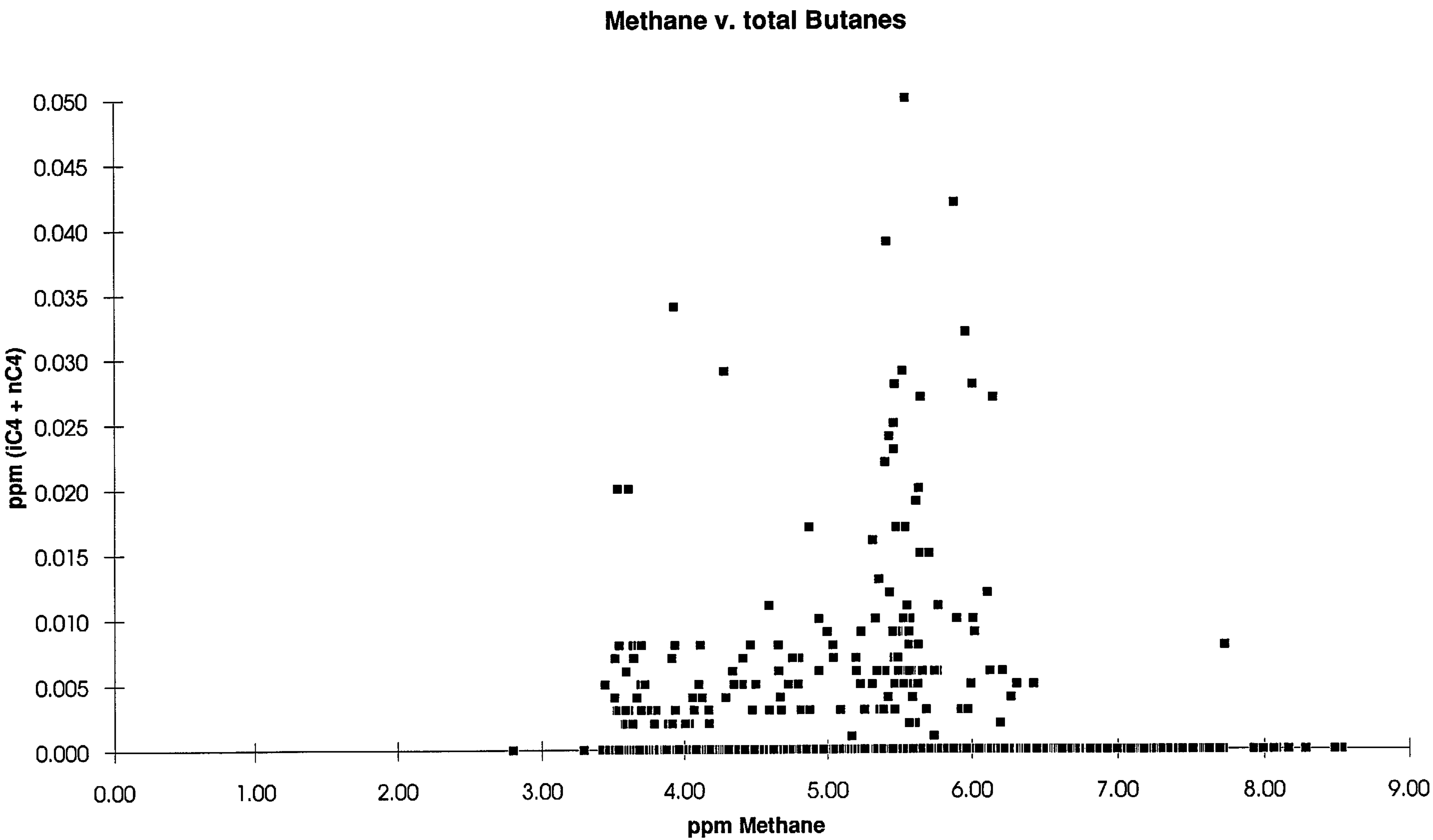
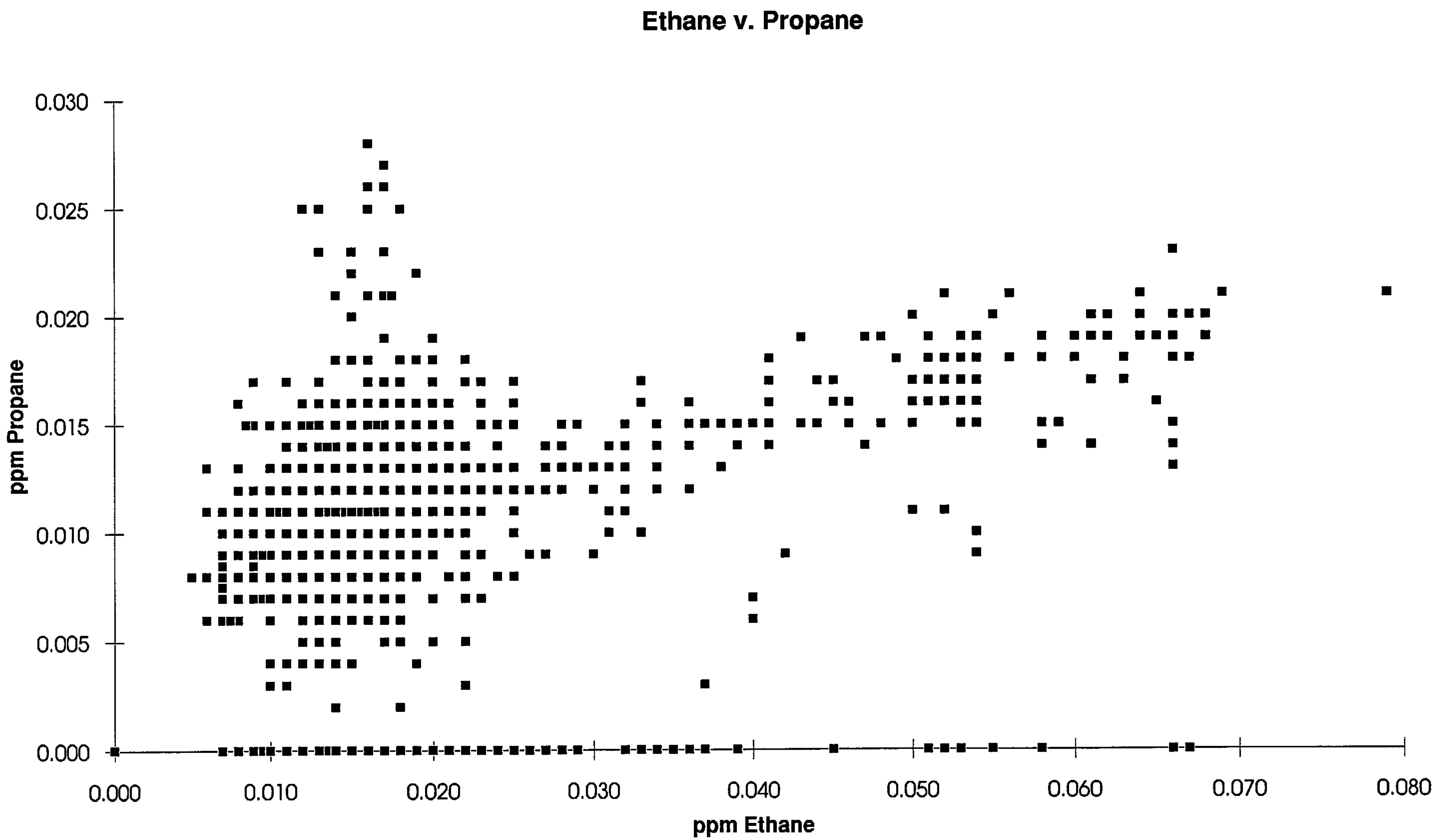


Figure 7d Methane versus total Butanes: Lines 100/004, 100/T1 and 100/007



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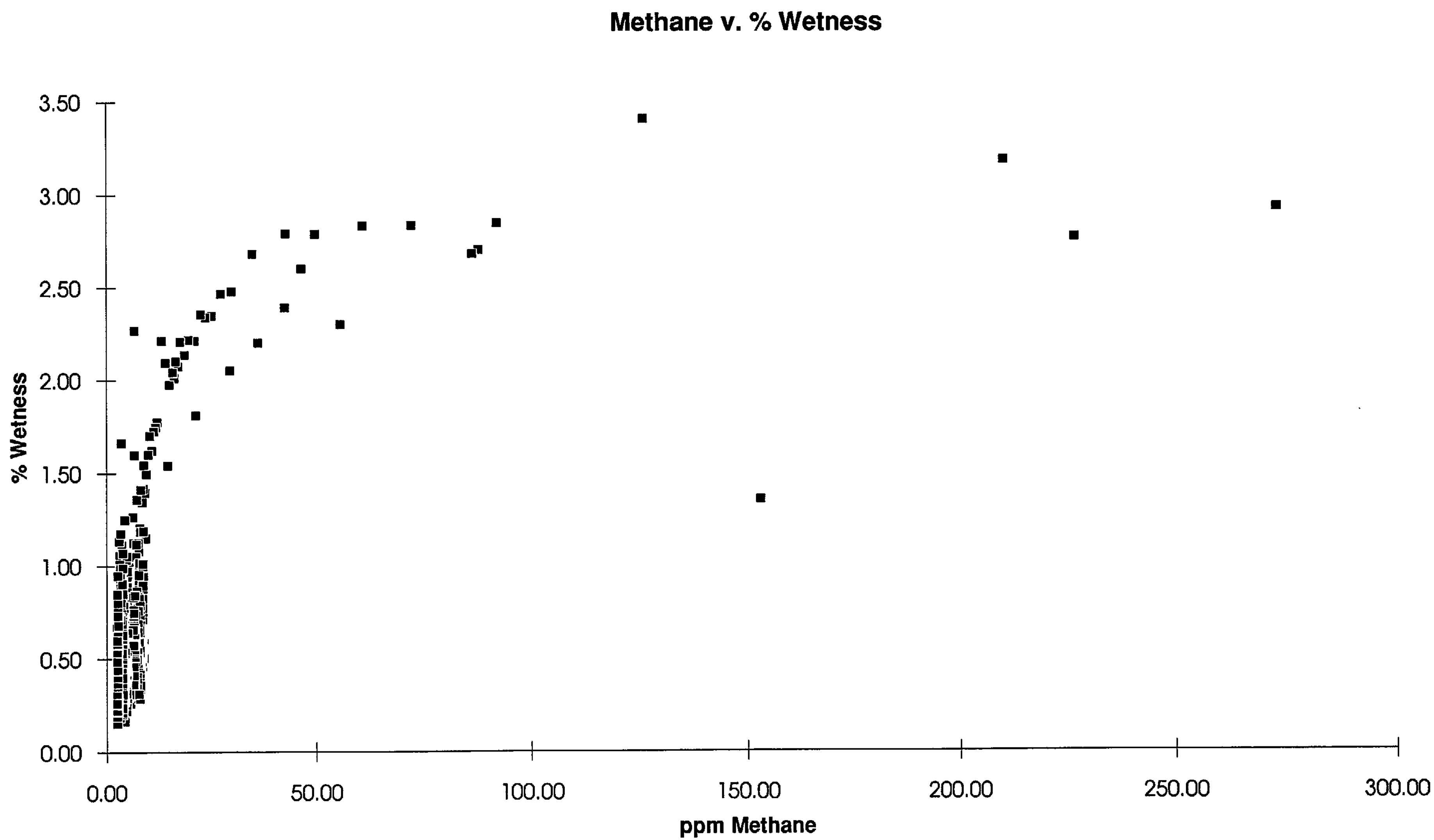

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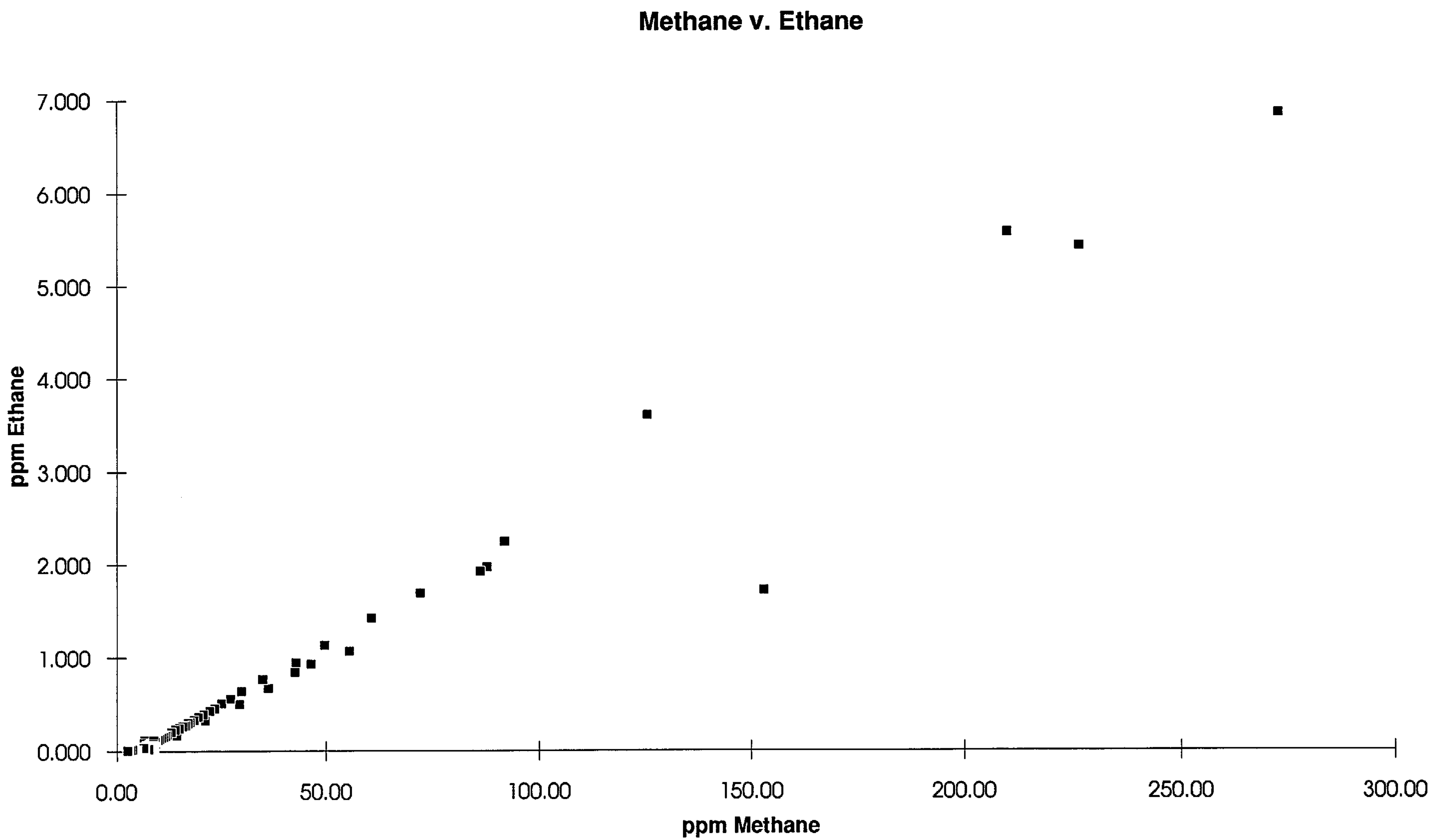

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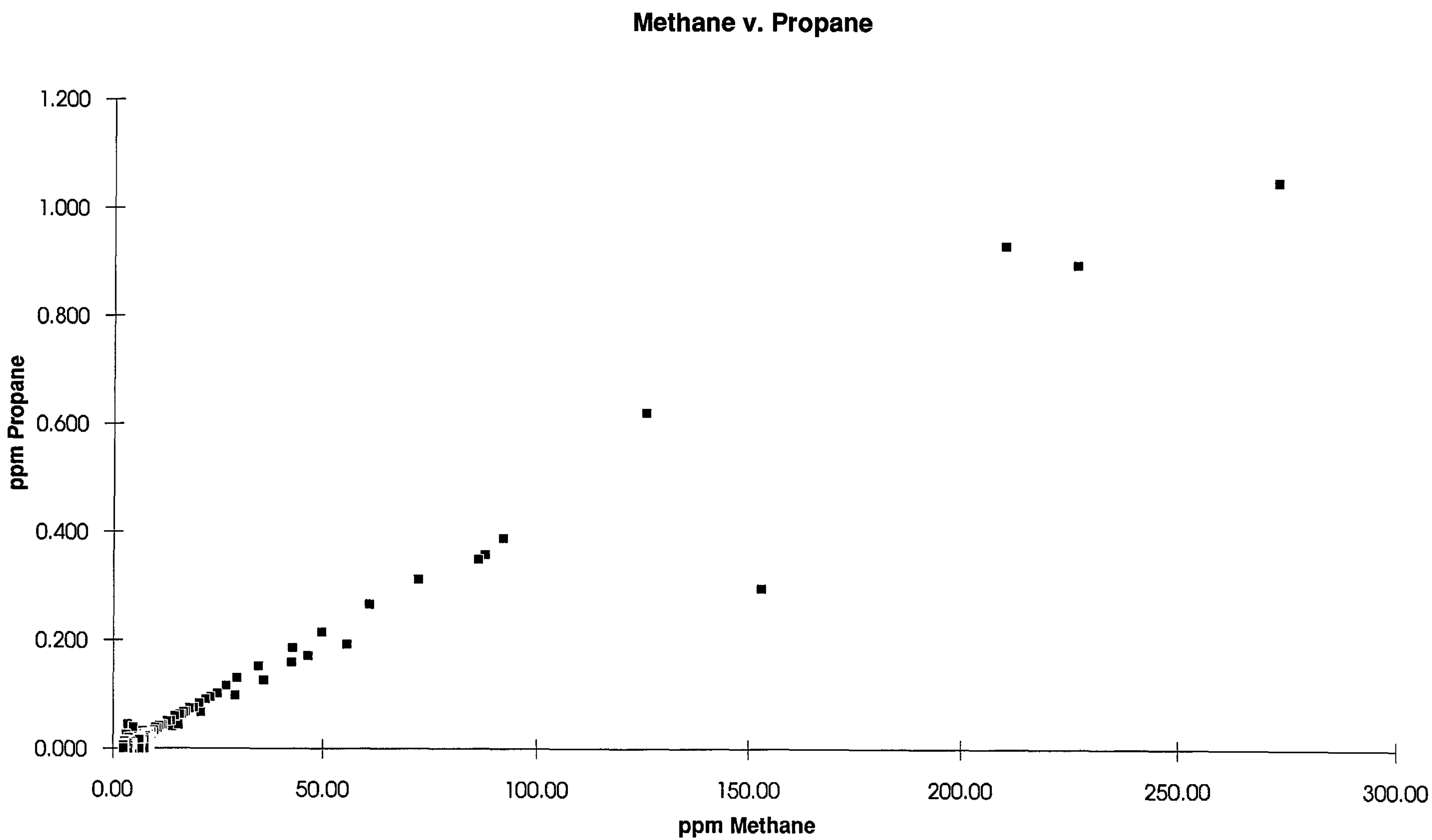

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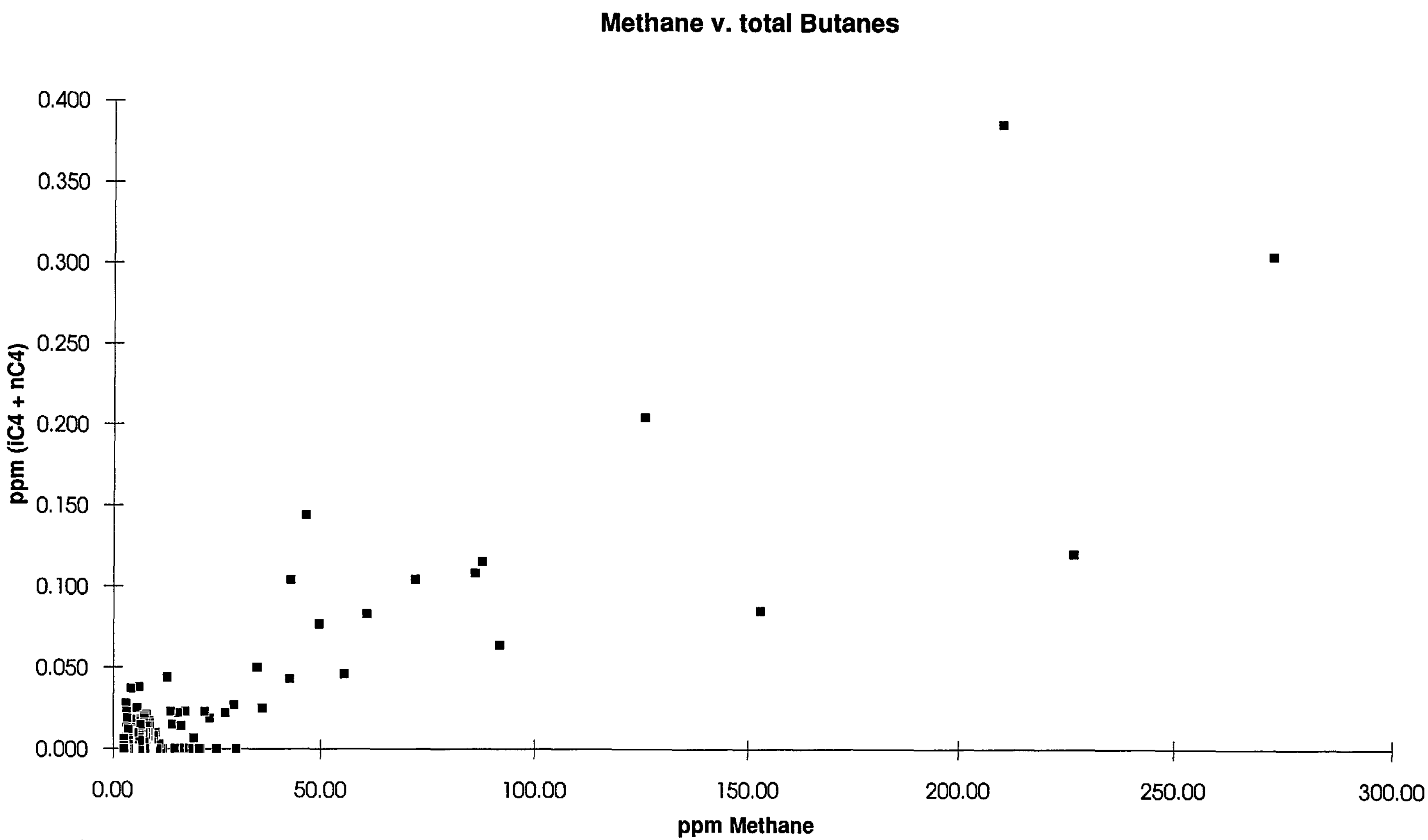


Figure 8d Methane versus total Butanes: Lines 100/005 and 100/006

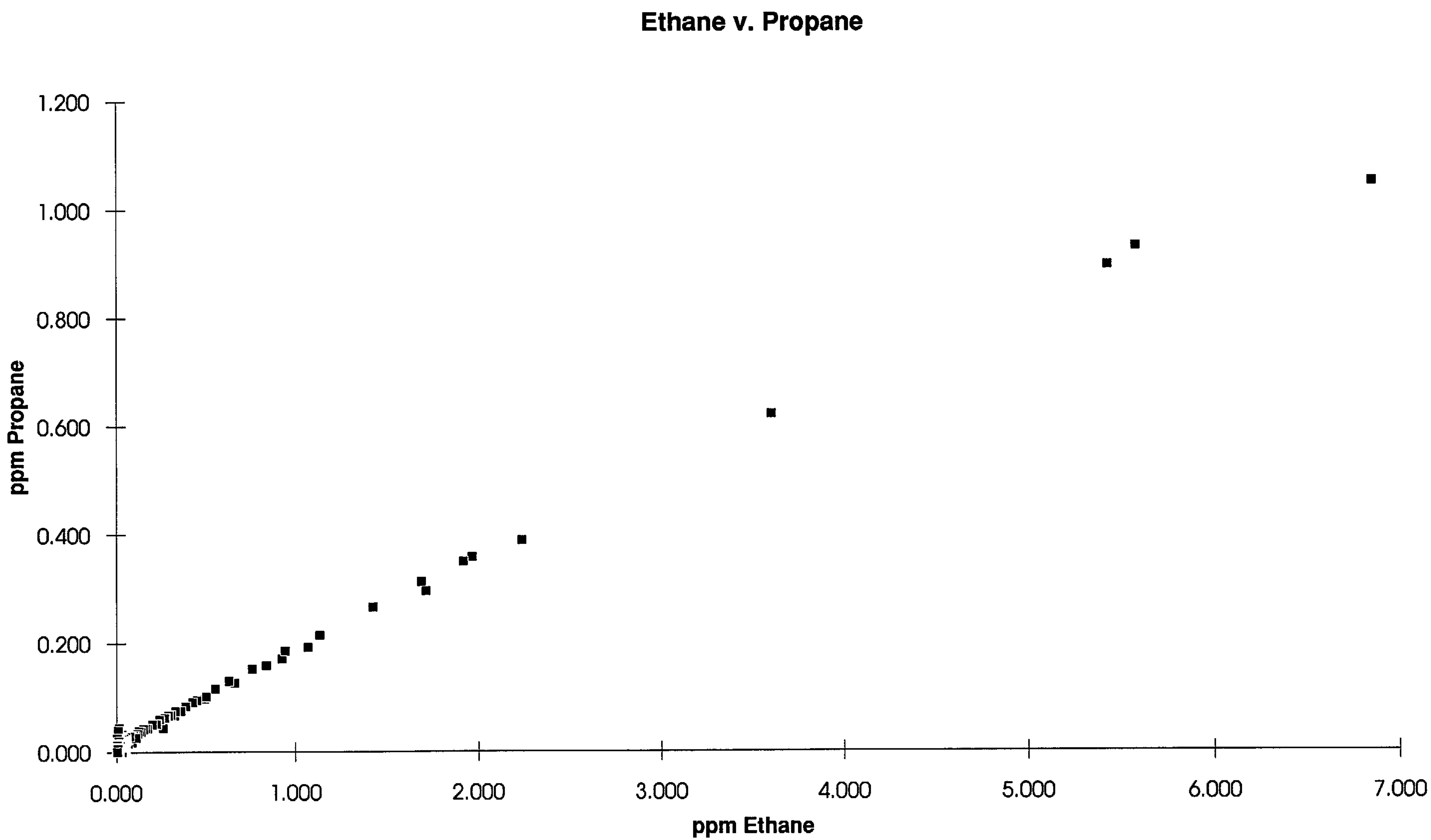


Figure 8e Ethane versus Propane: Lines 100/005 and 100/006

Appendix I

Individual line plots and line summary sheets

Line Summary

Line Number	100001
No. of Shotpoints	668

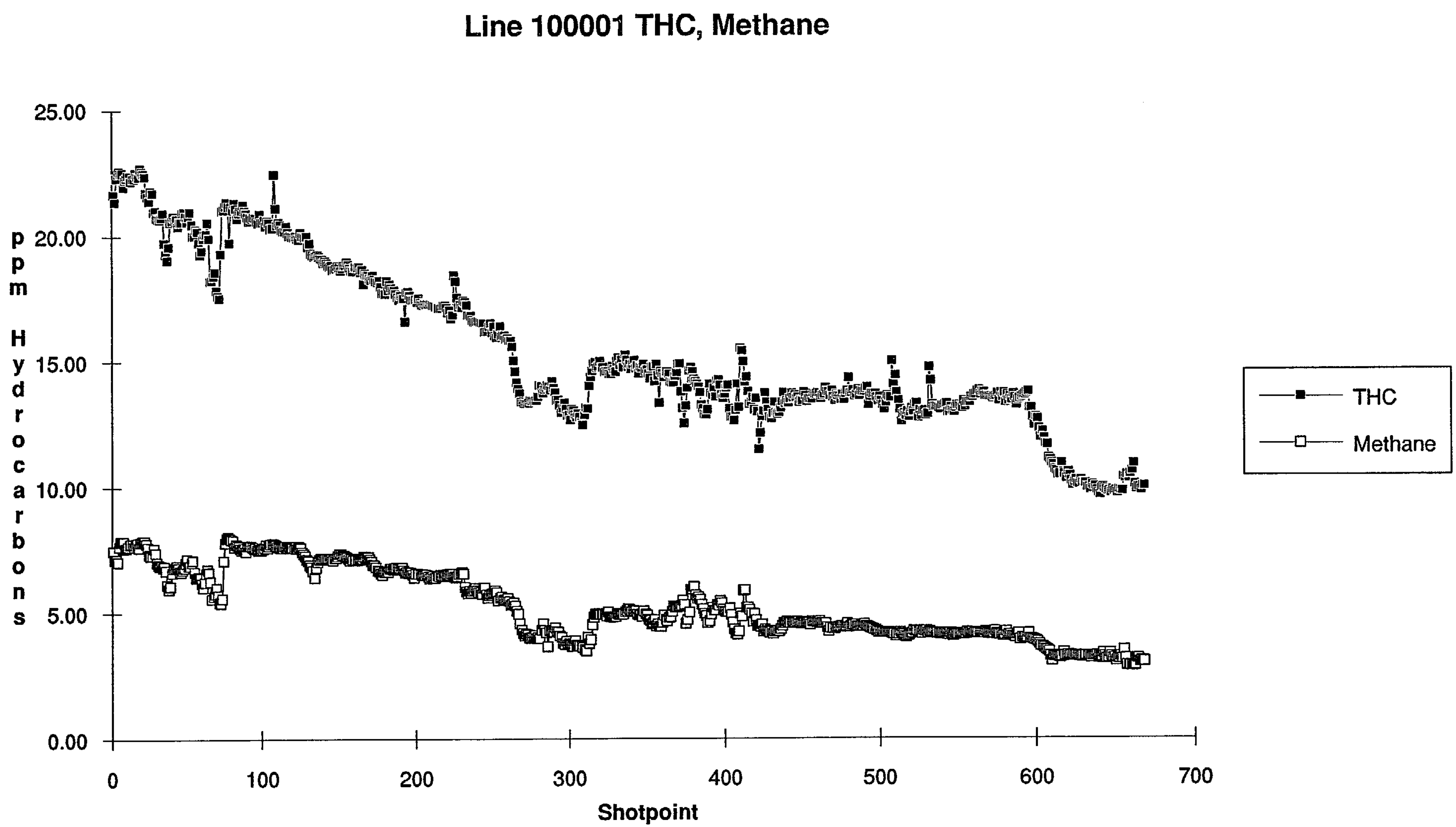
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	9-Apr-91	04:49:17	13	07.808	129	46.204
End	670	10-Apr-91	08:04:34	14	28.452	128	25.485

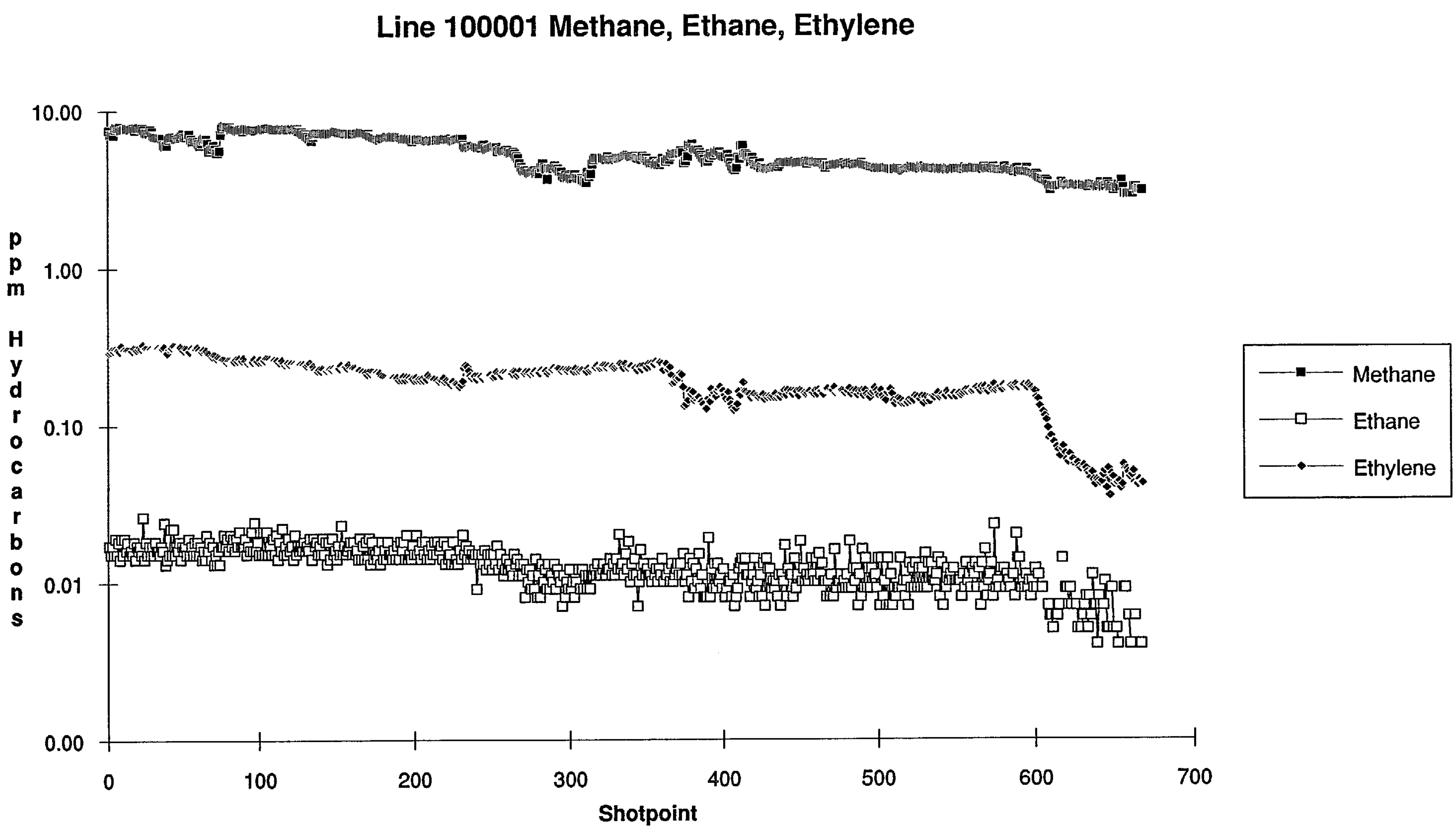
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	15.483	5.278	0.013	0.193	0.012	0.043	0.001	0.001	0.004	0.163	0.001	0.019	0.487
Std. Dev.	3.349	1.432	0.004	0.066	0.008	0.013	0.002	0.004	0.005	0.065	0.004	0.014	0.179
Minimum	9.649	2.863	0.004	0.035	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.124
Maximum	22.675	8.016	0.026	0.327	0.044	0.072	0.030	0.033	0.032	0.319	0.061	0.092	1.323

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	63.503	29.937	28.013	39.592	11.580
Std. Dev.	1.393	1.158	5.455	4.458	2.604
Minimum	60.610	27.330	13.100	30.600	6.300
Maximum	65.780	31.590	38.500	51.800	21.000

Notes

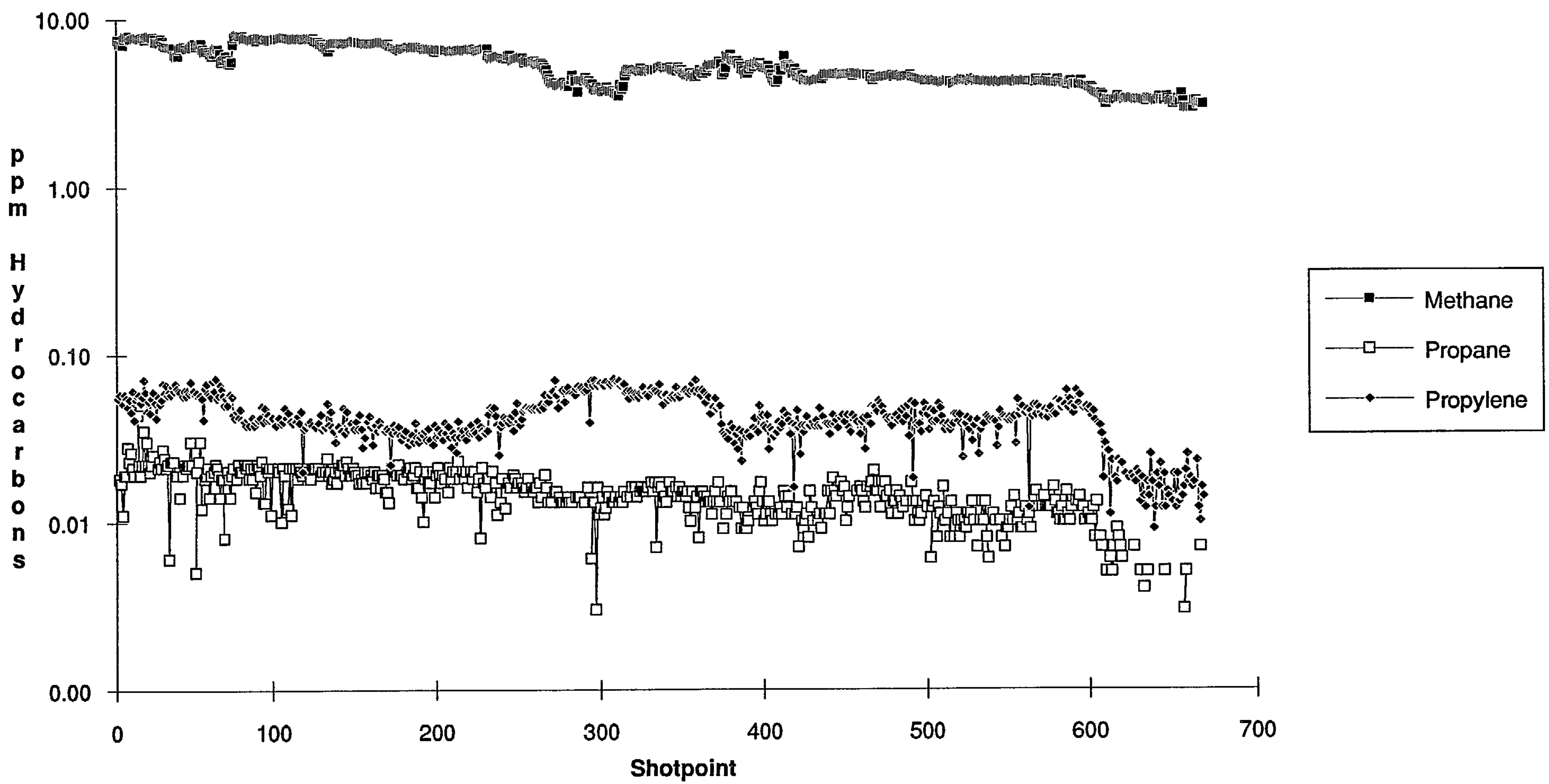
High THC and C1 concentrations at start of line probably due to retermination prior to start of line.
Weak C4 anomaly from sp 452 to 480 (approx).

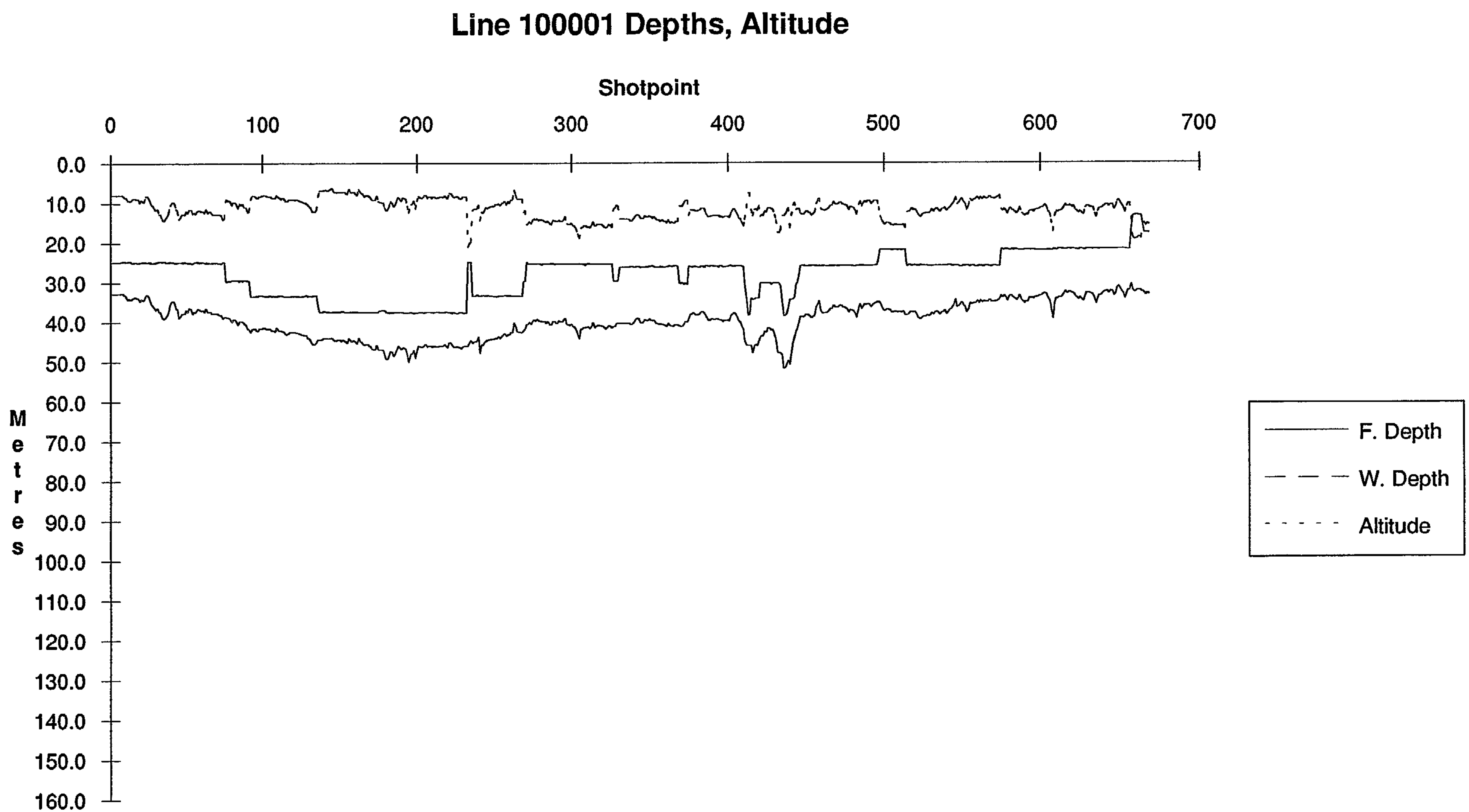

Line 100001 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane



Line 100001 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 100001 Methane, Propane, Propylene




Line 100001 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
130.0
140.0
150.0
160.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	100001A
No. of Shotpoints	715

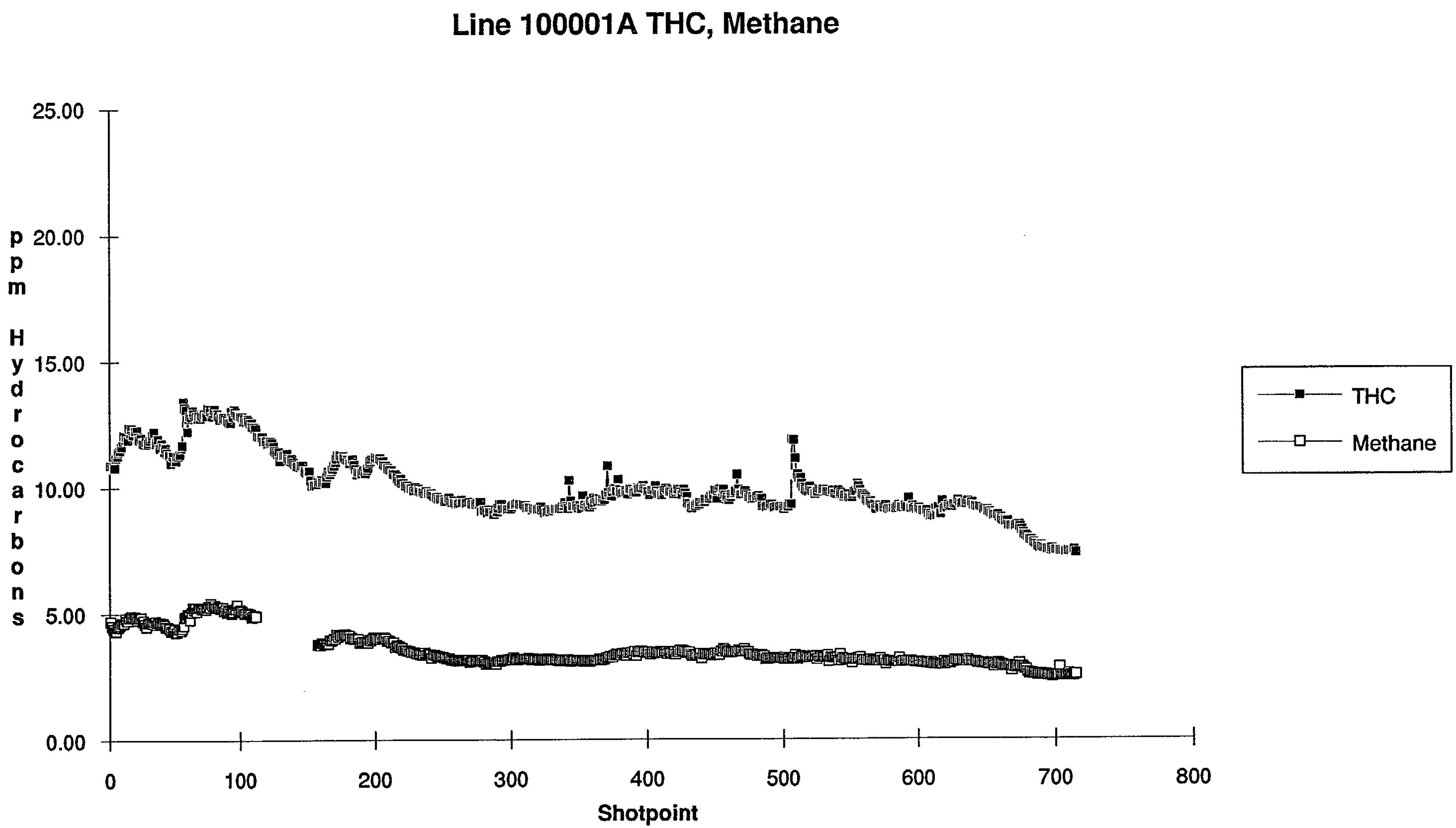
	Shotpoint	Date	Time	Latitude		Longitude	
Start	3	14-Apr-91	11:20:22	13	08.091	129	45.890
End	717	15-Apr-91	11:22:50	14	28.717	128	25.251

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.985	3.494	0.012	0.122	0.006	0.029	0.001	0.003	0.005	0.129	0.004	0.023	0.644
Std. Dev.	1.292	0.693	0.004	0.028	0.005	0.008	0.011	0.023	0.006	0.050	0.014	0.017	1.019
Minimum	7.336	2.431	0.004	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.106
Maximum	13.380	5.405	0.034	0.185	0.067	0.049	0.176	0.387	0.030	0.382	0.120	0.113	16.300

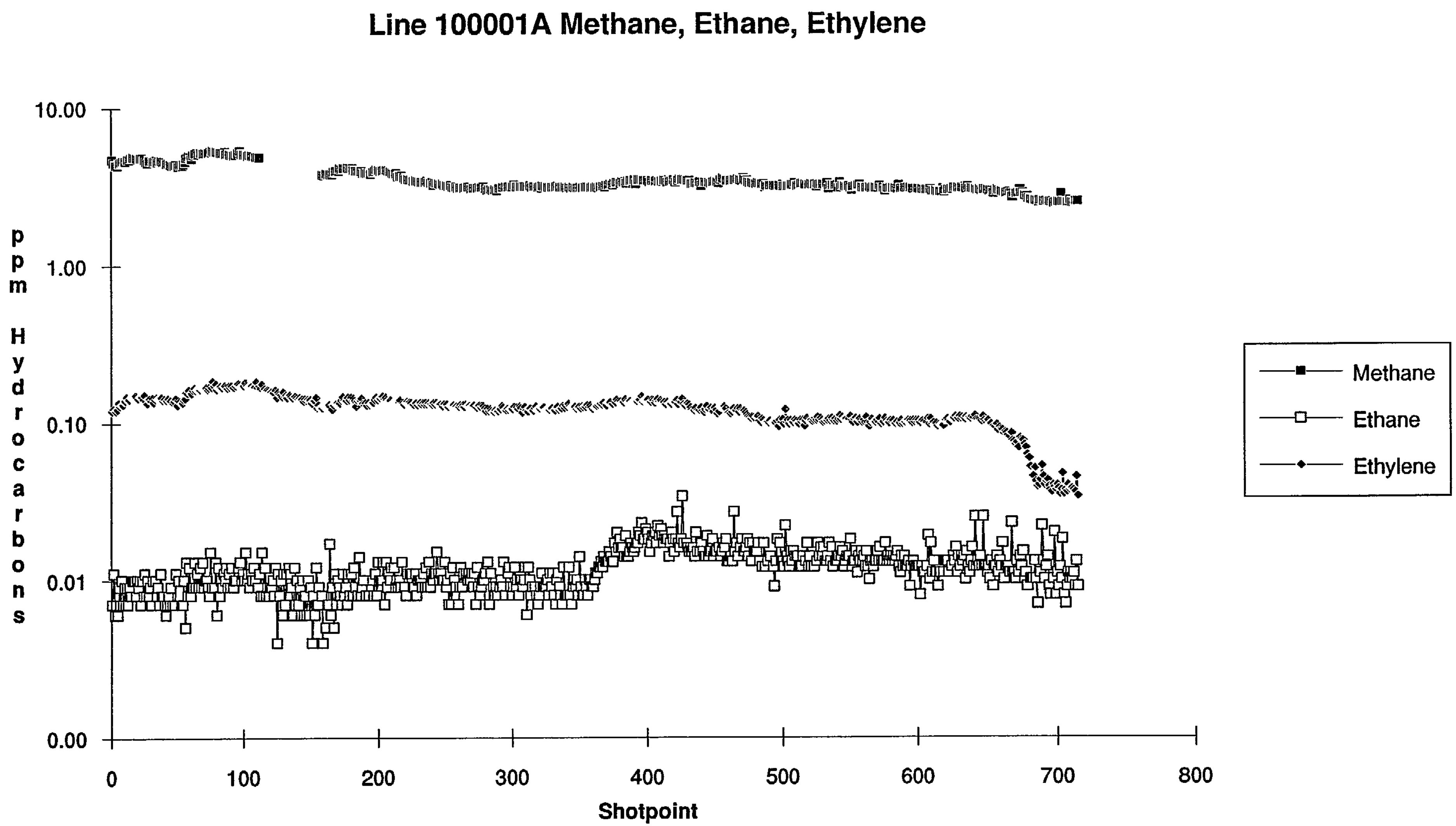
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	63.528	30.132	28.275	39.750	12.152
Std. Dev.	0.813	0.722	4.925	4.937	1.836
Minimum	62.470	29.230	17.300	28.600	8.100
Maximum	65.070	31.570	39.900	51.400	20.300

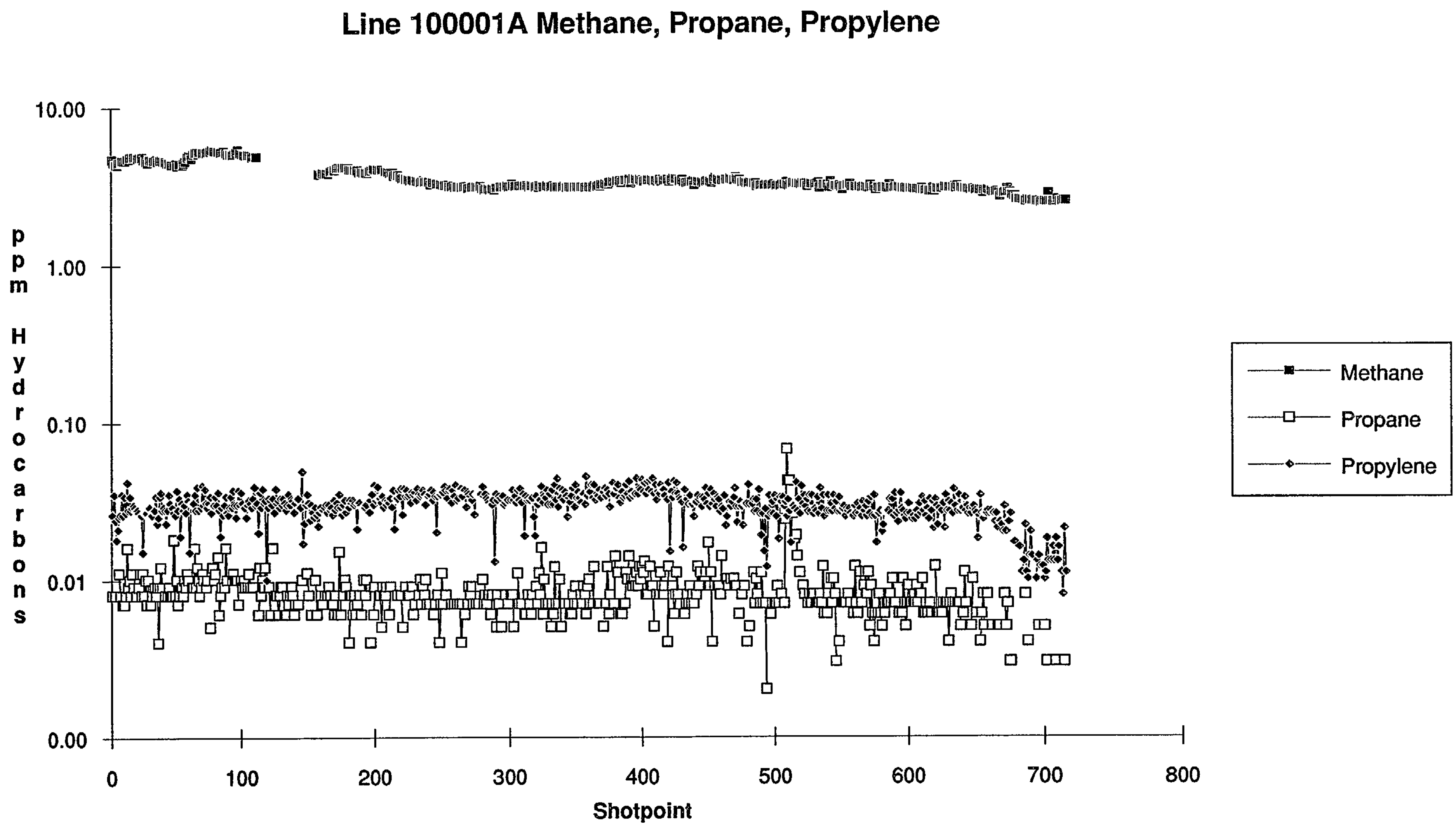
Notes

Strong butane anomaly, with moderate propane, from sp 510 to 524, between Bouganville-1 and Lacrosse-1.
No methane data from sp 115 to 159 due to blocked sample line.



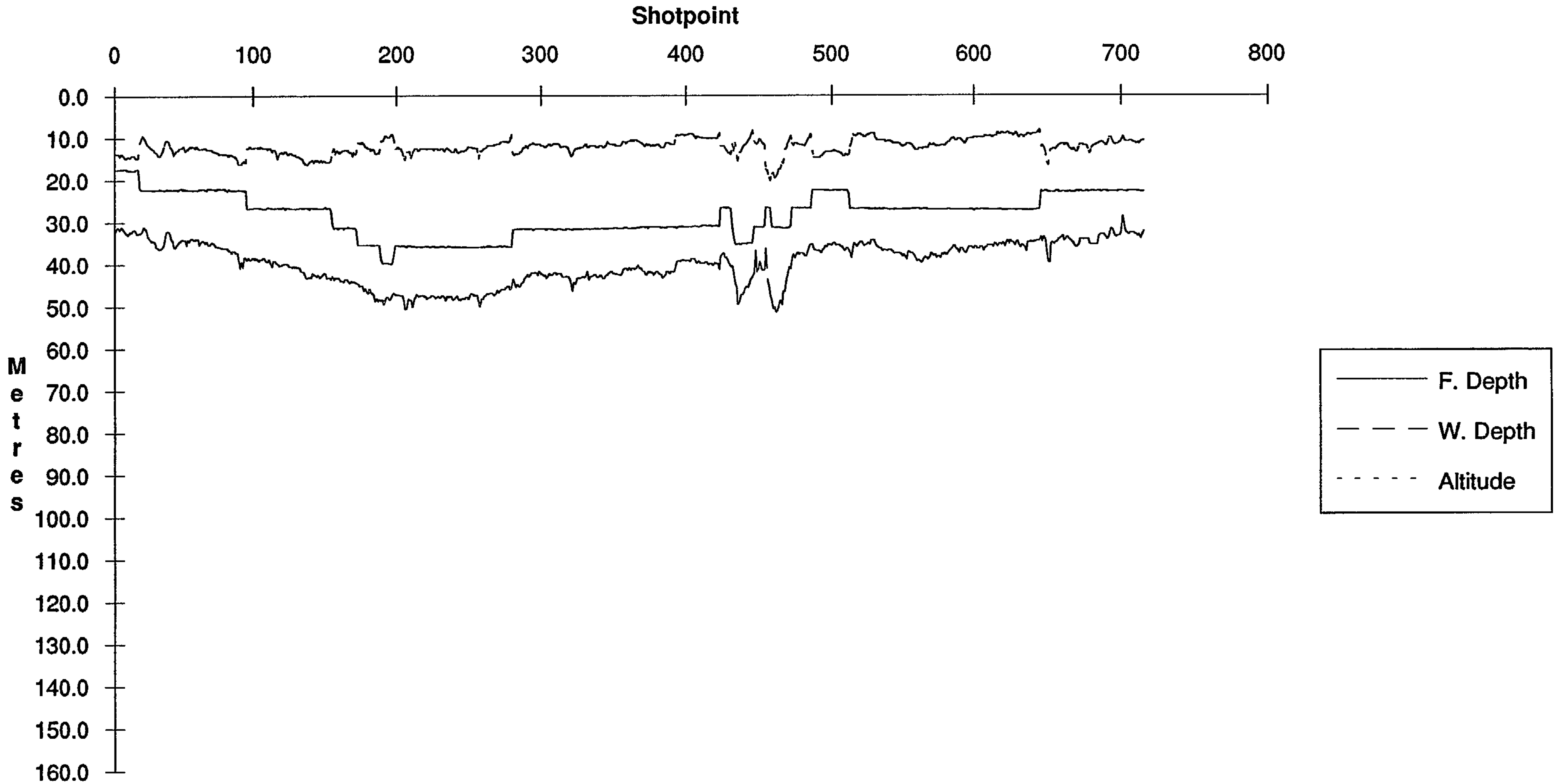
Line 100001A THC, Methane
25.00
20.00
15.00
10.00
5.00
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
Shotpoint
THC
Methane


Line 100001A Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
100
200
300
400
500
600
700
800
Shotpoint
Methane
Ethane
Ethylene



Line 100001A Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
Shotpoint
Methane
Propane
Propylene

Line 100001A Depths, Altitude



Line Summary

Line Number	100002
No. of Shotpoints	1001

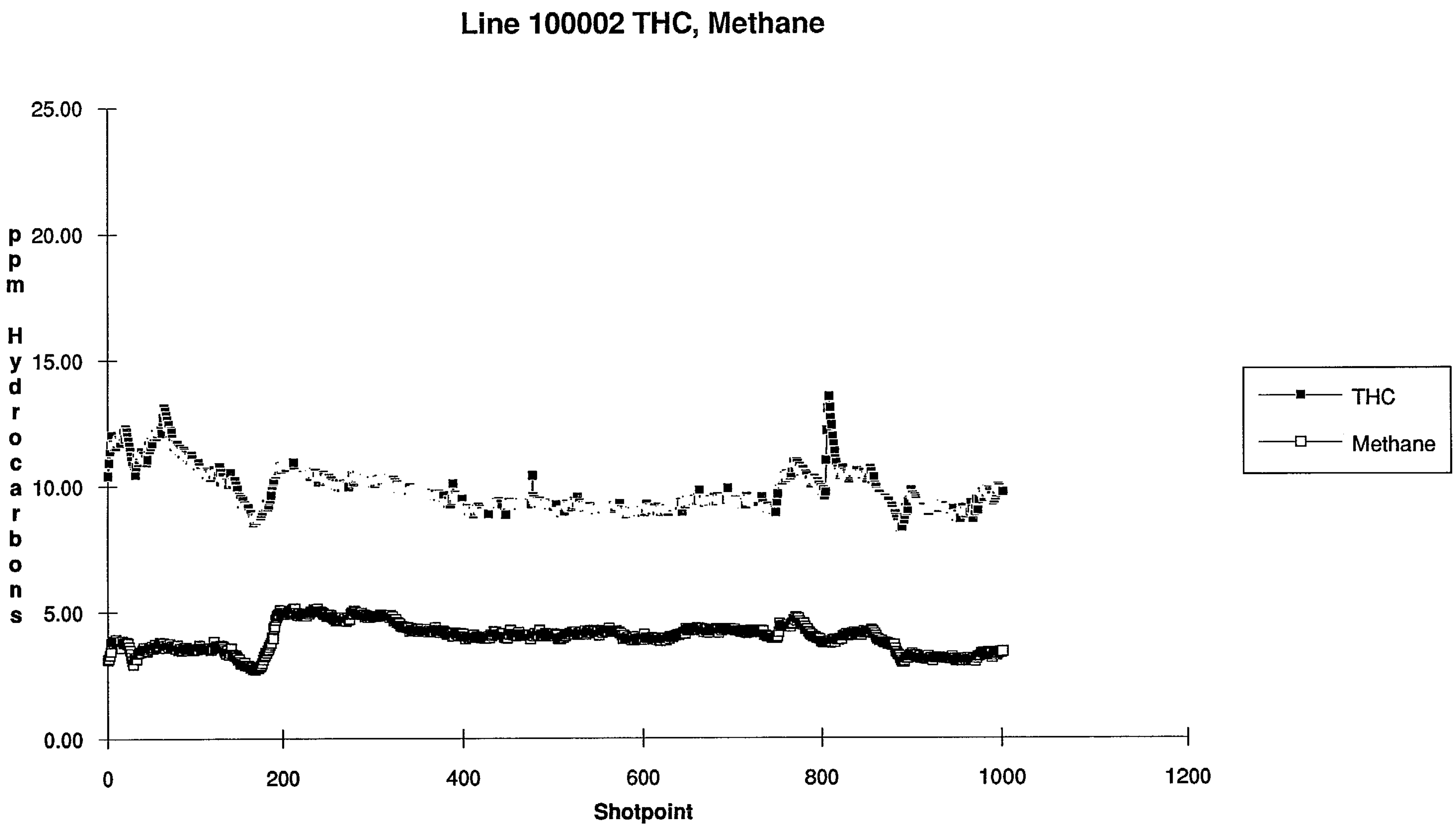
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	12-Apr-91	10:02:11	14	11.301	127	52.685
End	1001	13-Apr-91	19:32:36	12	24.591	129	40.474

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.837	3.986	0.011	0.099	0.007	0.019	0.000	0.001	0.008	0.098	0.036	0.016	0.479
Std. Dev.	0.878	0.537	0.004	0.023	0.005	0.009	0.001	0.004	0.004	0.042	0.051	0.015	0.190
Minimum	8.309	2.706	0.004	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.127
Maximum	13.528	5.144	0.027	0.177	0.017	0.048	0.006	0.062	0.024	0.244	0.390	0.201	2.191

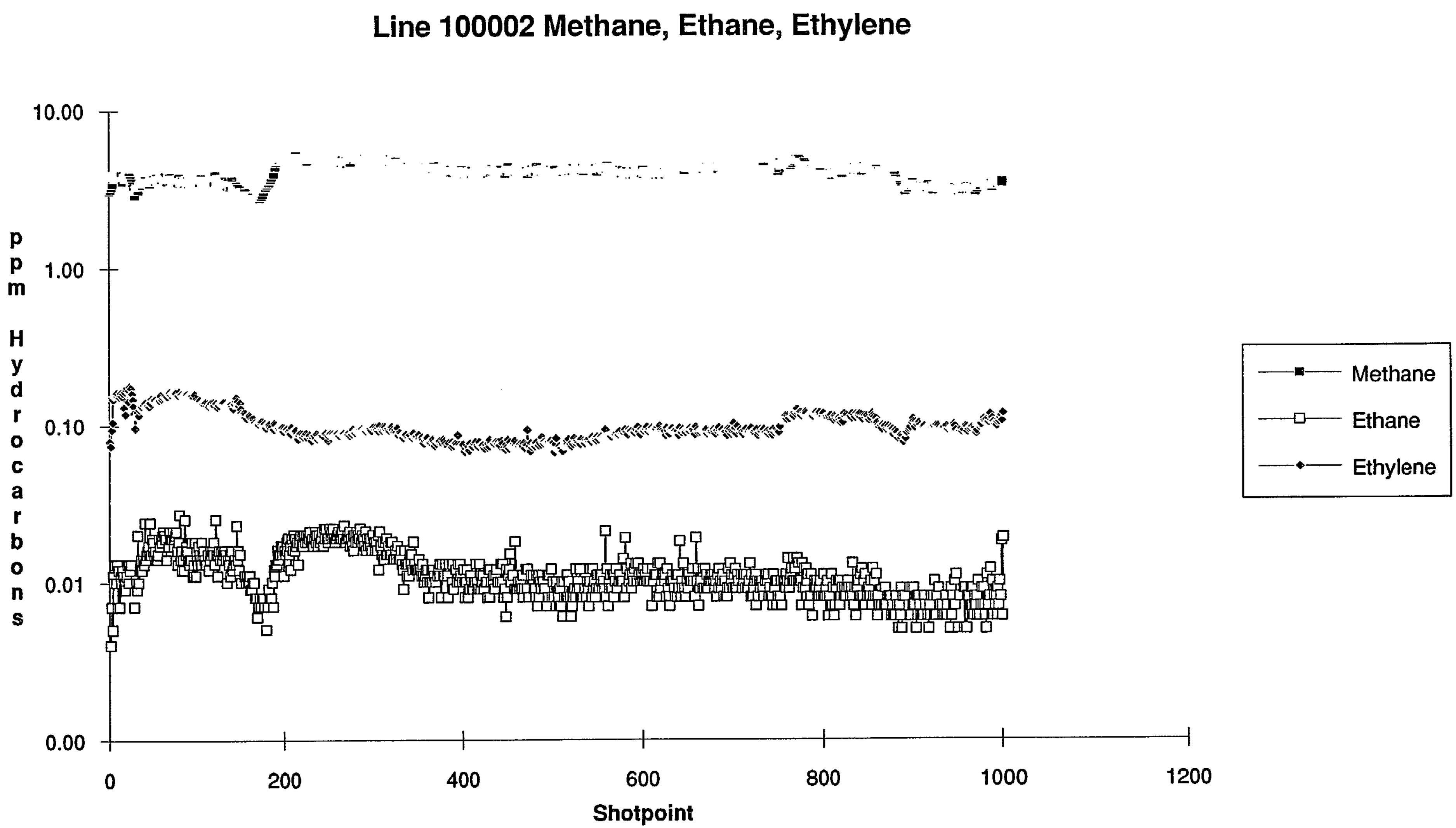
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.671	28.963	53.704	66.607	12.470
Std. Dev.	0.743	0.575	6.919	6.778	1.905
Minimum	60.090	26.850	34.300	46.400	7.200
Maximum	64.130	30.050	66.300	83.000	20.100

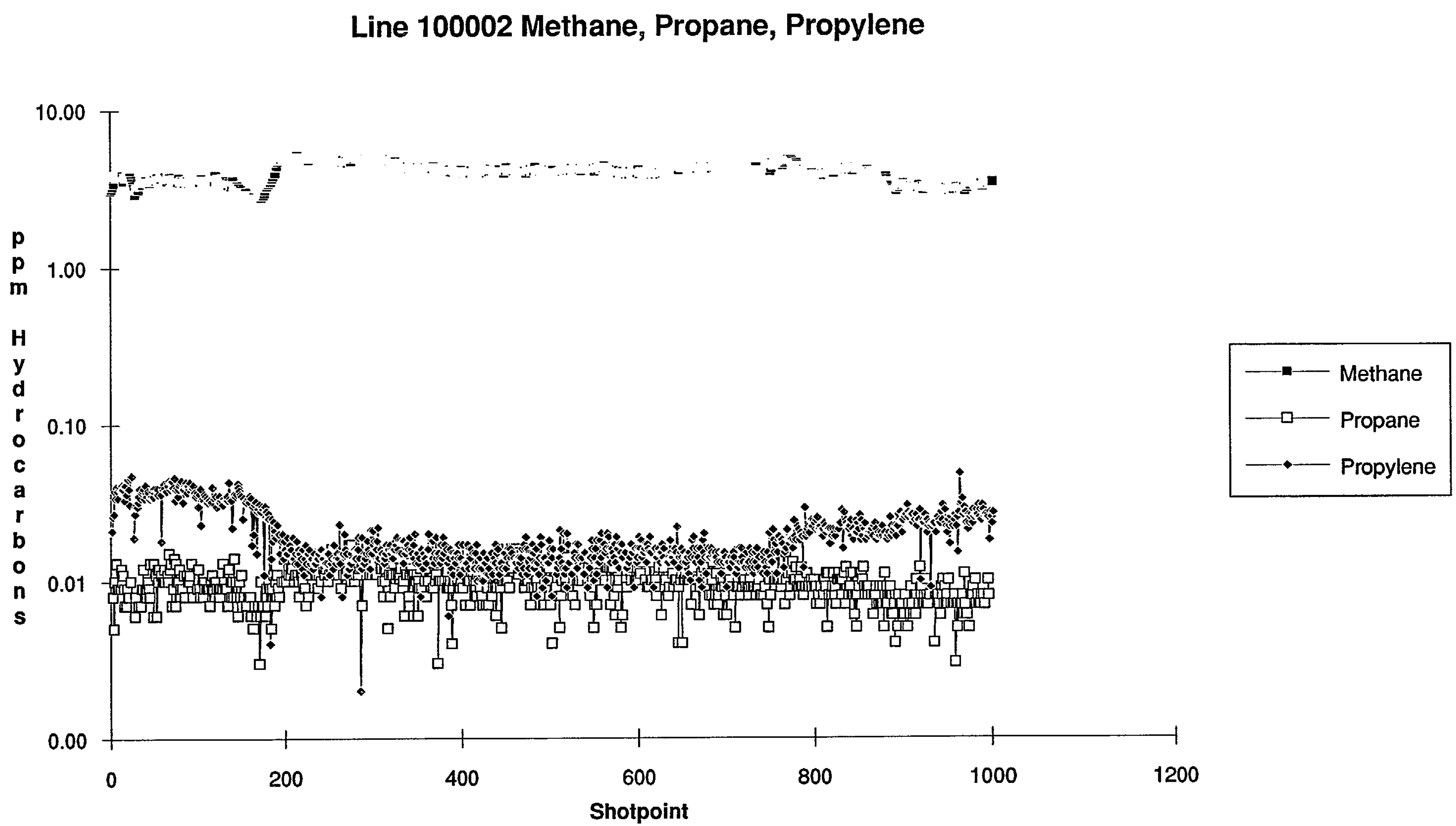
Notes

Druck pressure transducer failed between shotpoints 411 to 933. Fish depth therefore estimated from Water Depth - Altitude.
Weak THC, C1 and C2 anomaly between Leseur-1 and Penguin-1.
Weak ethane anomaly before Leseur-1.

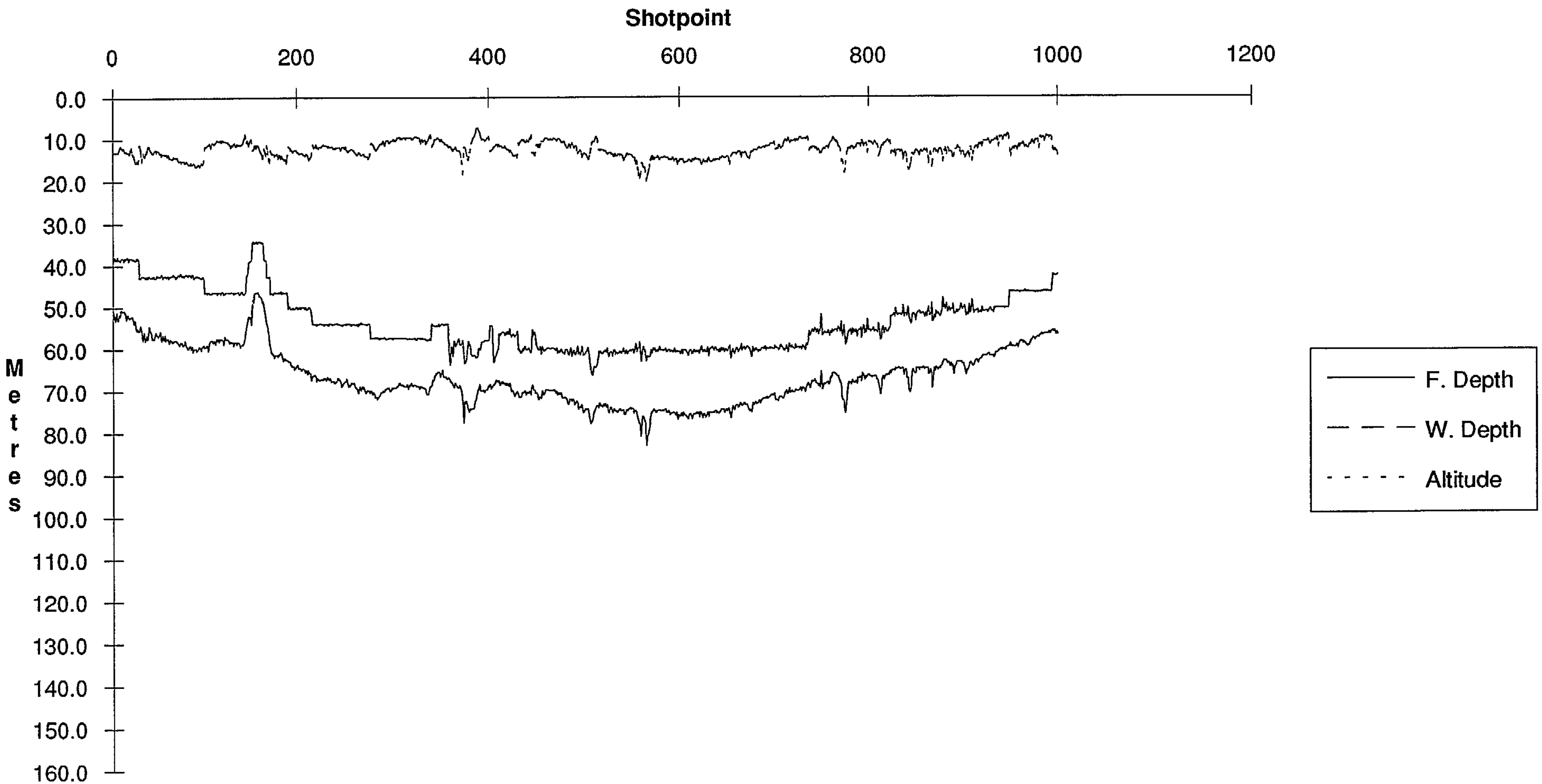


Line 100002 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
200
400
600
800
1000
1200
Shotpoint
THC
Methane


Line 100002 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
Shotpoint
Methane
Ethane
Ethylene


Line 100002 Methane, Propane, Propylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
Shotpoint
Methane
Propane
Propylene

Line 100002 Depths, Altitude



Line Summary

Line Number	100003
No. of Shotpoints	1019

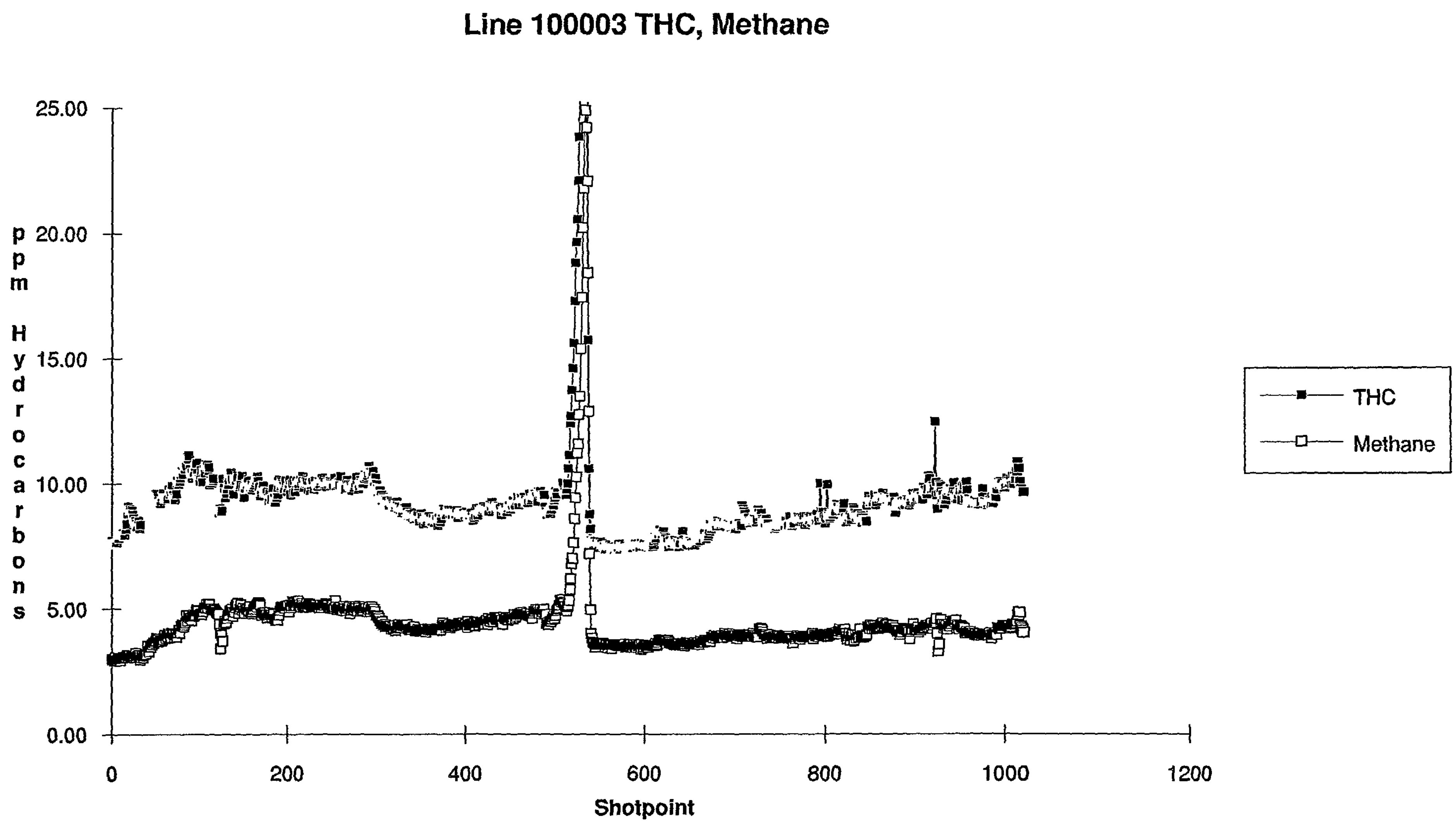
	Shotpoint	Date	Time	Latitude		Longitude	
Start	2	16-Apr-91	02:07:24	13	50.179	127	25.840
End	1023	17-Apr-91	13:07:57	11	58.117	129	21.746

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	9.380	4.444	0.024	0.086	0.009	0.014	0.001	0.001	0.005	0.059	0.006	0.002	0.651
Std. Dev.	2.720	1.806	0.044	0.014	0.009	0.006	0.003	0.003	0.008	0.033	0.015	0.006	0.328
Minimum	7.355	2.914	0.006	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.138
Maximum	40.329	24.887	0.522	0.118	0.101	0.034	0.059	0.040	0.034	0.297	0.126	0.067	2.656

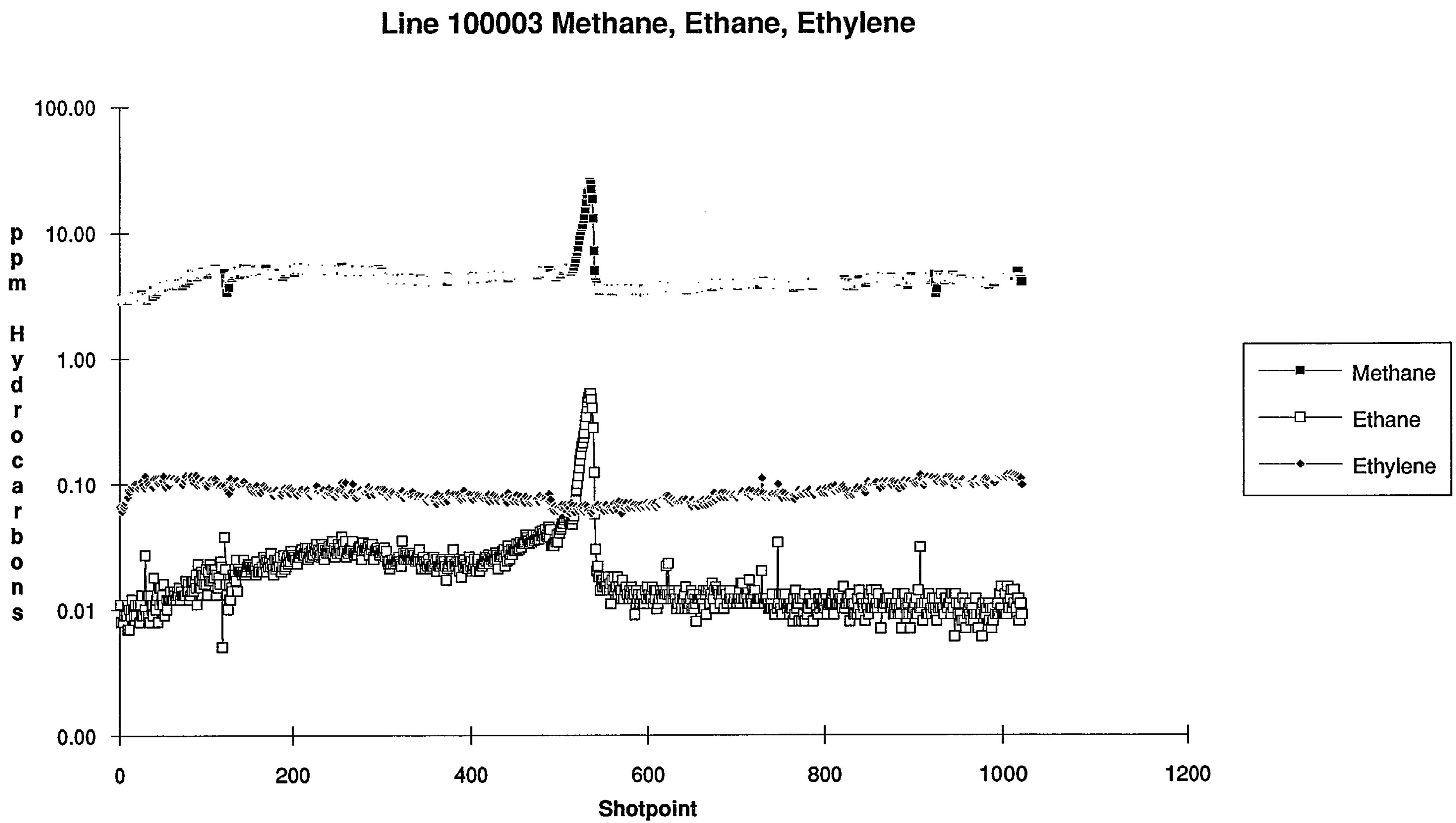
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.675	28.960	74.205	88.572	12.802
Std. Dev.	1.011	0.809	9.744	9.762	2.686
Minimum	60.560	27.330	45.900	64.600	6.500
Maximum	65.300	30.990	87.700	102.200	30.300

Notes

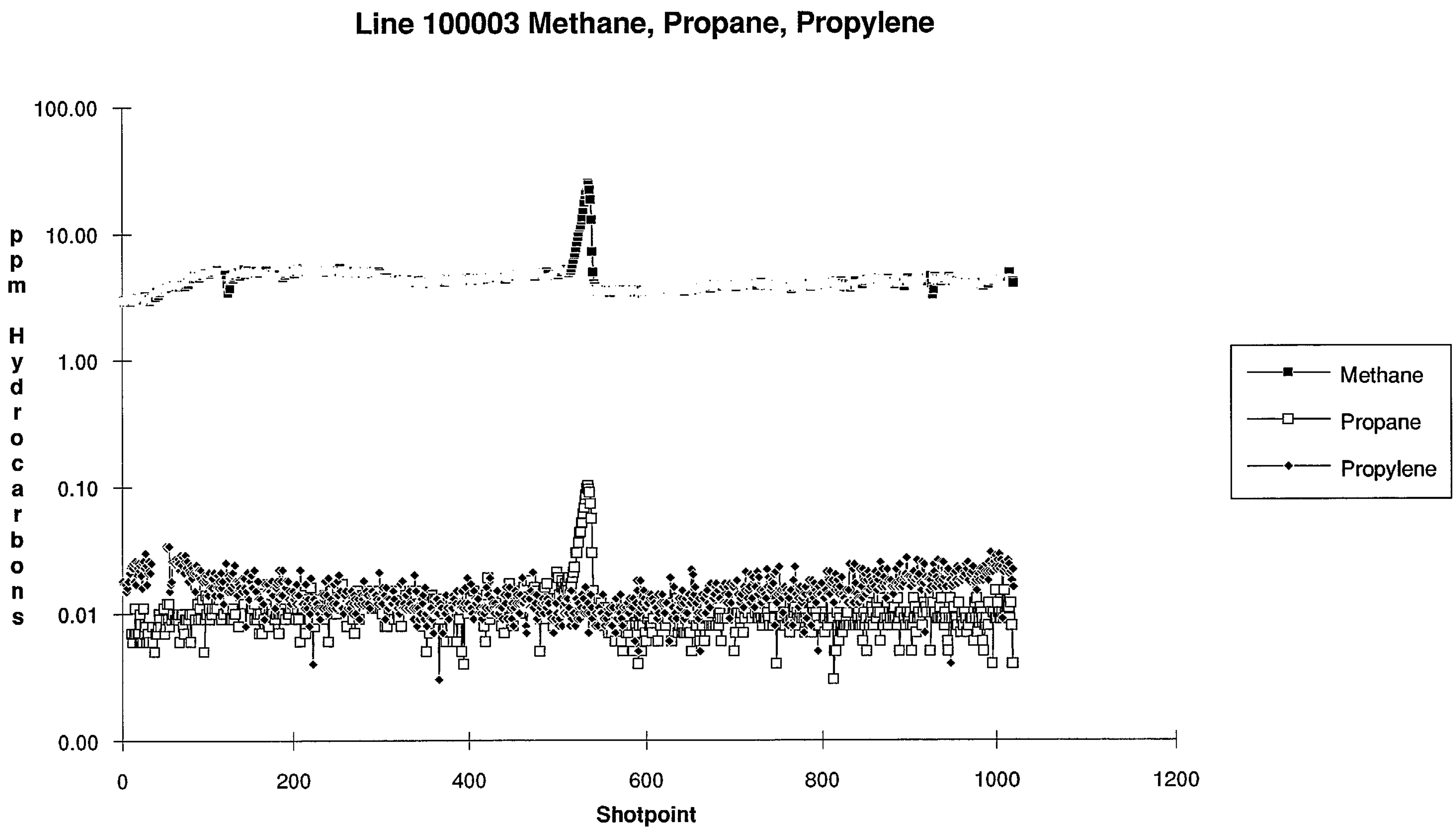
A moderate to strong THC and C1-C4 anomaly over Petrel-1 (maximum values at sp 537).
A weak methane anomaly from sp 100 to 300 (approximately), immediately to the west of Tern-1.
No THC or propylene data sp 35 to 51 due to leak checking.
Fish hit bottom, sp 124 (approx). No THC data sp 119-125.



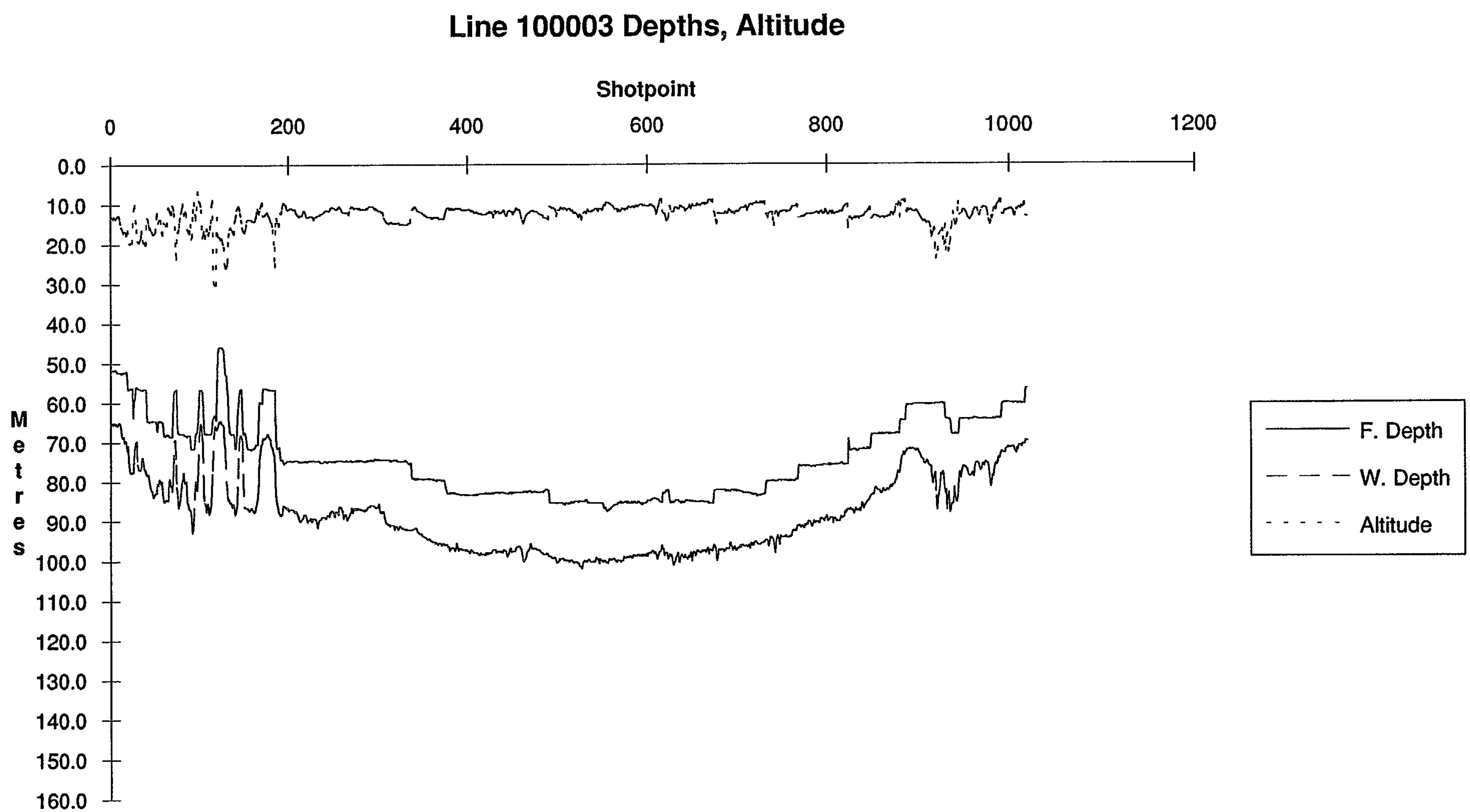
Line 100003 THC, Methane
25.00
20.00
15.00
10.00
5.00
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
Shotpoint
THC
Methane



Line 100003 Methane, Ethane, Ethylene
100.00
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
Shotpoint
Methane
Ethane
Ethylene



Line 100003 Methane, Propane, Propylene
ppm Hydrocarbons
100.00
10.00
1.00
0.10
0.01
0.00
0
200
400
600
800
1000
1200
Shotpoint
Methane
Propane
Propylene



Line 100003 Depths, Altitude
Shotpoint
0
200
400
600
800
1000
1200
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
130.0
140.0
150.0
160.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	100004
No. of Shotpoints	611

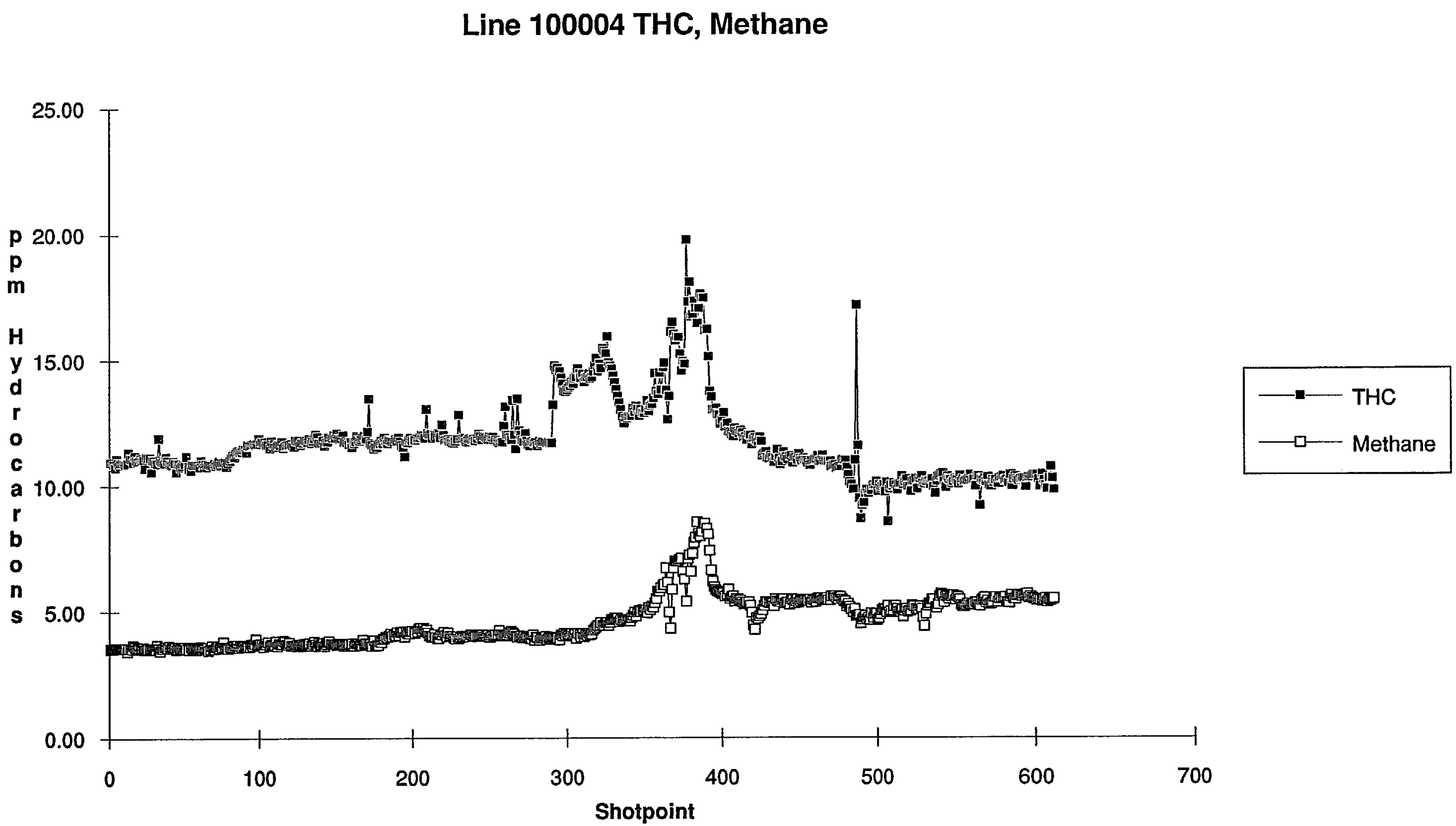
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	18-Apr-91	00:05:03	11	16.660	129	19.861
End	615	18-Apr-91	22:10:09	12	00.733	127	45.693

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	11.755	4.596	0.013	0.136	0.009	0.032	0.001	0.000	0.006	0.104	0.017	0.002	0.502
Std. Dev.	1.583	0.959	0.004	0.011	0.005	0.009	0.002	0.002	0.005	0.051	0.014	0.004	0.155
Minimum	8.554	3.429	0.005	0.113	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.181
Maximum	19.783	8.539	0.033	0.161	0.018	0.052	0.029	0.034	0.024	0.188	0.060	0.023	1.203

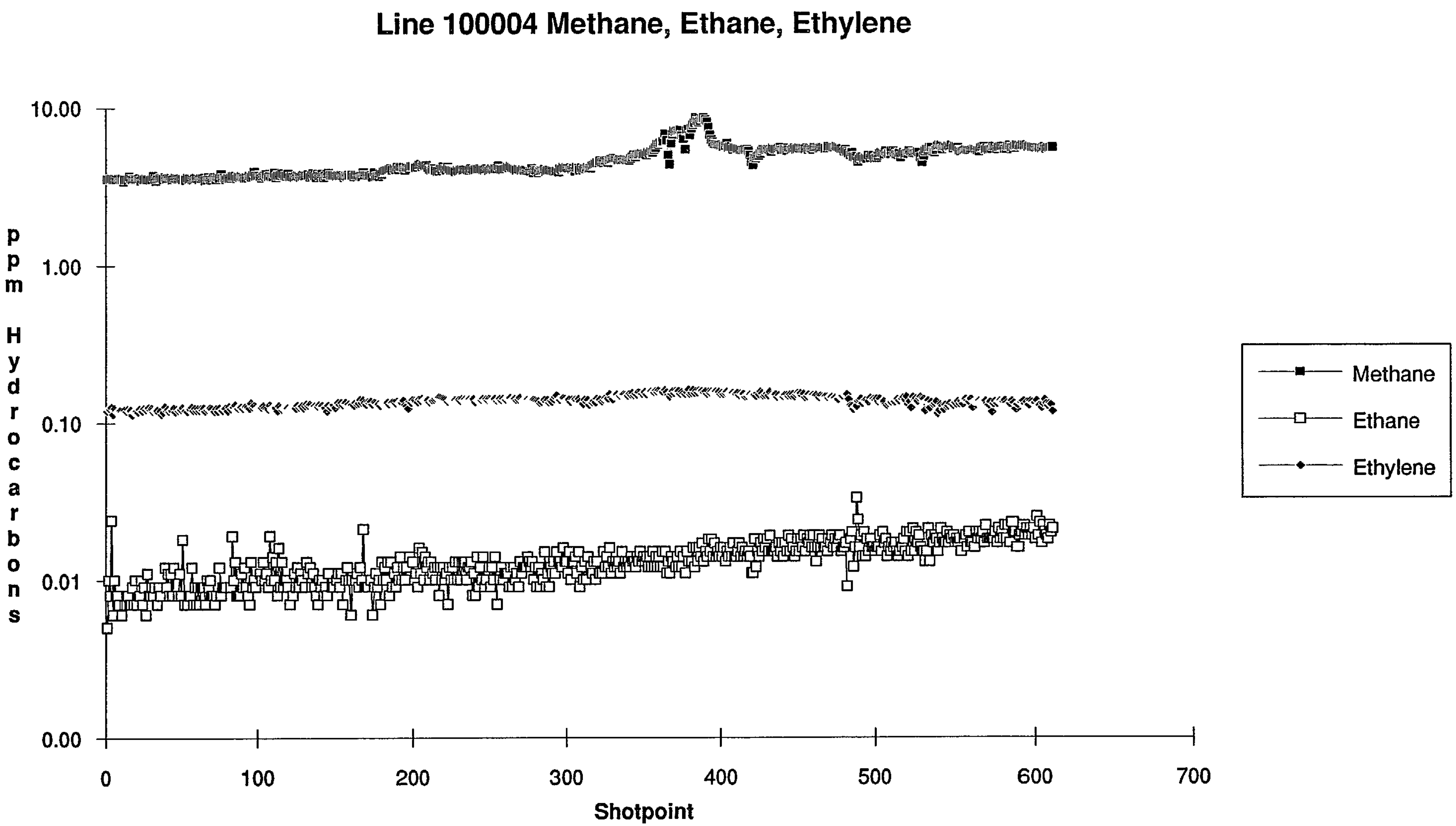
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.126	28.749	61.562	80.745	19.195
Std. Dev.	0.946	0.834	29.724	33.029	11.573
Minimum	60.630	27.580	9.600	31.200	6.330
Maximum	63.690	30.020	111.900	146.600	123.400

Notes

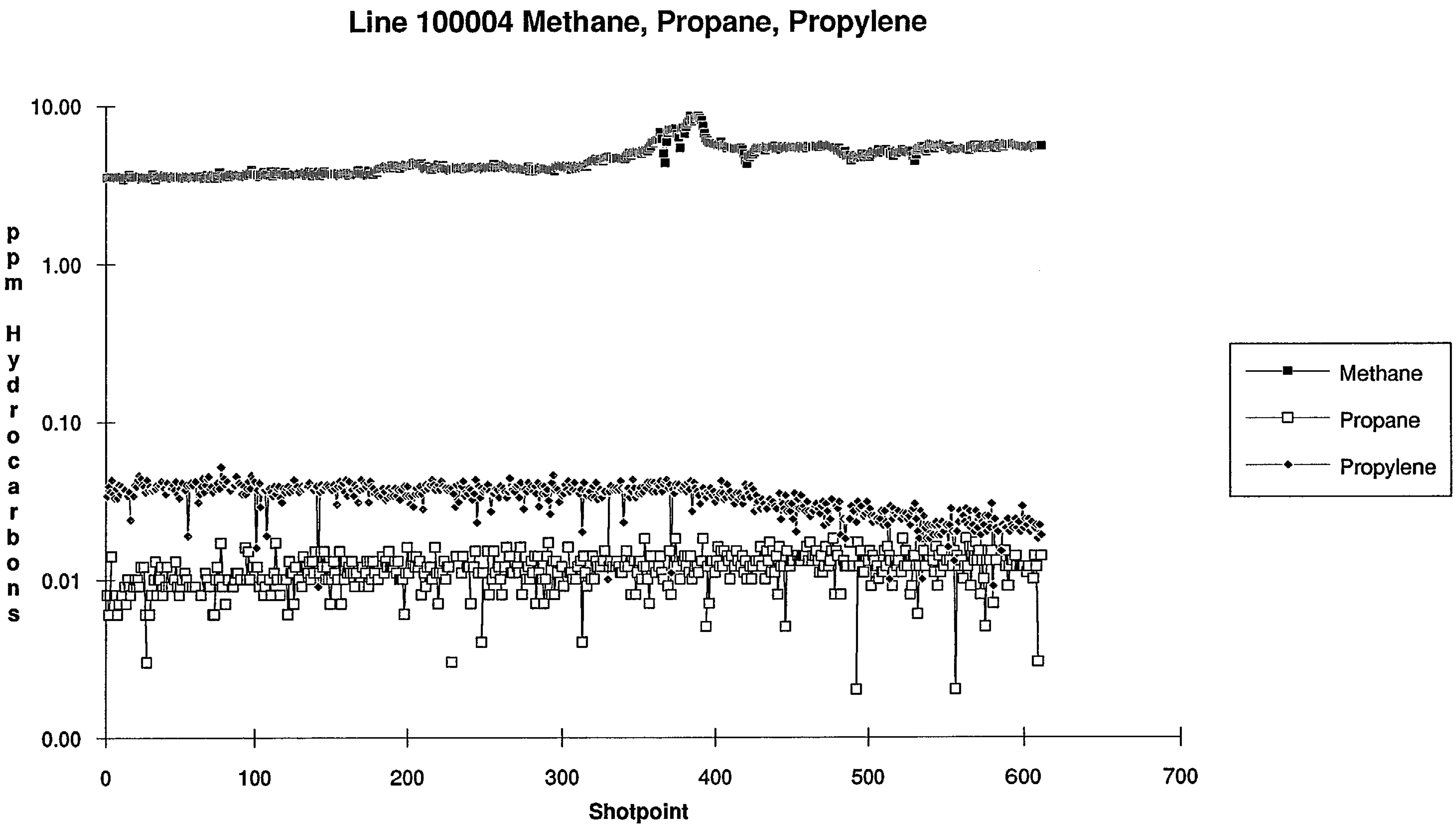
No data collected between 1012 and 1125 (shotpoints 293 to 294) due to electrical short in fish pump motor.
High THC values from sp 294 due to contamination from pump replacement.
Weak THC and C1 anomaly, around sp 390 (approx 4-5km east of Curlew-1).
Reduced water flow from sp 486 to EOL due to partially disconnect sub. pump hose.



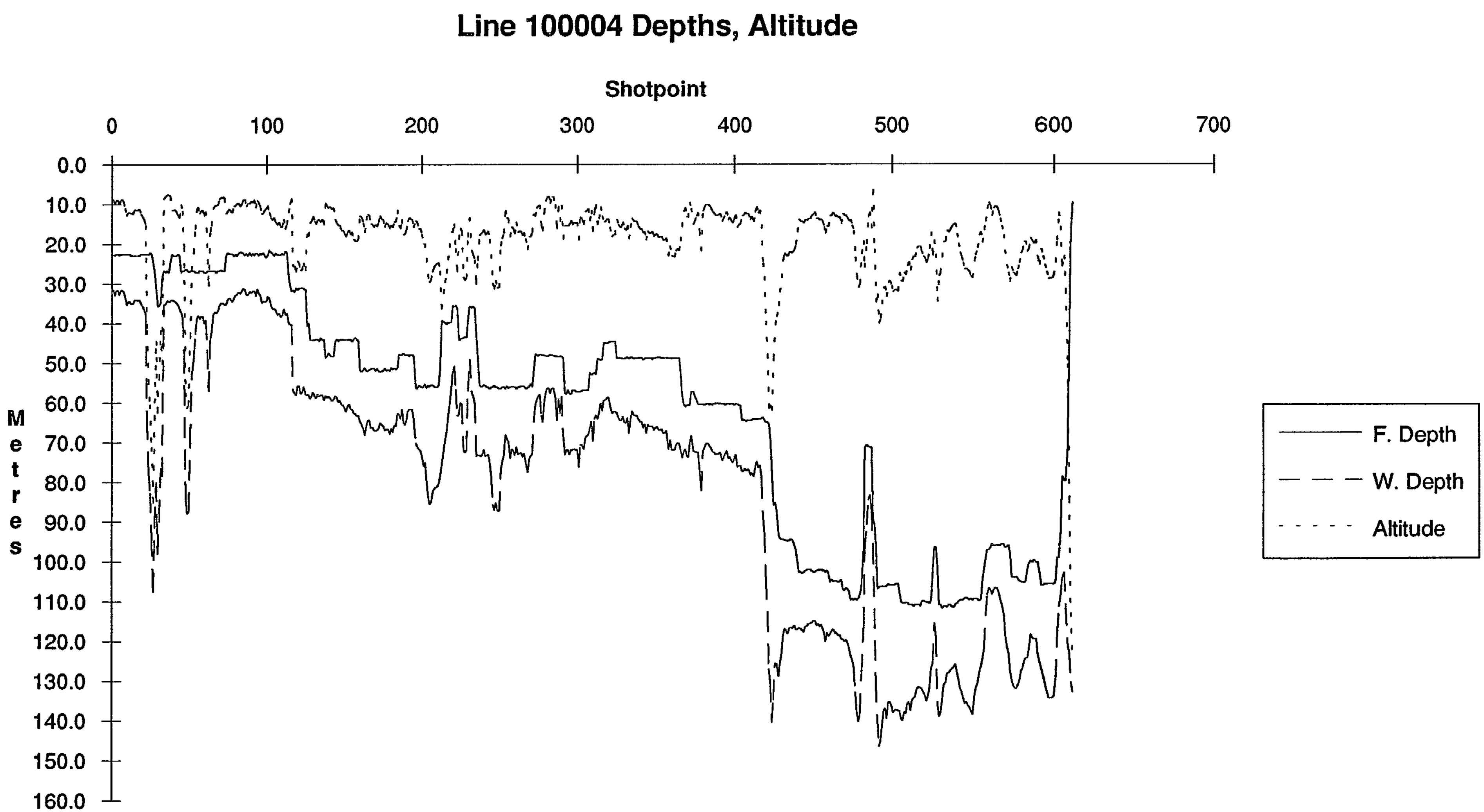
Line 100004 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane



Line 100004 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 100004 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 100004 Depths, Altitude
Shotpoint
0
100
200
300
400
500
600
700
Metres
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
130.0
140.0
150.0
160.0
F. Depth
W. Depth
Altitude

Line Summary

Line Number	100005
No. of Shotpoints	1232

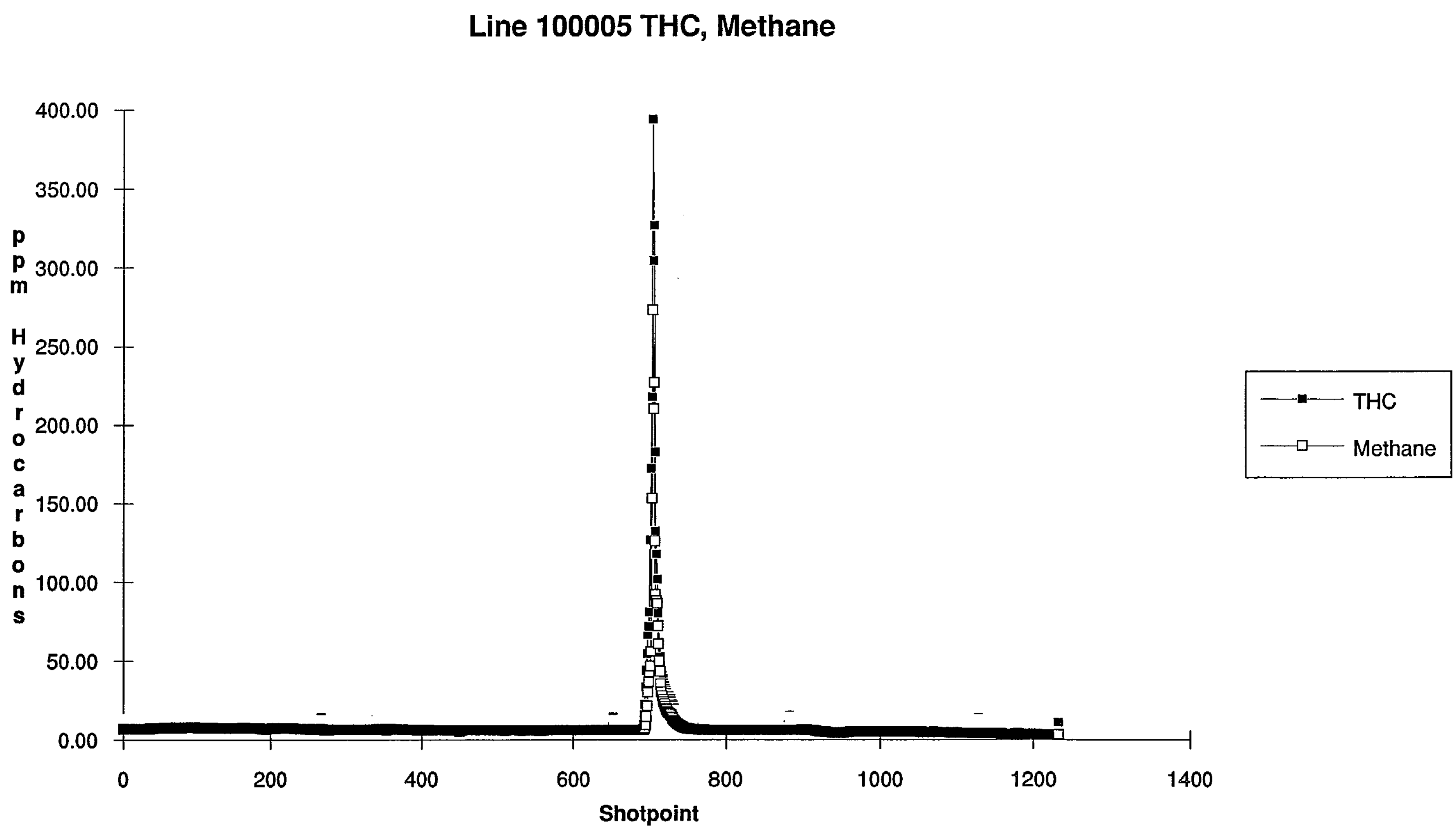
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	20-Apr-91	00:30:10	11	12.797	127	31.897
End	1231	22-Apr-91	01:38:29	14	04.670	129	13.799

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	14.602	7.402	0.060	0.156	0.018	0.029	0.002	0.002	0.002	0.073	0.001	0.001	0.668
Std. Dev.	20.177	13.946	0.344	0.019	0.057	0.010	0.007	0.011	0.005	0.041	0.003	0.003	0.359
Minimum	10.887	3.327	0.009	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260
Maximum	393.817	272.825	6.852	0.199	1.049	0.134	0.167	0.218	0.057	0.269	0.036	0.049	3.398

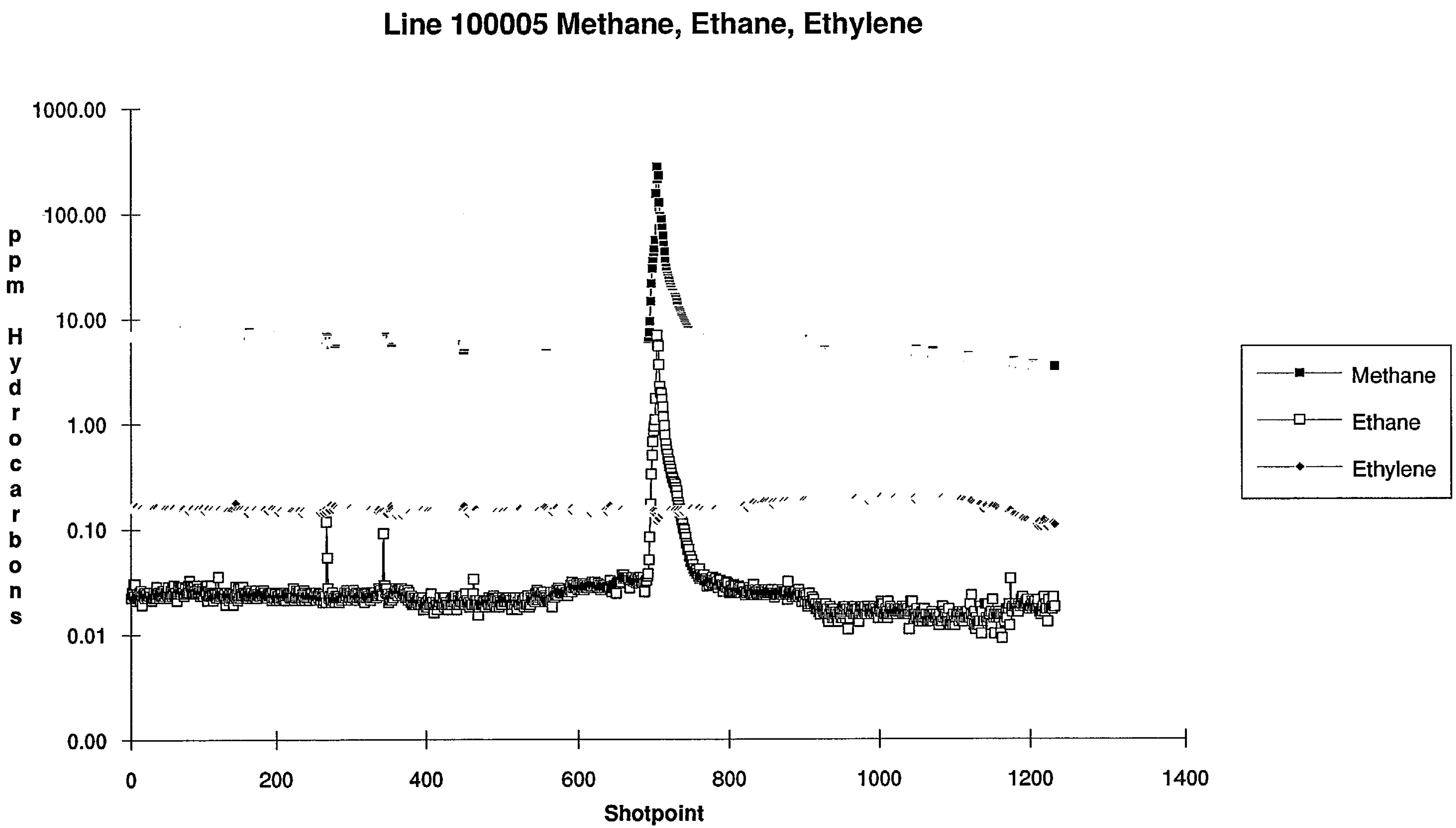
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.706	28.137	82.886	96.142	13.266
Std. Dev.	0.754	0.672	28.718	31.008	4.179
Minimum	60.190	27.040	17.500	30.300	5.410
Maximum	63.710	30.570	119.700	140.600	29.910

Notes

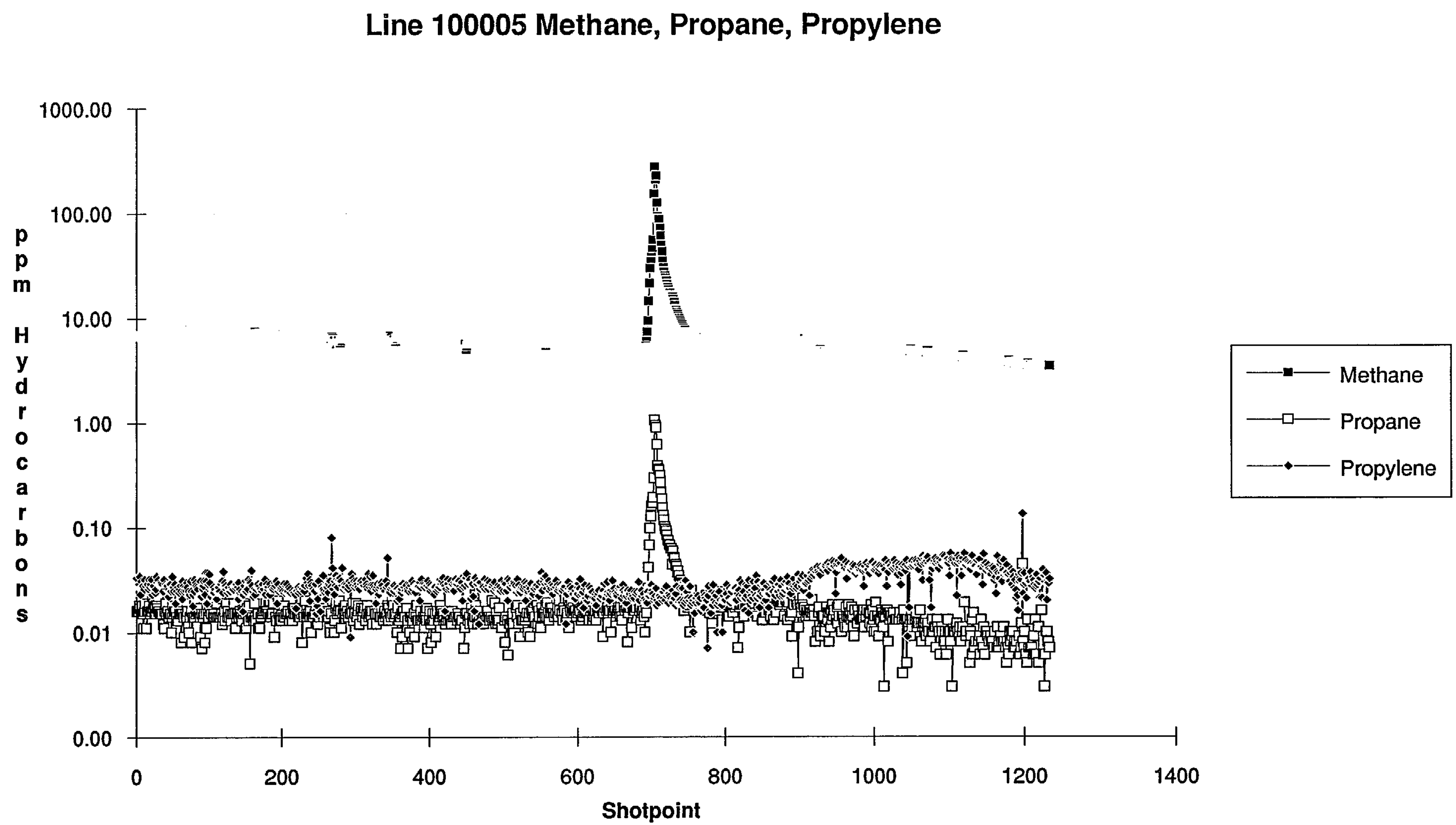
Weak to moderate C2 and C3 anomaly sp 268-270.
Strong THC and C1-C4 anomaly over Petrel-1 well location.



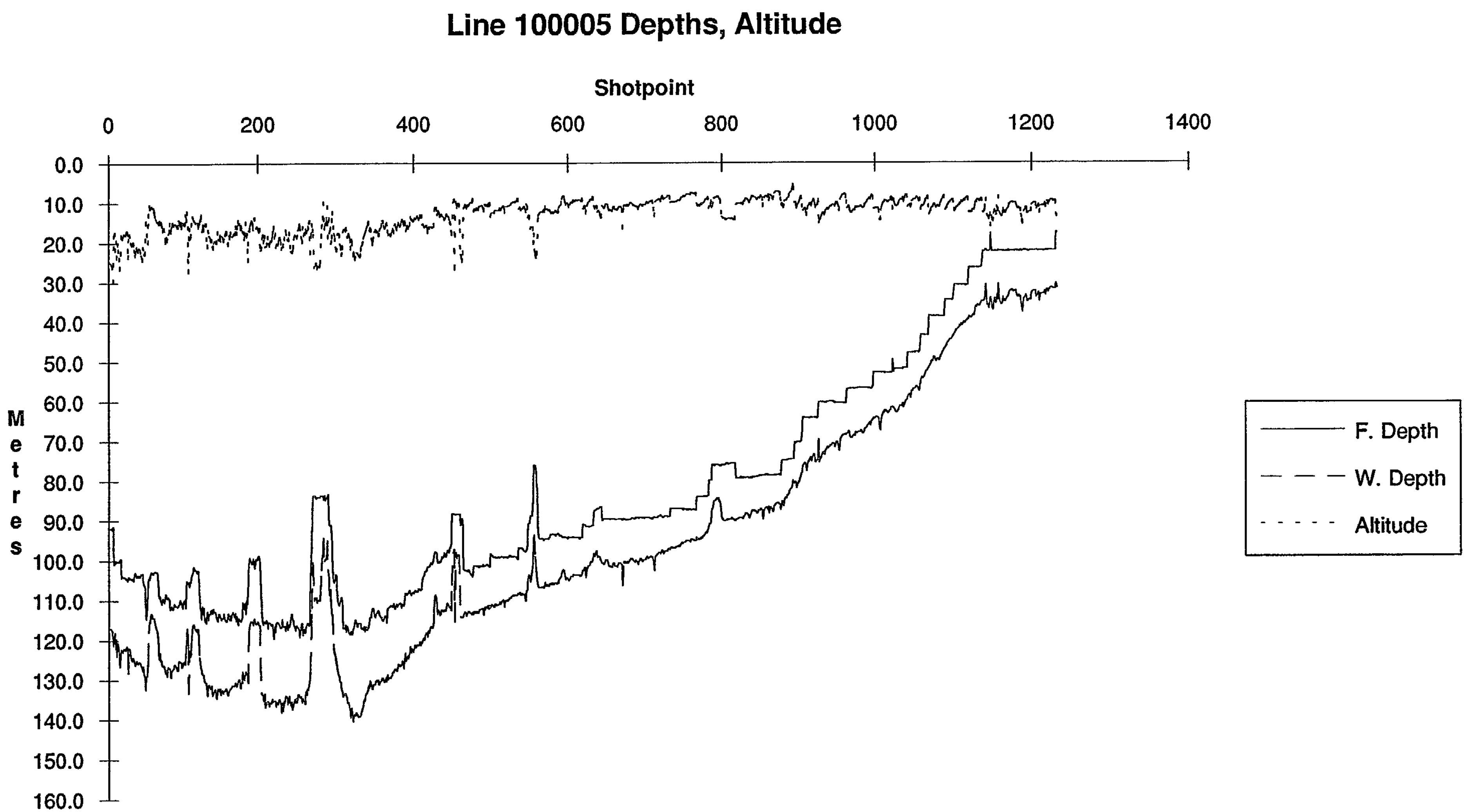
Line 100005 THC, Methane
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
1400
Shotpoint
THC
Methane



Line 100005 Methane, Ethane, Ethylene
1000.00
100.00
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
1400
Shotpoint
Methane
Ethane
Ethylene



Line 100005 Methane, Propane, Propylene
1000.00
100.00
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
200
400
600
800
1000
1200
1400
Shotpoint
Methane
Propane
Propylene



Line 100005 Depths, Altitude
Shotpoint
0
200
400
600
800
1000
1200
1400
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
130.0
140.0
150.0
160.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	100006
No. of Shotpoints	1776

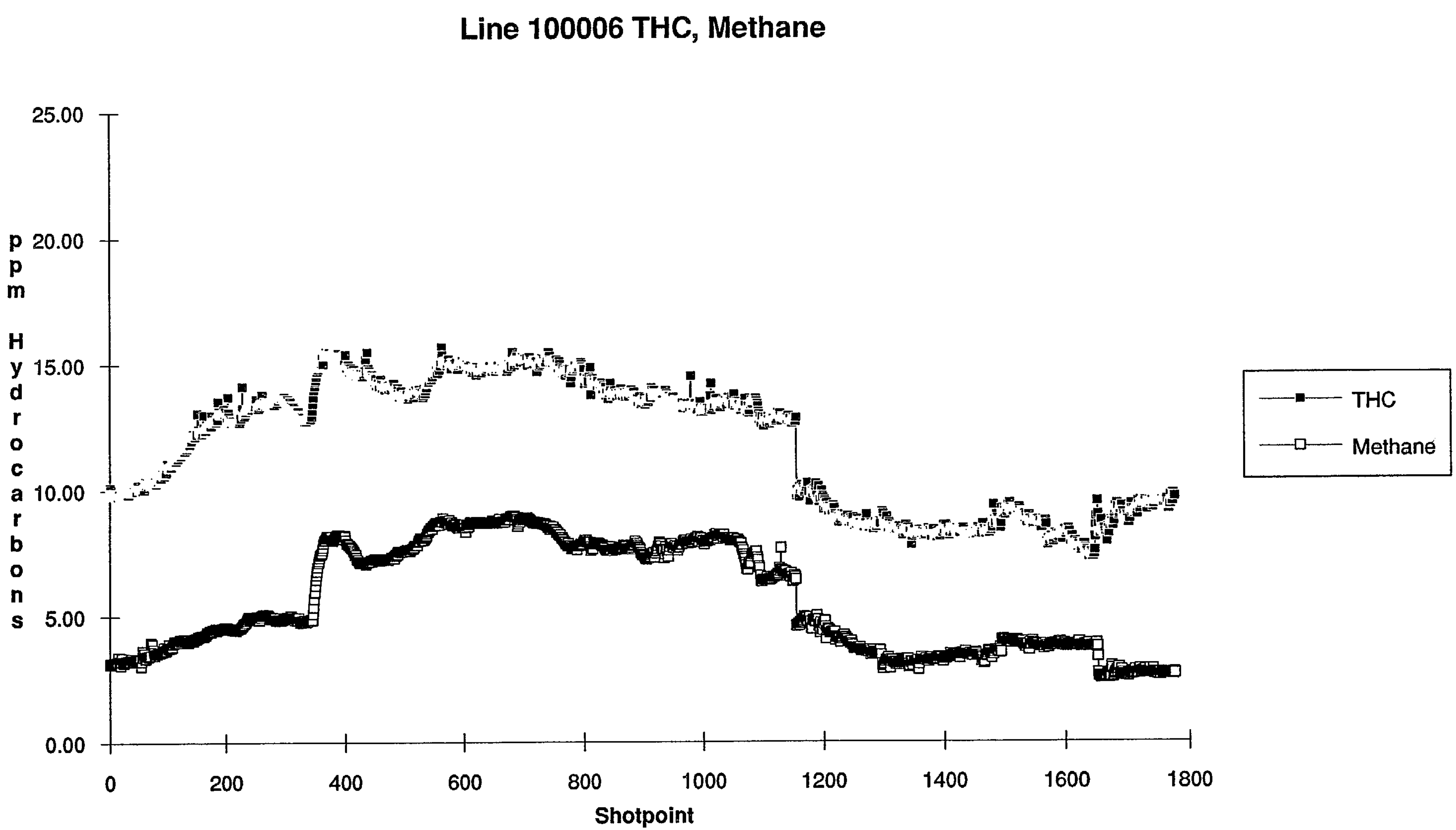
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	22-Apr-91	08:49:33	14	19.277	128	53.232
End	1409	29-Apr-91	22:11:43	10	33.793	125	48.742

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	11.845	5.627	0.021	0.135	0.010	0.026	0.001	0.001	0.001	0.077	0.013	0.004	0.538
Std. Dev.	2.591	2.154	0.014	0.041	0.008	0.012	0.002	0.002	0.002	0.039	0.035	0.015	0.181
Minimum	7.311	2.505	0.004	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153
Maximum	15.685	8.987	0.113	0.220	0.039	0.064	0.019	0.037	0.010	0.449	0.963	0.303	1.541

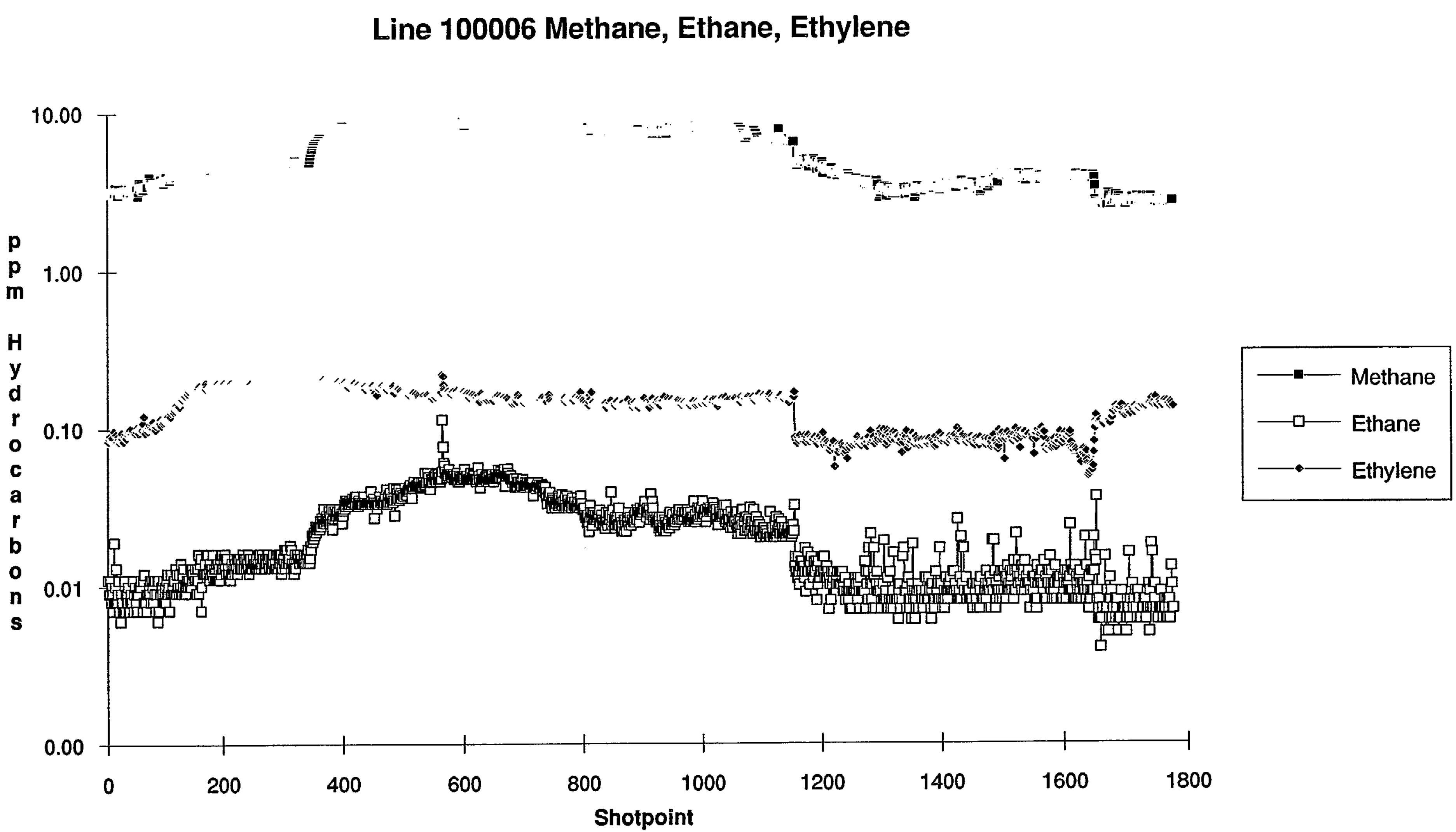
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.896	28.196	63.125	100.343	37.227
Std. Dev.	0.986	0.729	23.808	70.883	79.440
Minimum	57.240	24.640	3.500	25.600	8.200
Maximum	64.390	29.890	117.800	503.600	500.070

Notes

Data was acquired in two parts - 1) 0849 to 2212 22/4/91, and 2) 0223 27/4/91 to 2211 29/4/91.
Regional THC, C1, C2 and C3 anomaly extending from 100/006 sp350 to 100/006B sp790 (approx)

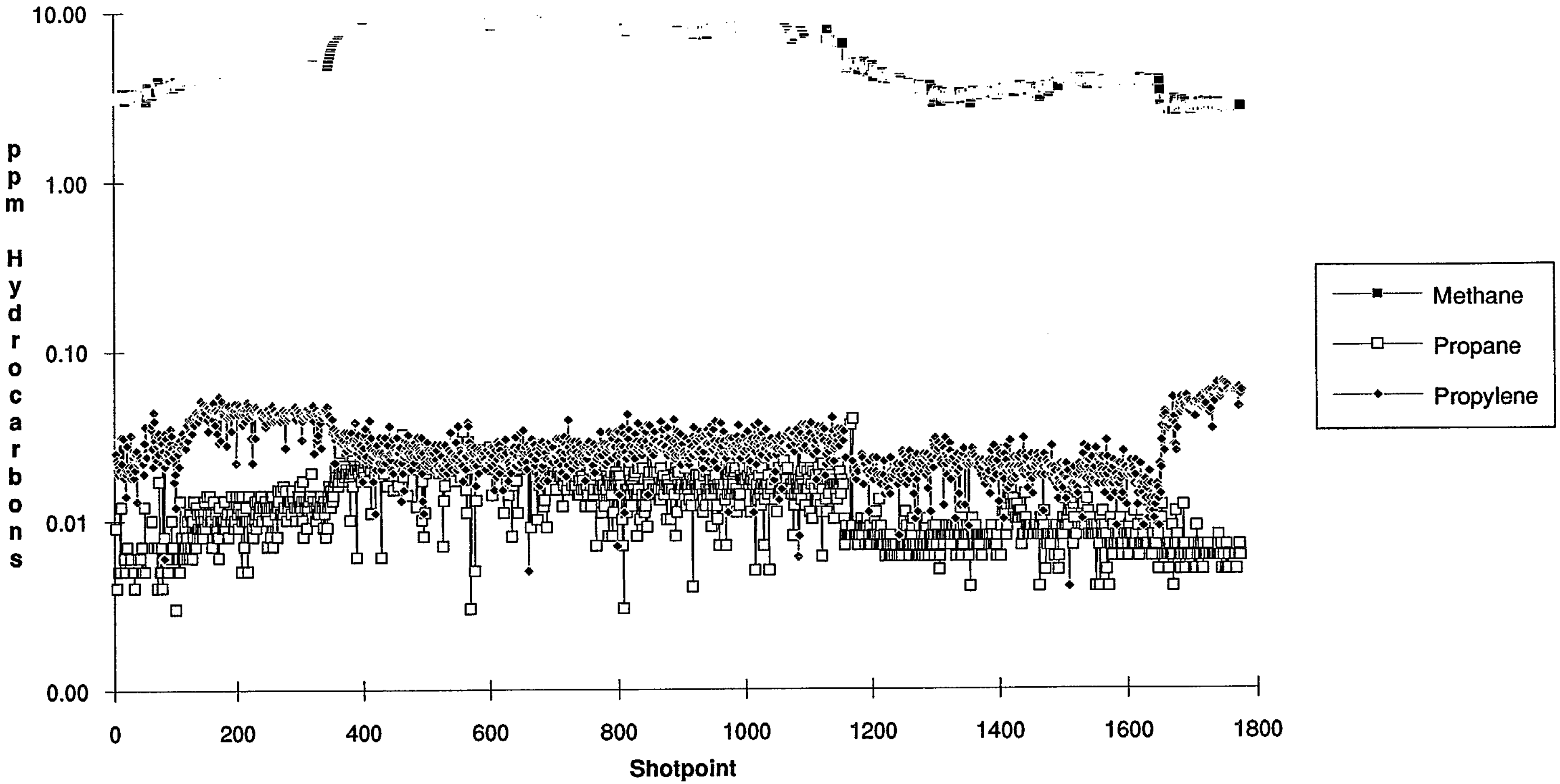


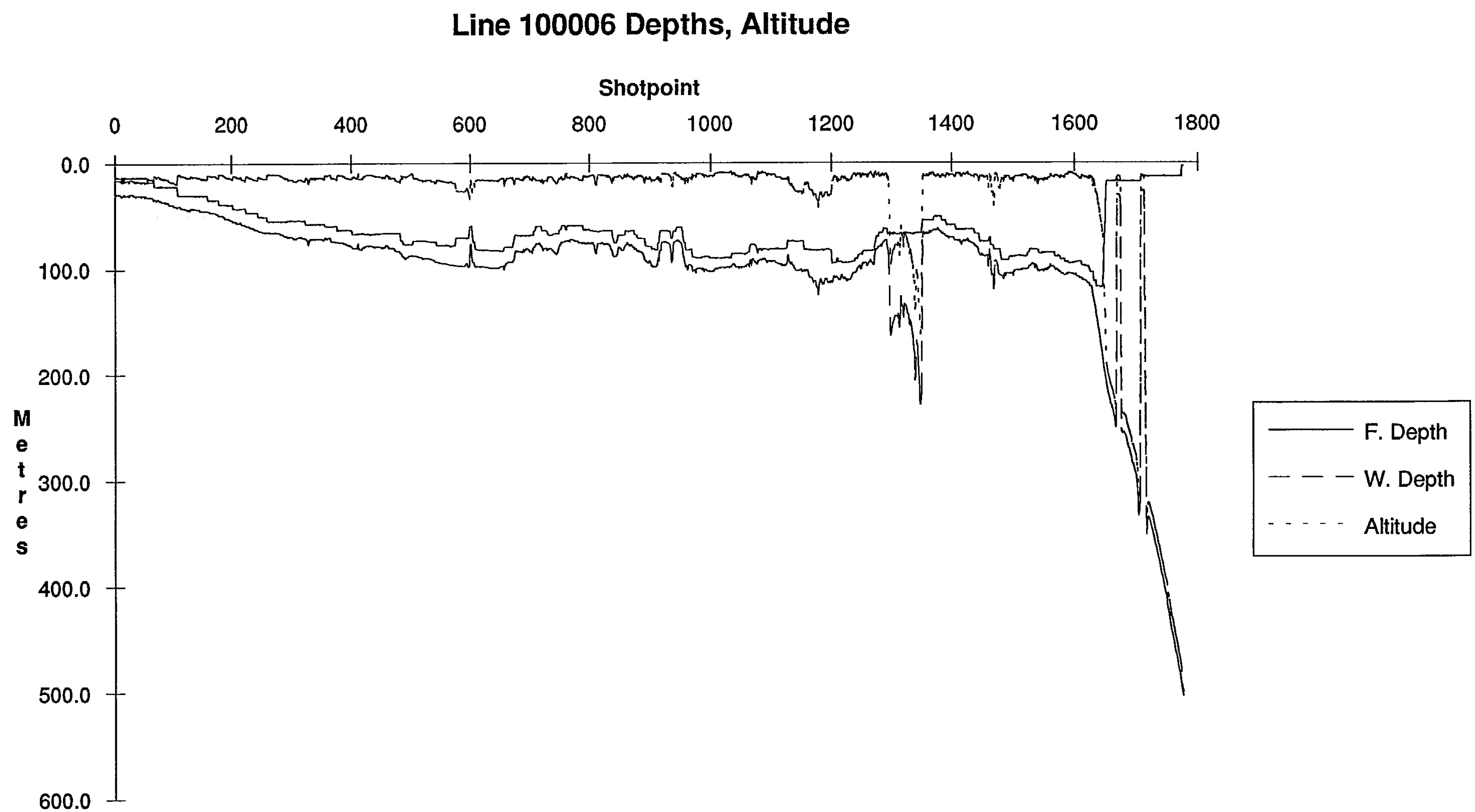
Line 100006 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Shotpoint
THC
Methane



Line 100006 Methane, Ethane, Ethylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Shotpoint
Methane
Ethane
Ethylene

Line 100006 Methane, Propane, Propylene





Line 100006 Depths, Altitude
Shotpoint
0
200
400
600
800
1000
1200
1400
1600
1800
0.0
100.0
200.0
300.0
400.0
500.0
600.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

Line Number	100007
No. of Shotpoints	629

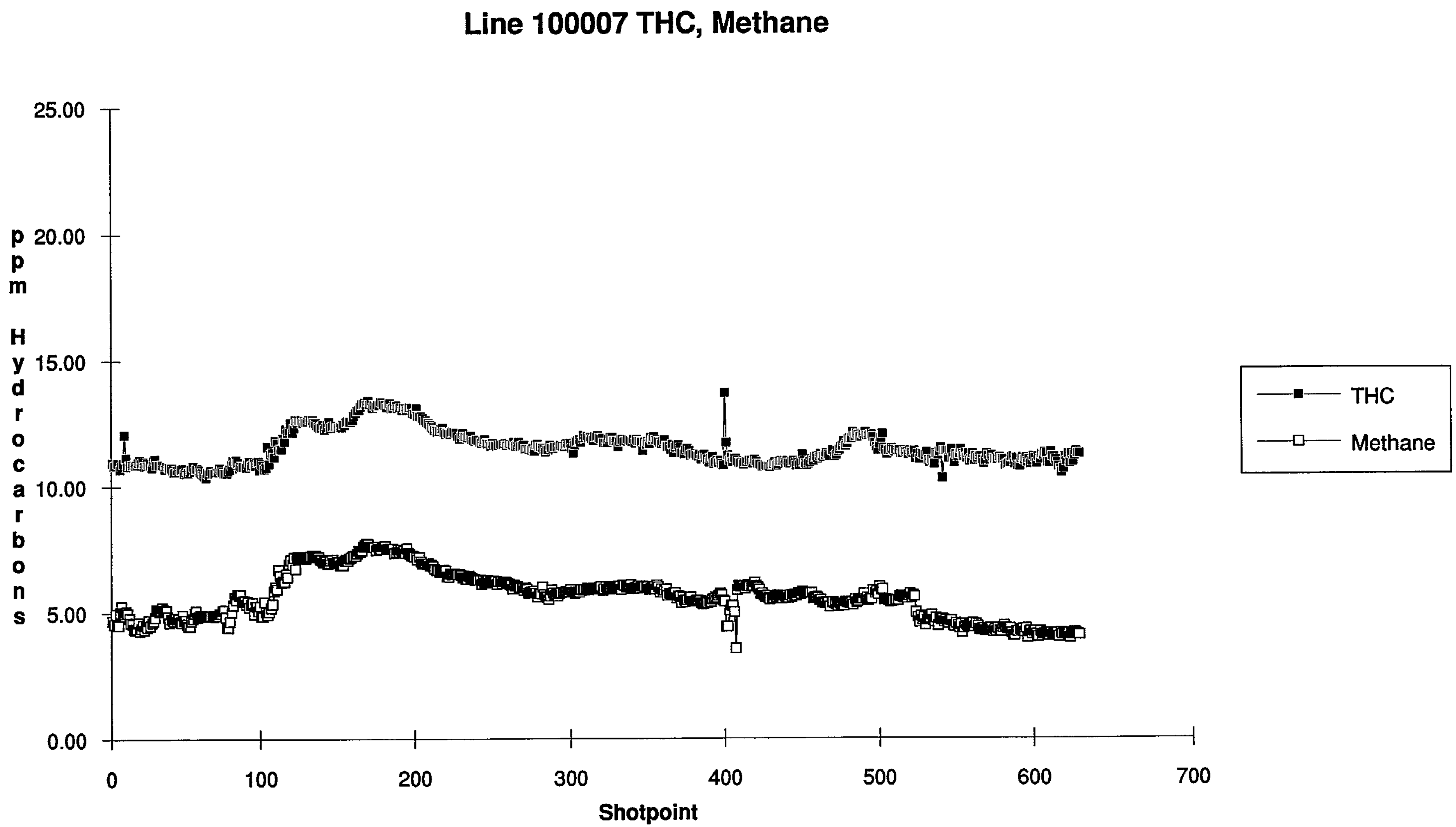
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	1-May-91	07:32:01	11	48.788	128	02.934
End	3	1-May-91	07:36:00	11	49.010	128	02.694

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	11.493	5.603	0.026	0.109	0.011	0.021	0.001	0.001	0.002	0.070	0.021	0.008	0.629
Std. Dev.	0.694	0.940	0.016	0.022	0.006	0.007	0.004	0.003	0.004	0.026	0.020	0.015	0.245
Minimum	10.281	3.540	0.010	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maximum	13.671	7.715	0.079	0.152	0.028	0.038	0.050	0.033	0.025	0.142	0.095	0.083	1.546

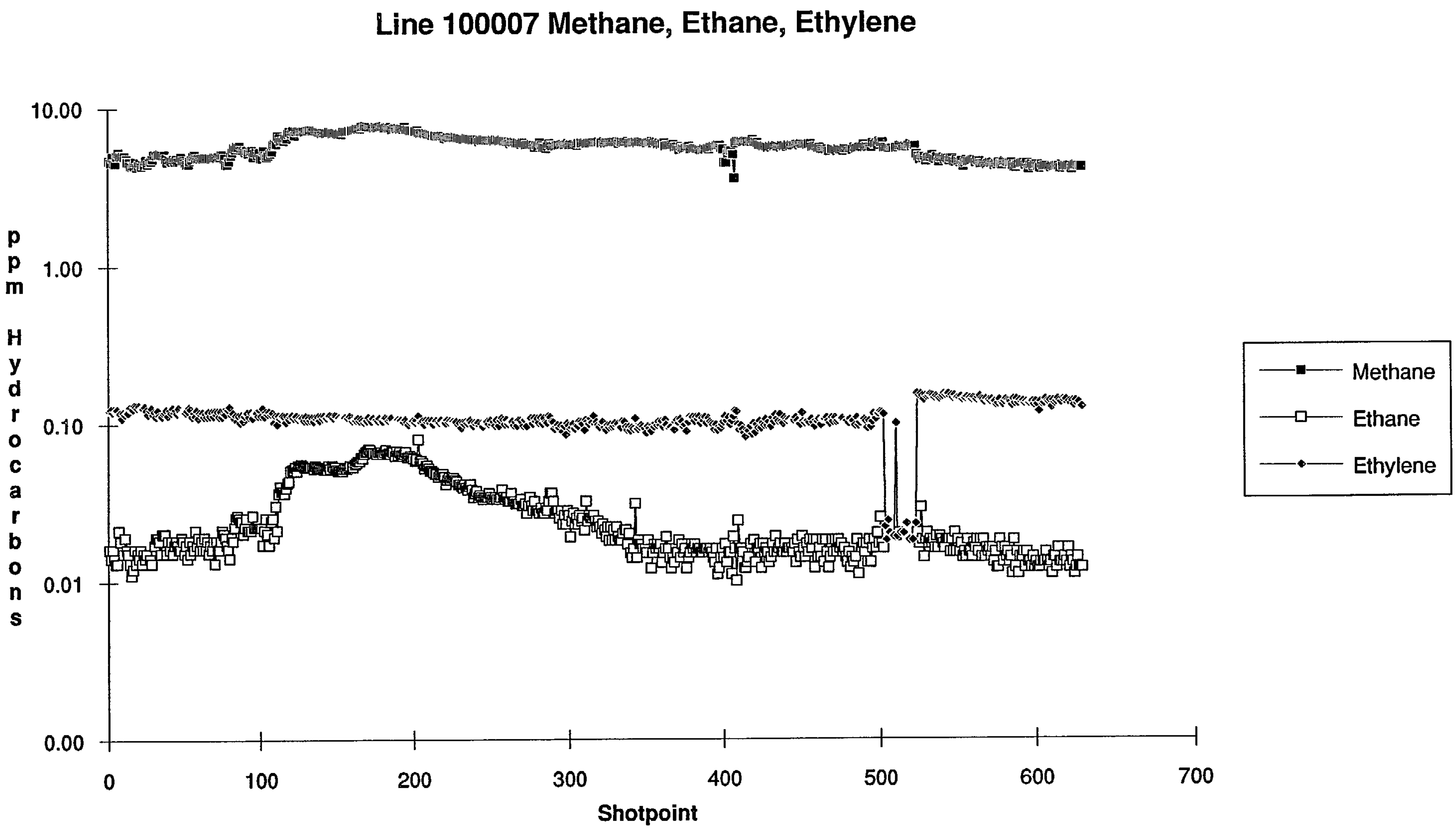
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	61.599	27.839	82.724	100.795	18.082
Std. Dev.	0.521	0.445	15.295	21.949	9.578
Minimum	60.840	27.330	56.600	68.100	7.800
Maximum	63.000	28.880	104.500	158.100	58.800

Notes

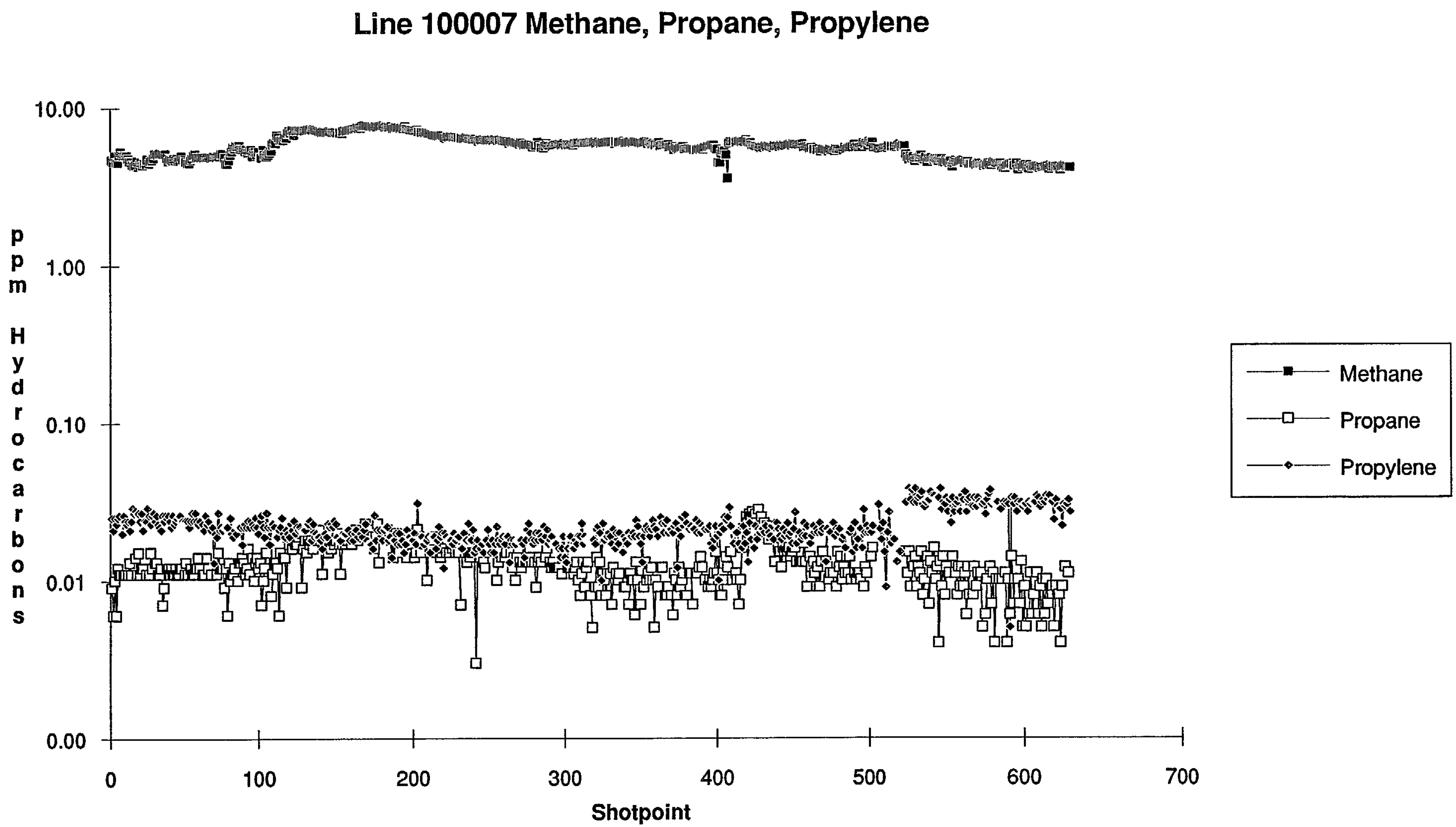
Weak but extensive THC, C1-C3 anomaly from sp 110 to 300 (approx)
Weak C3 and C4 anomaly, sp 418 to 438 approx.
No data for sp 505 to 558 due to system power failure at 0732.



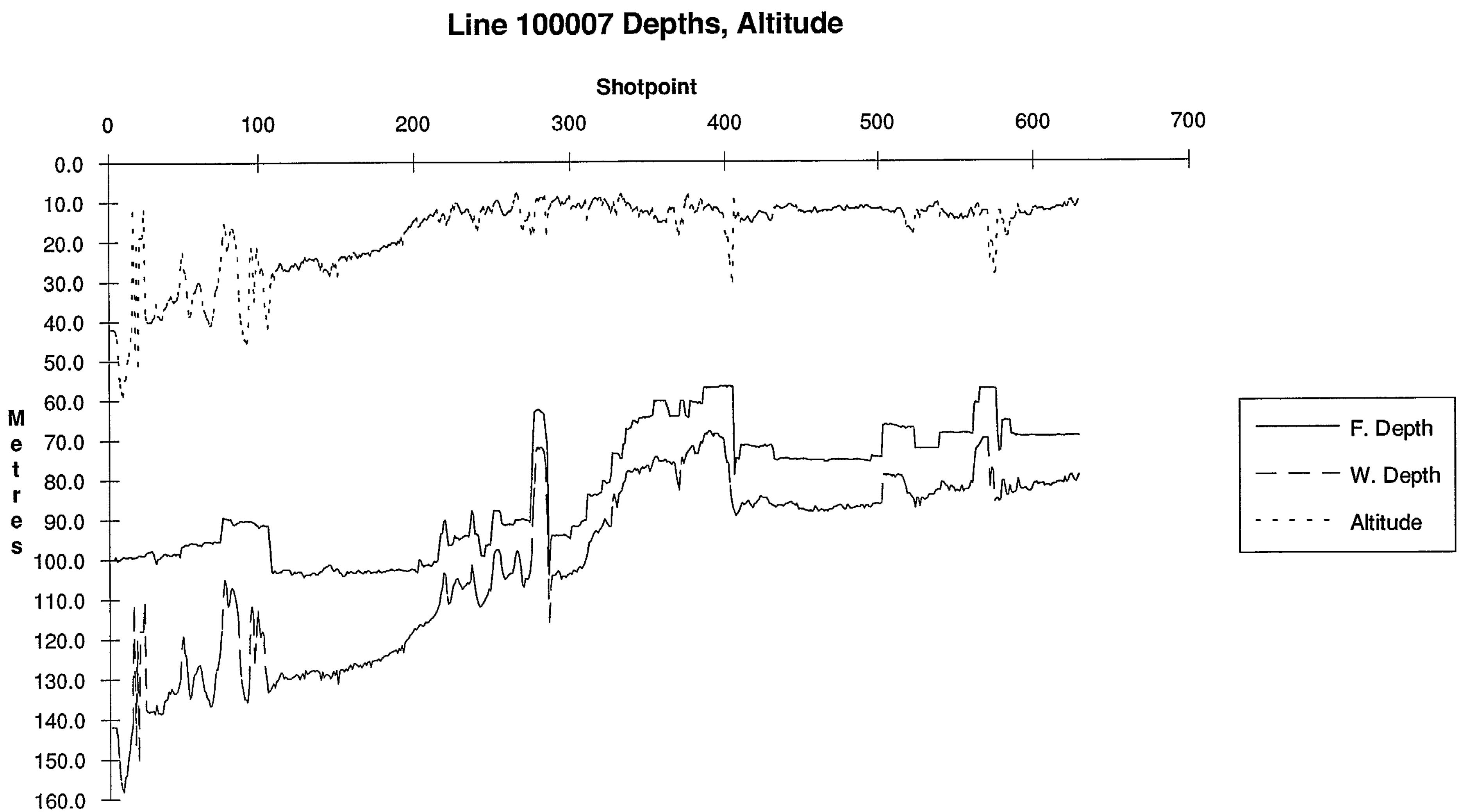
Line 100007 THC, Methane
25.00
20.00
15.00
10.00
5.00
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
Shotpoint
THC
Methane



Line 100007 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 100007 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 100007 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
130.0
140.0
150.0
160.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

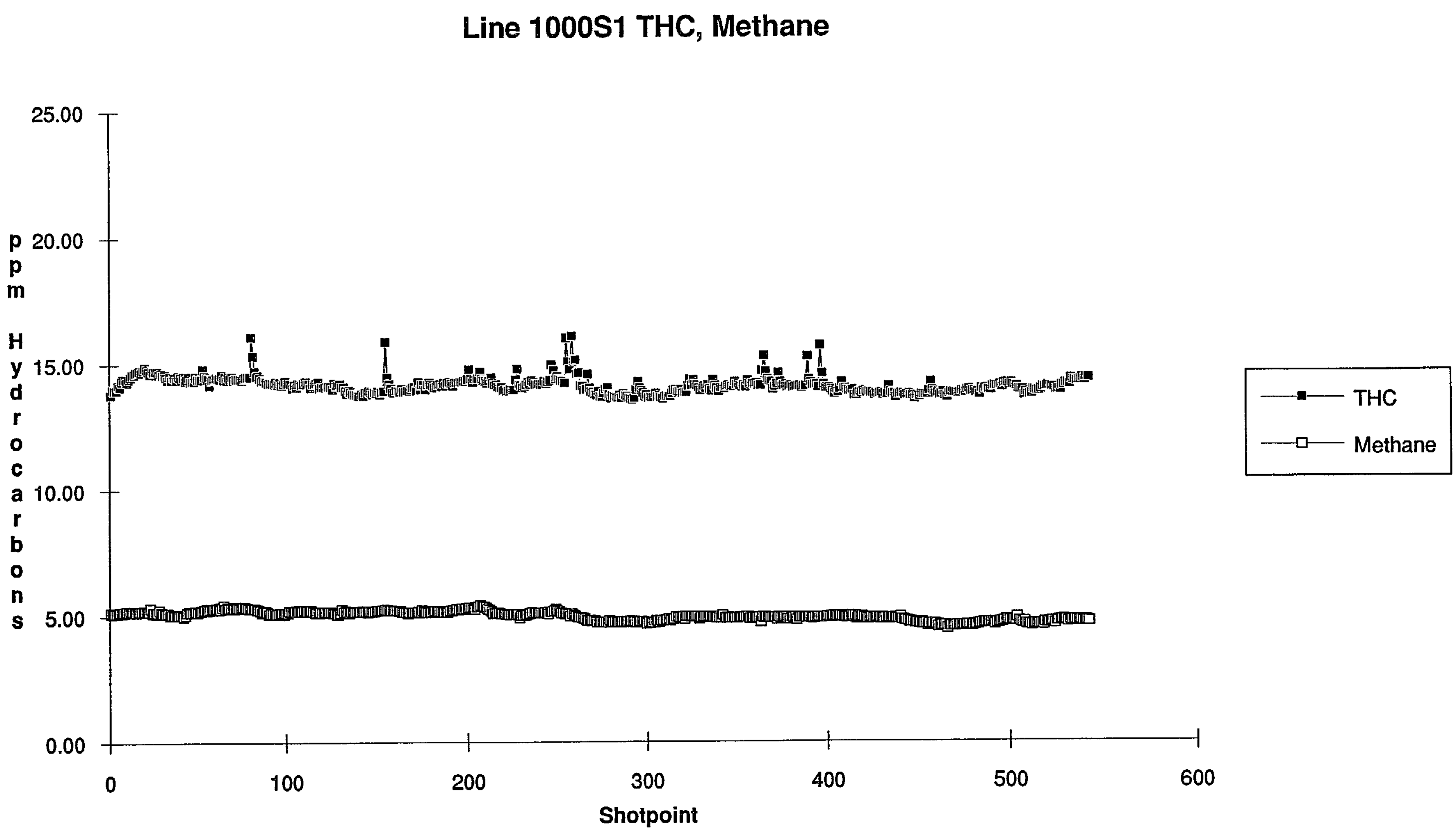
Line Number	1000S1
No. of Shotpoints	542

	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	24-Apr-91	18:10:43	13	50.120	128	38.867
End	542	25-Apr-91	12:21:21	12	48.261	129	40.750

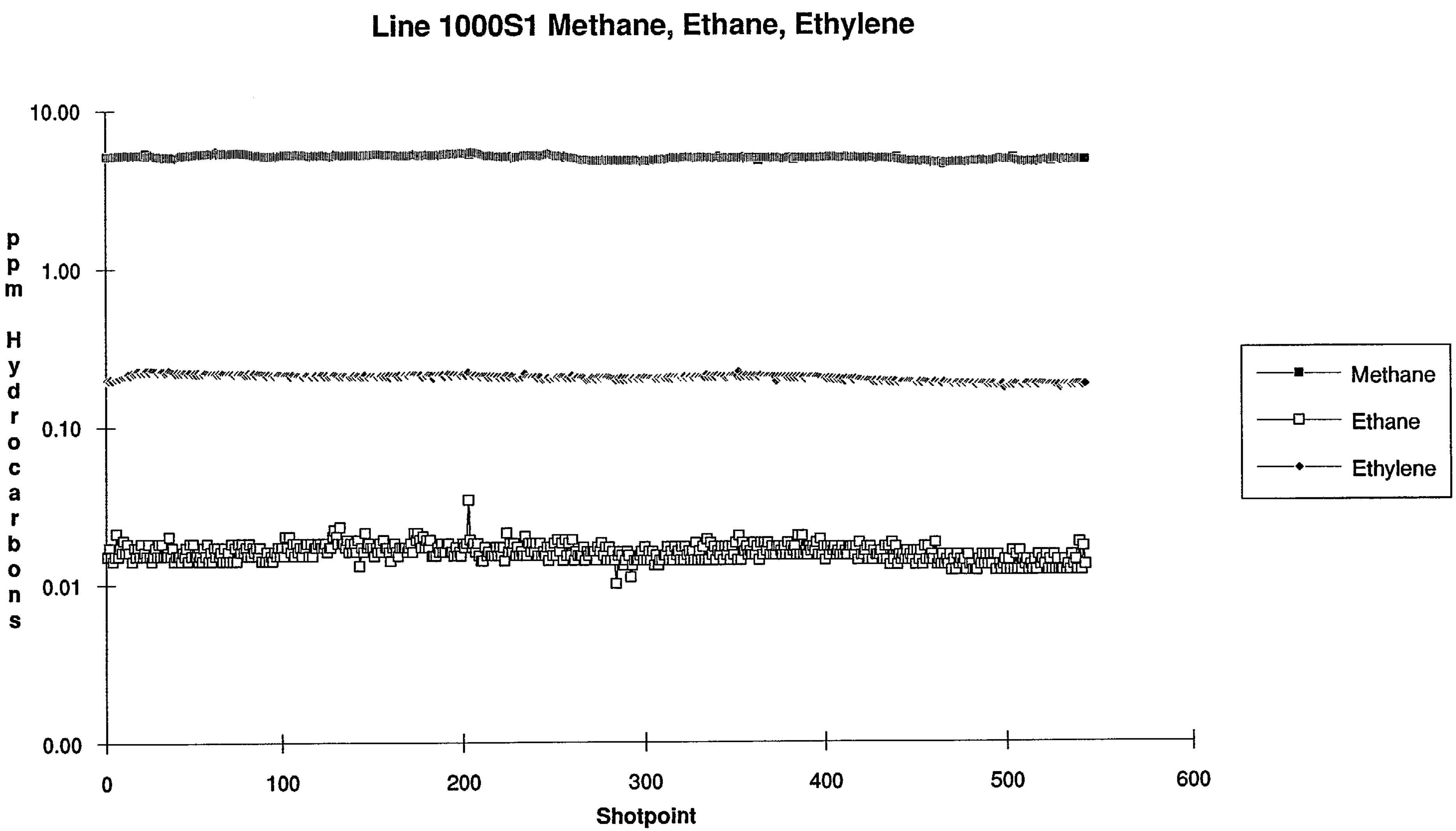
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	14.122	4.970	0.016	0.201	0.012	0.043	0.000	0.000	0.012	0.142	0.000	0.001	0.560
Std. Dev.	0.349	0.215	0.002	0.012	0.006	0.004	0.001	0.002	0.007	0.044	0.000	0.016	0.130
Minimum	13.563	4.464	0.010	0.172	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.249
Maximum	16.089	5.423	0.034	0.226	0.024	0.056	0.009	0.025	0.041	0.225	0.008	0.361	0.999

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	63.870	29.726	46.454	59.167	12.820
Std. Dev.	1.285	0.960	5.154	5.622	1.585
Minimum	62.430	28.620	35.000	47.800	8.700
Maximum	66.000	31.330	55.800	69.900	18.800

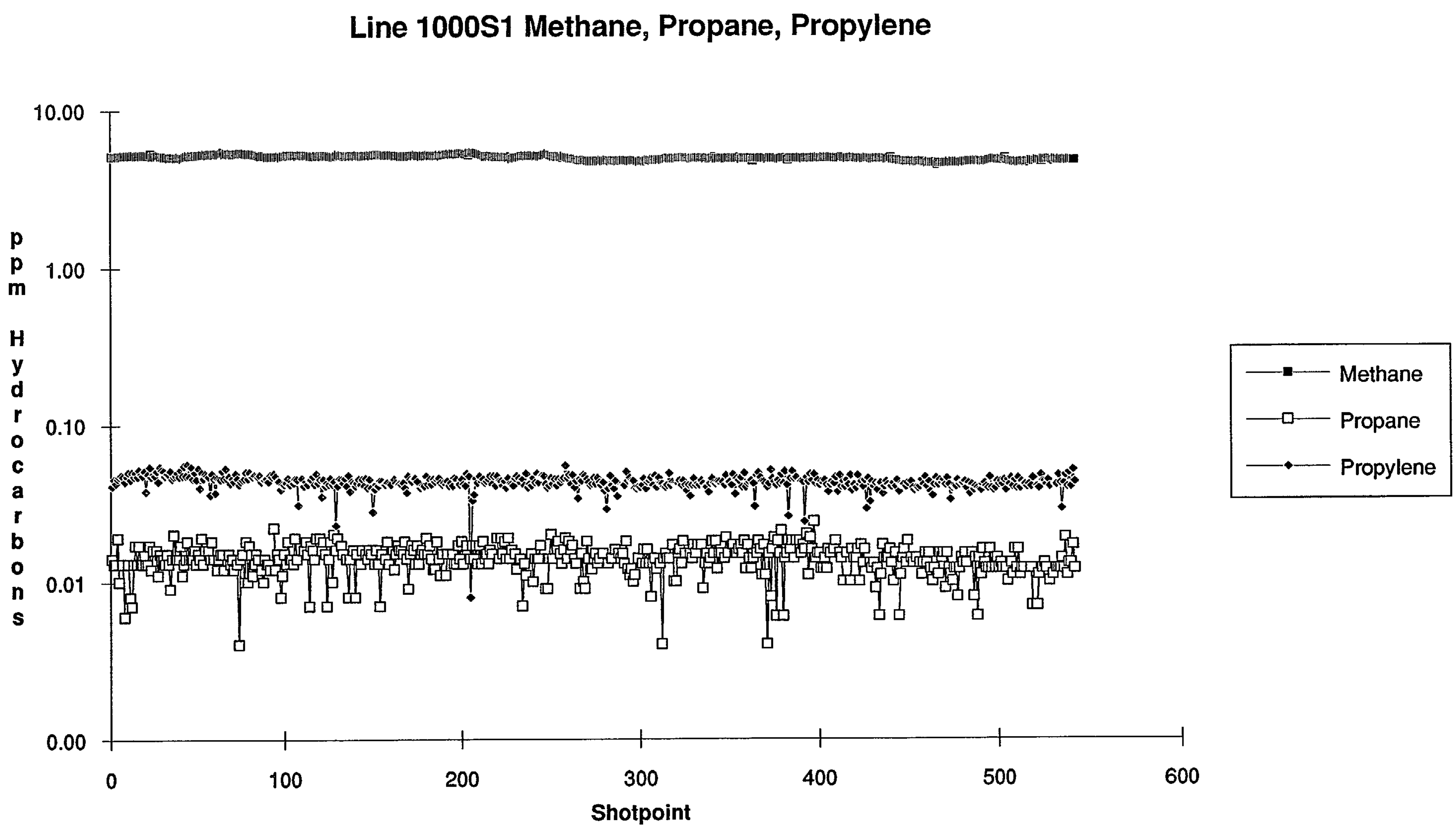
Notes: No anomalies detected.

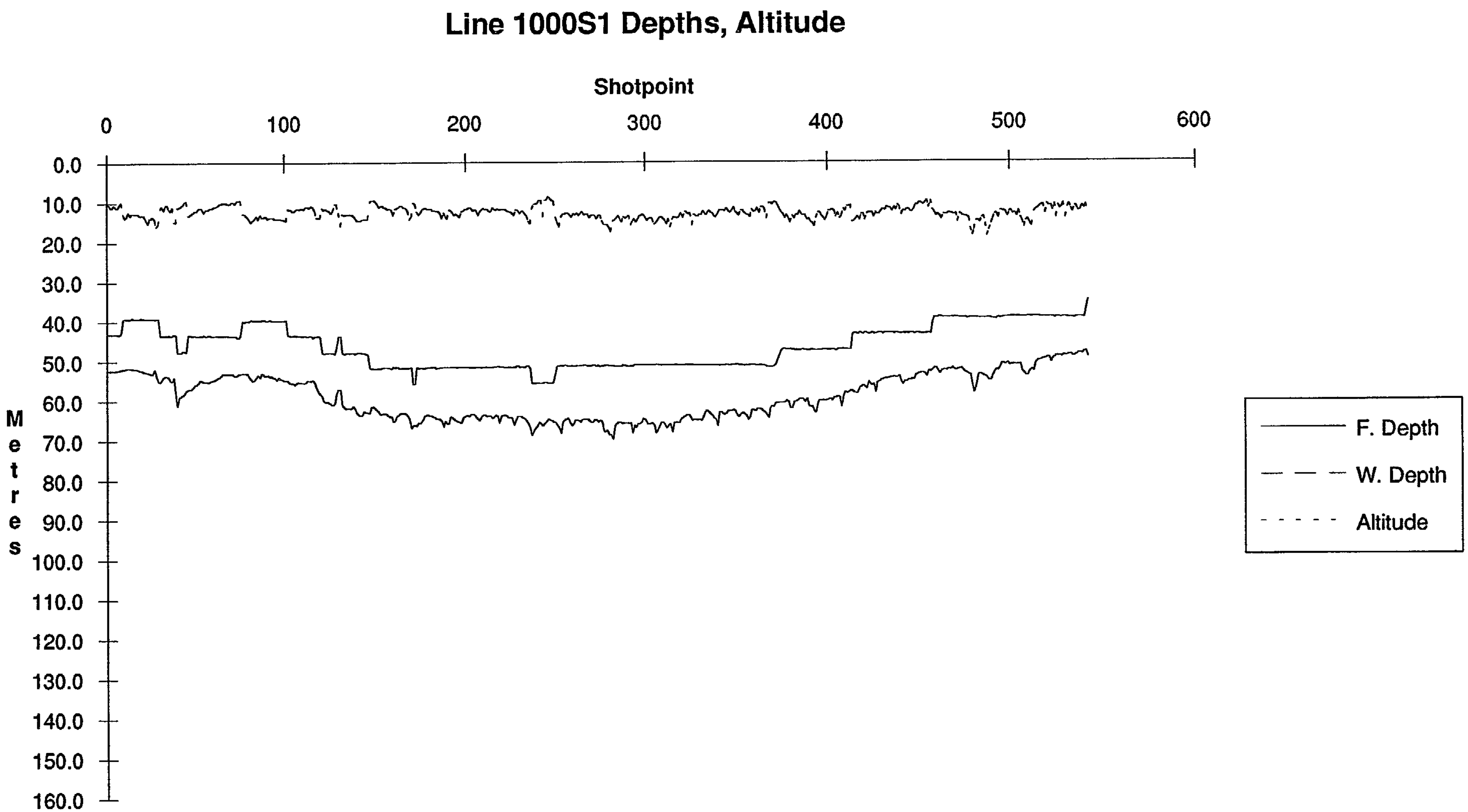


Line 1000S1 THC, Methane
25.00
20.00
15.00
10.00
5.00
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
Shotpoint
THC
Methane



Line 1000S1 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
Shotpoint
Methane
Ethane
Ethylene


Line 1000S1 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 1000S1 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
130.0
140.0
150.0
160.0
Metres
F. Depth
W. Depth
Altitude

Line Summary

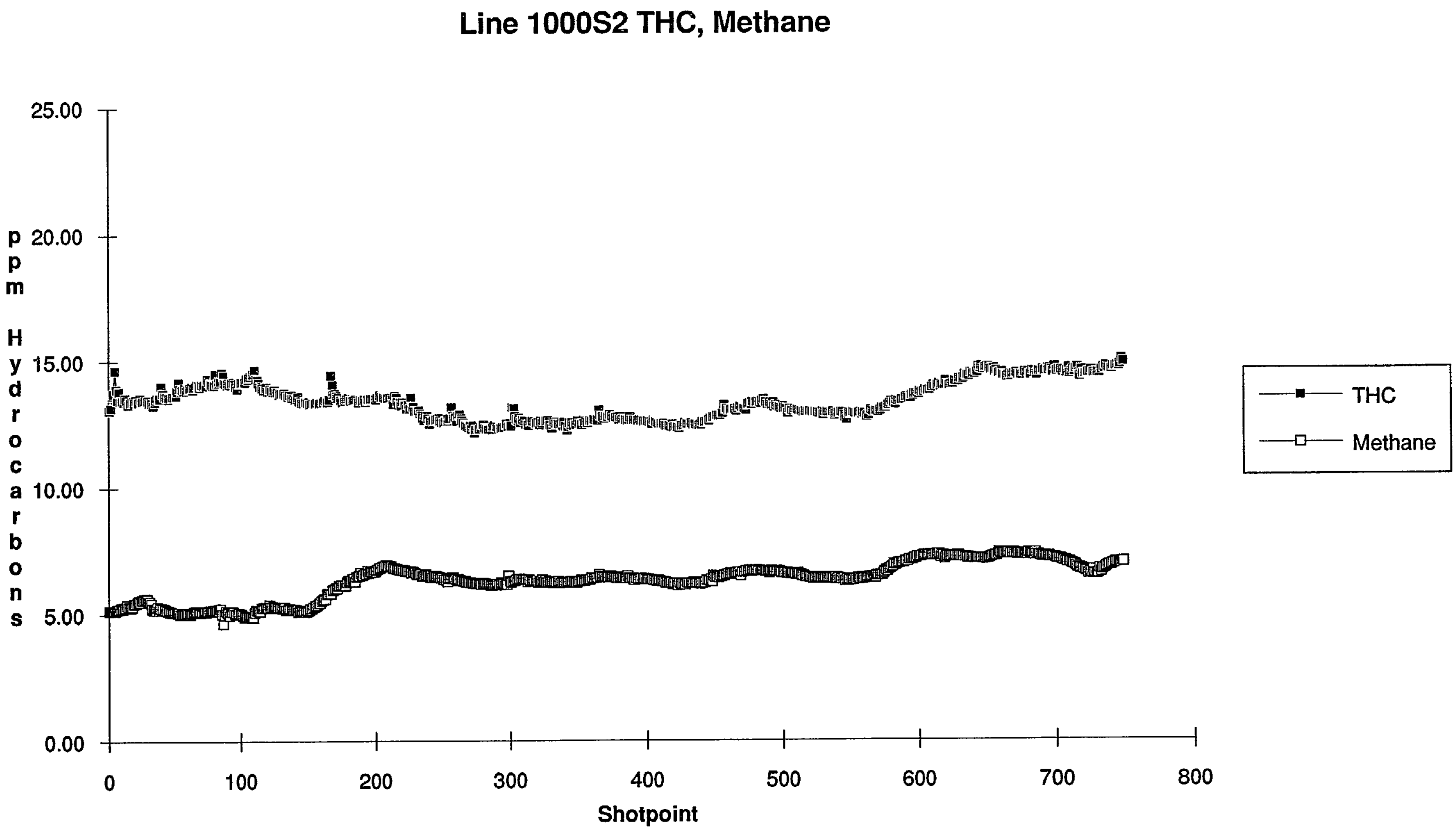
Line Number	1000S2
No. of Shotpoints	748

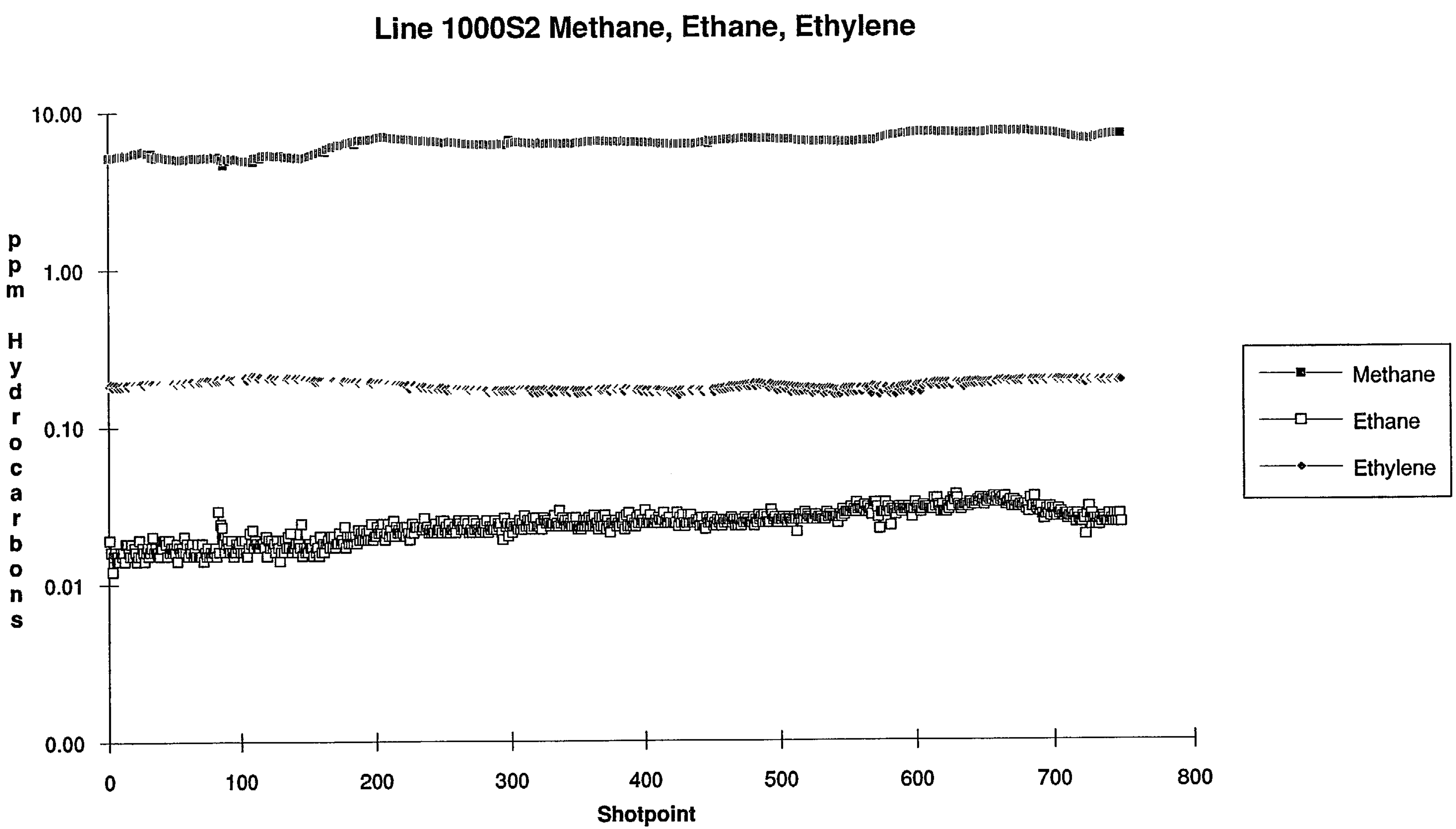
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	25-Apr-91	20:54:07	12	13.914	129	27.072
End	752	26-Apr-91	22:20:30	13	35.474	128	21.380

	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	13.374	6.288	0.024	0.181	0.016	0.028	0.000	0.000	0.005	0.077	0.000	0.000	0.623
Std. Dev.	0.722	0.677	0.005	0.012	0.007	0.009	0.001	0.002	0.007	0.036	0.000	0.000	0.122
Minimum	12.169	4.629	0.012	0.156	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.268
Maximum	15.033	7.381	0.036	0.211	0.028	0.064	0.009	0.027	0.033	0.197	0.000	0.011	1.092

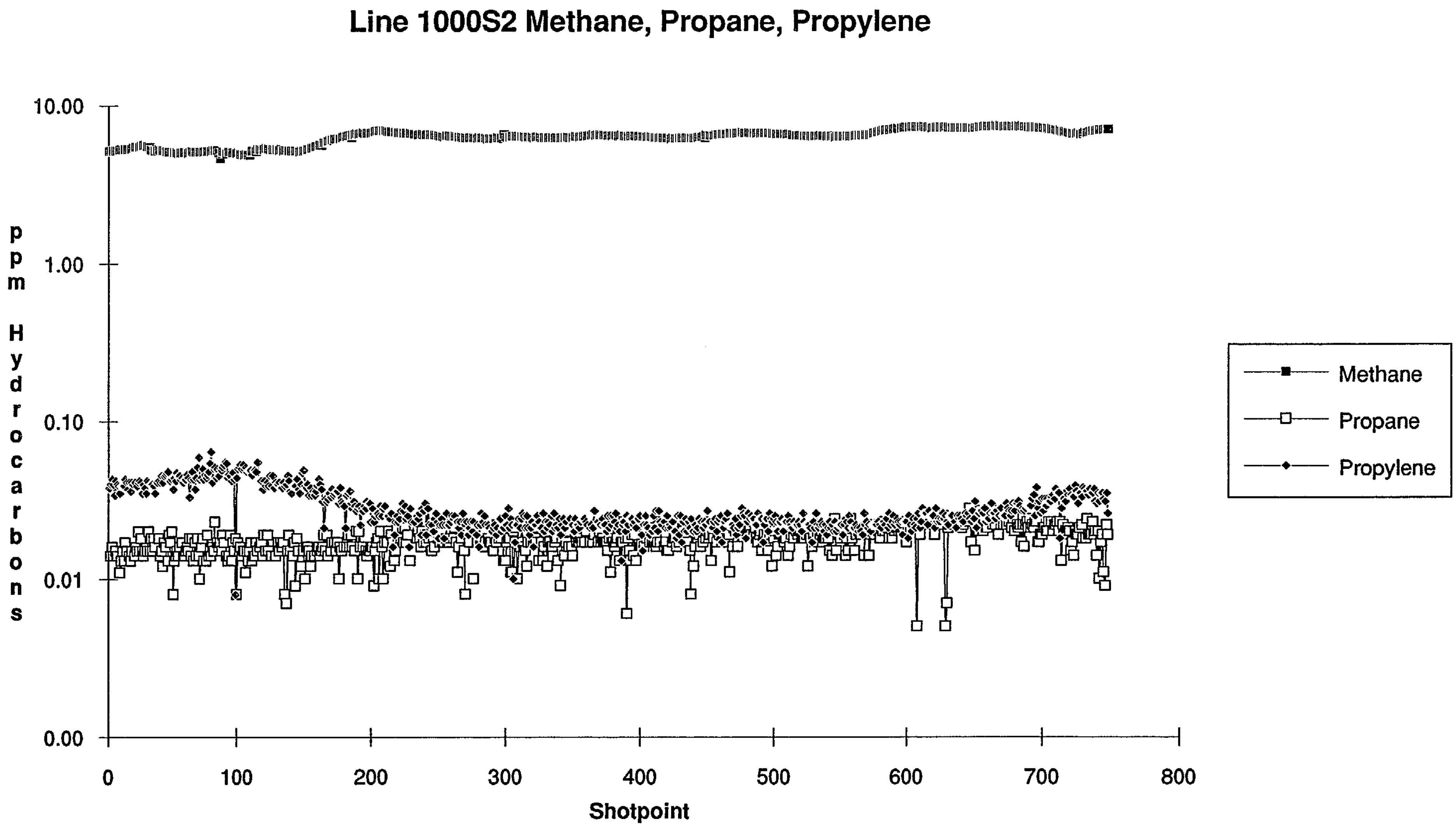
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.815	28.774	66.020	80.859	13.654
Std. Dev.	0.819	0.661	9.282	10.347	2.991
Minimum	61.890	28.000	22.000	33.700	6.900
Maximum	64.310	29.990	76.700	93.700	30.100

Notes A weak THC, C1-C3 anomaly towards the western end of the line.

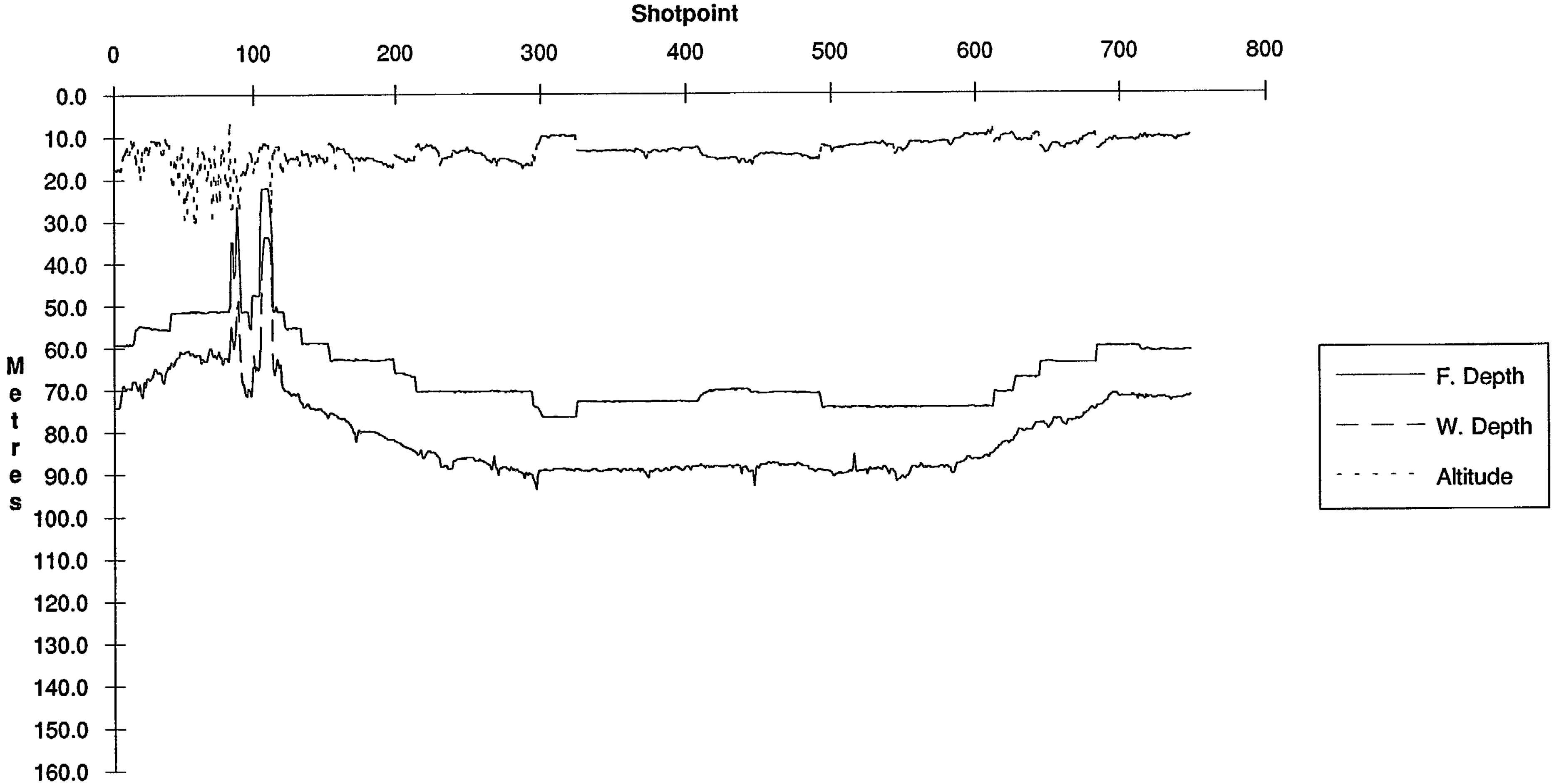

Line 1000S2 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600
700
800
Shotpoint
THC
Methane



Line 1000S2 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
100
200
300
400
500
600
700
800
Shotpoint
Methane
Ethane
Ethylene


Line 1000S2 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 1000S2 Depths, Altitude



Line Summary

Line Number	1000T1
No. of Shotpoints	327

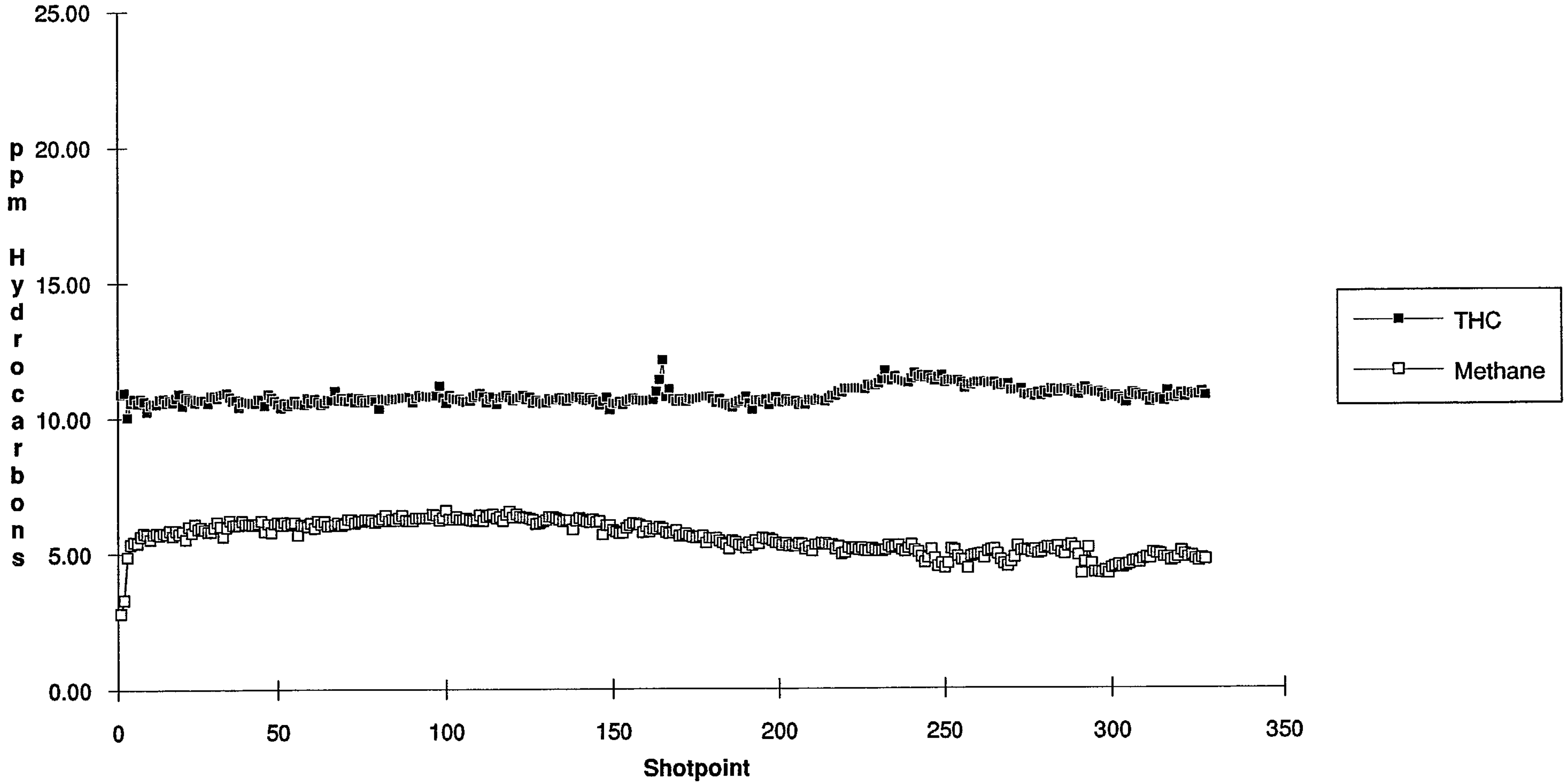
	Shotpoint	Date	Time	Latitude		Longitude	
Start	2	30-Apr-91	20:33:11	11	19.969	127	21.353
End	329	1-May-91	07:30:00	11	48.664	128	03.073

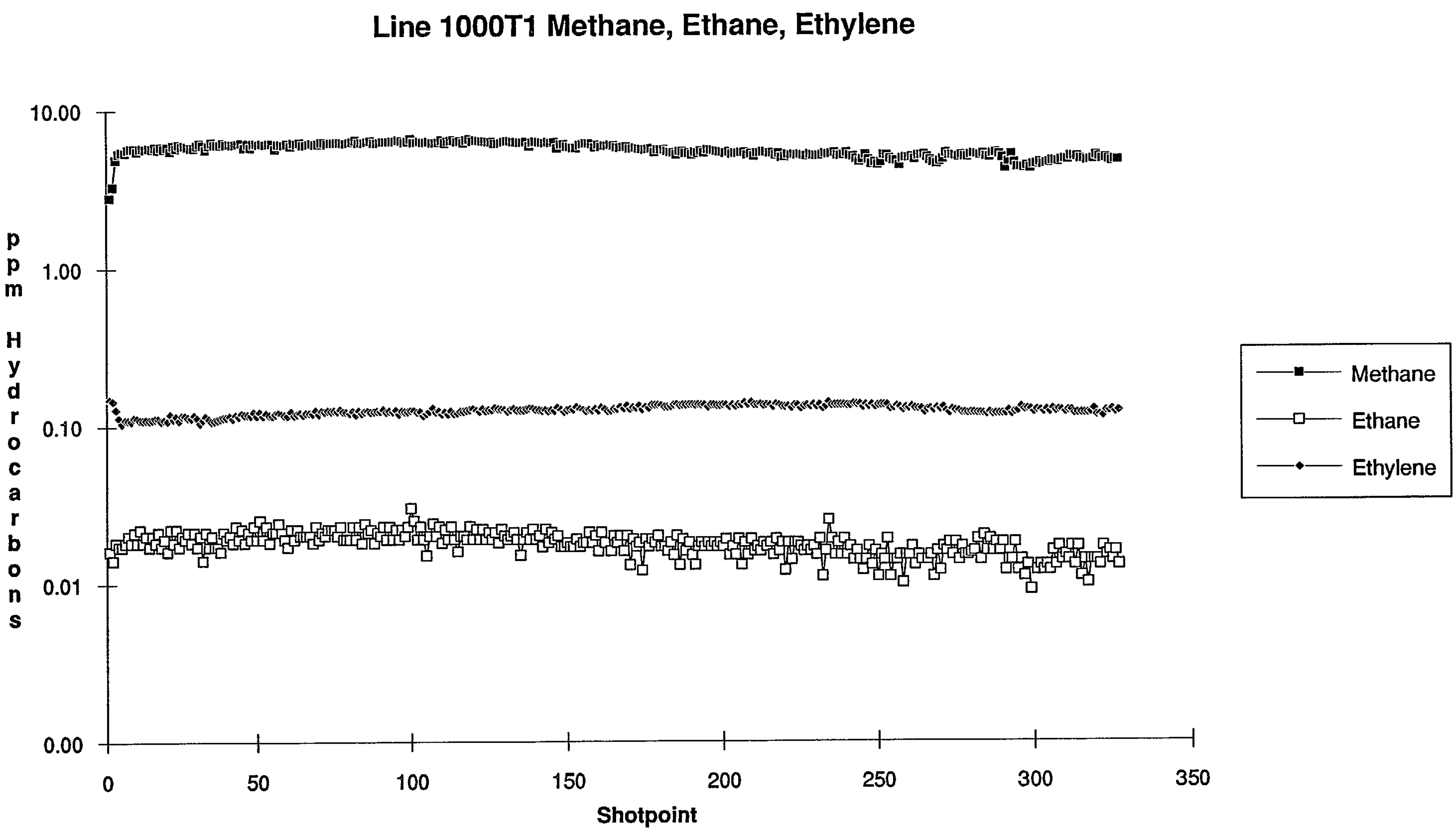
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	10.780	5.541	0.018	0.124	0.009	0.025	0.000	0.000	0.001	0.063	0.037	0.029	0.492
Std. Dev.	0.274	0.628	0.003	0.008	0.005	0.004	0.001	0.001	0.004	0.029	0.033	0.033	0.114
Minimum	10.024	2.802	0.009	0.104	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.242
Maximum	12.129	6.577	0.030	0.148	0.019	0.047	0.006	0.015	0.027	0.162	0.138	0.129	0.919

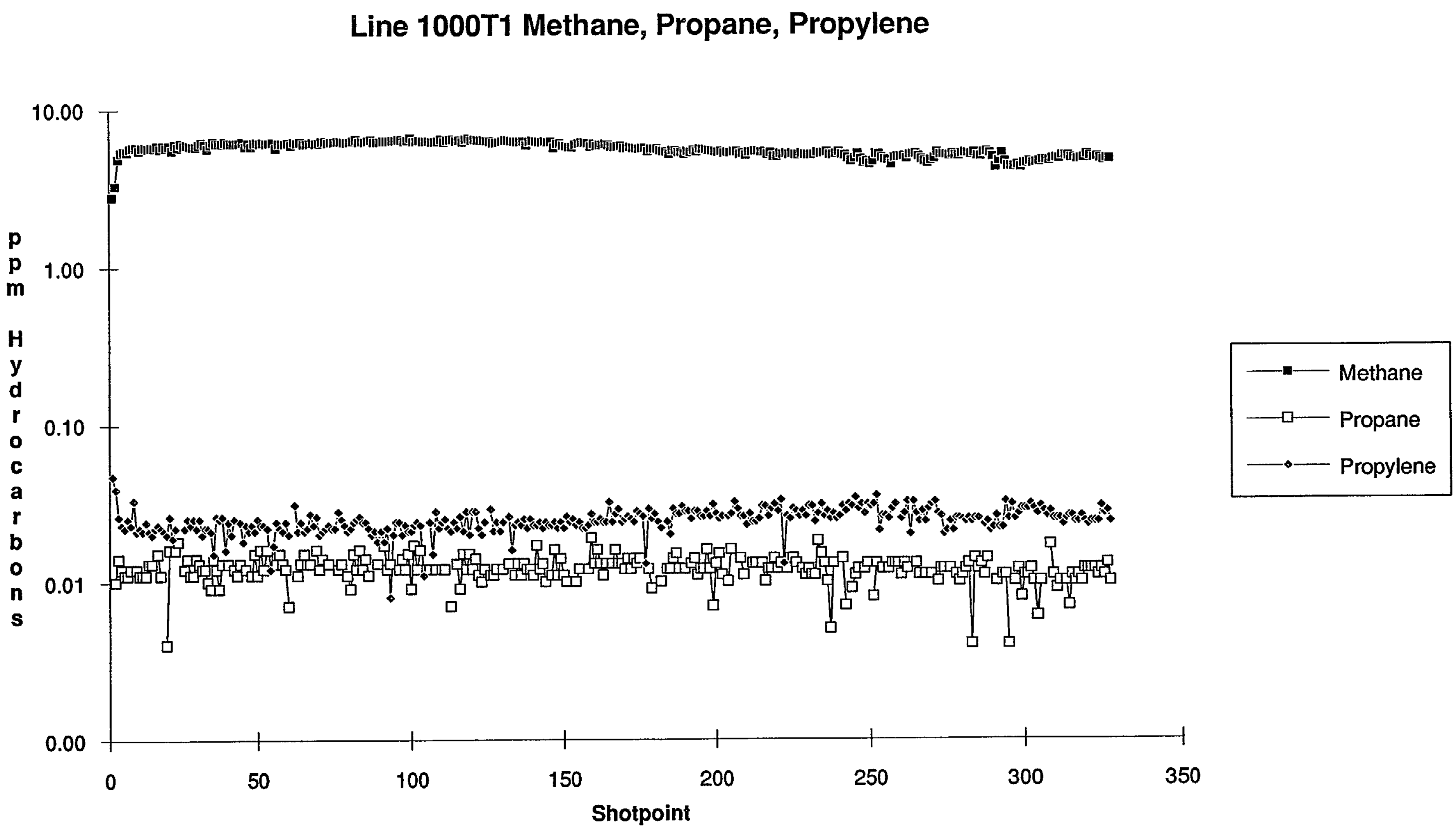
	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.310	28.469	102.362	128.108	25.771
Std. Dev.	0.885	0.799	7.939	8.802	9.099
Minimum	60.620	27.040	77.500	95.100	10.900
Maximum	63.410	29.470	109.600	149.000	58.600

Notes: No anomalies detected

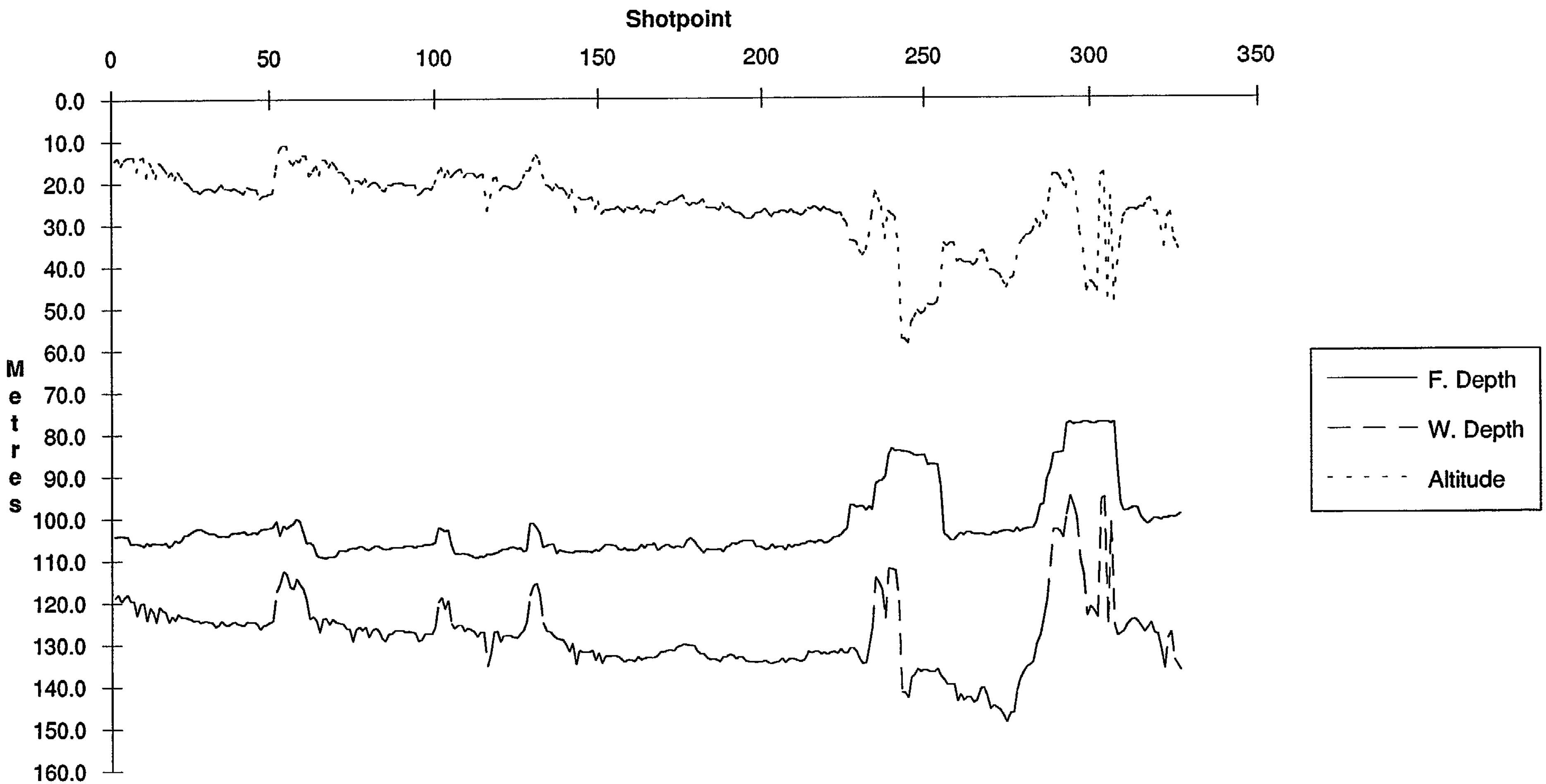
Line 1000T1 THC, Methane




Line 1000T1 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
50
100
150
200
250
300
350
Shotpoint
Methane
Ethane
Ethylene


Line 1000T1 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 1000T1 Depths, Altitude



Line Summary

Line Number	VP100007
No. of Shotpoints	108

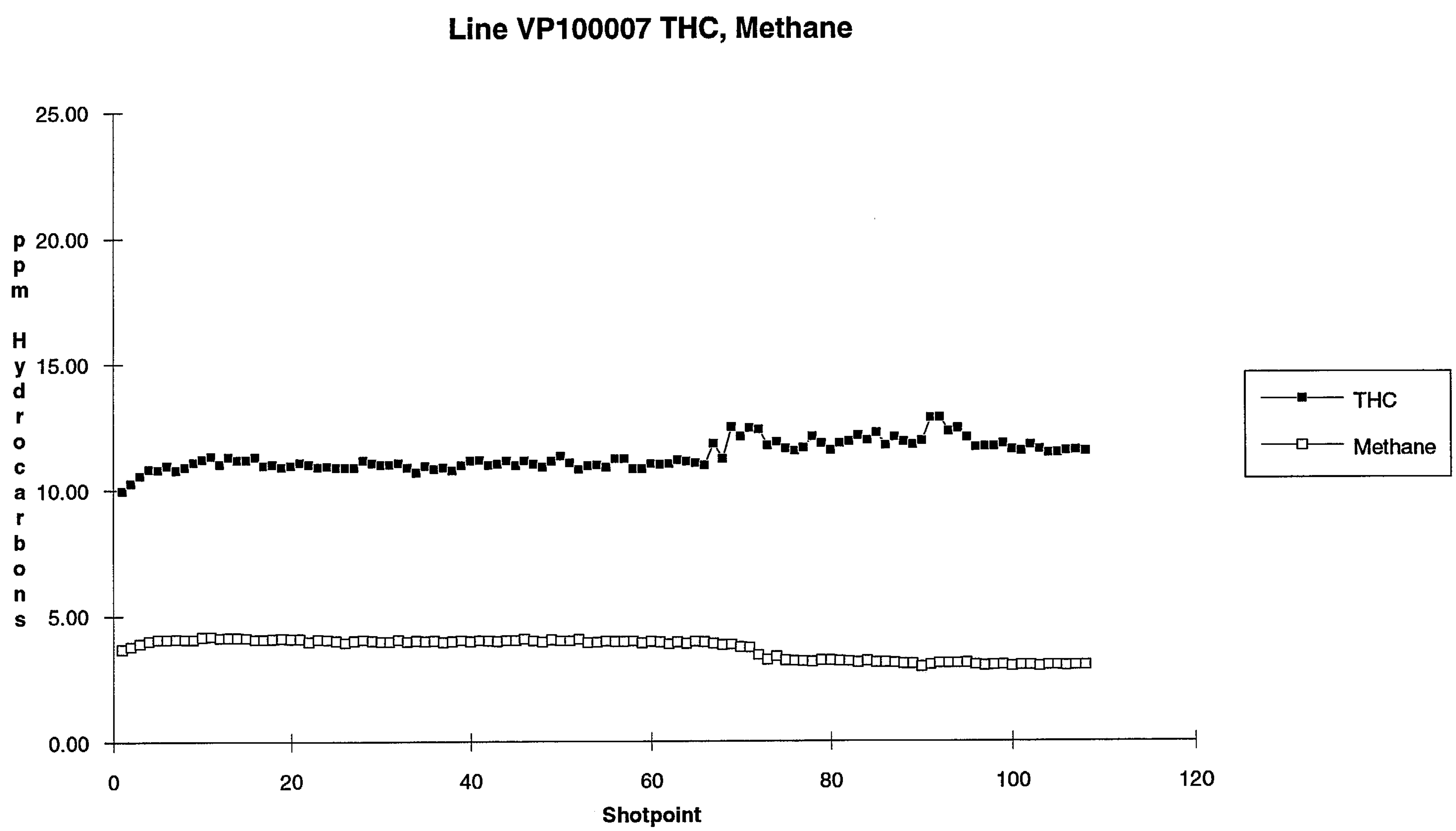
	Shotpoint	Date	Time	Latitude		Longitude	
Start	1	2-May-91	14:10:30	13	12.642	126	31.736
End	108	2-May-91	17:44:41	13	14.230	126	35.823

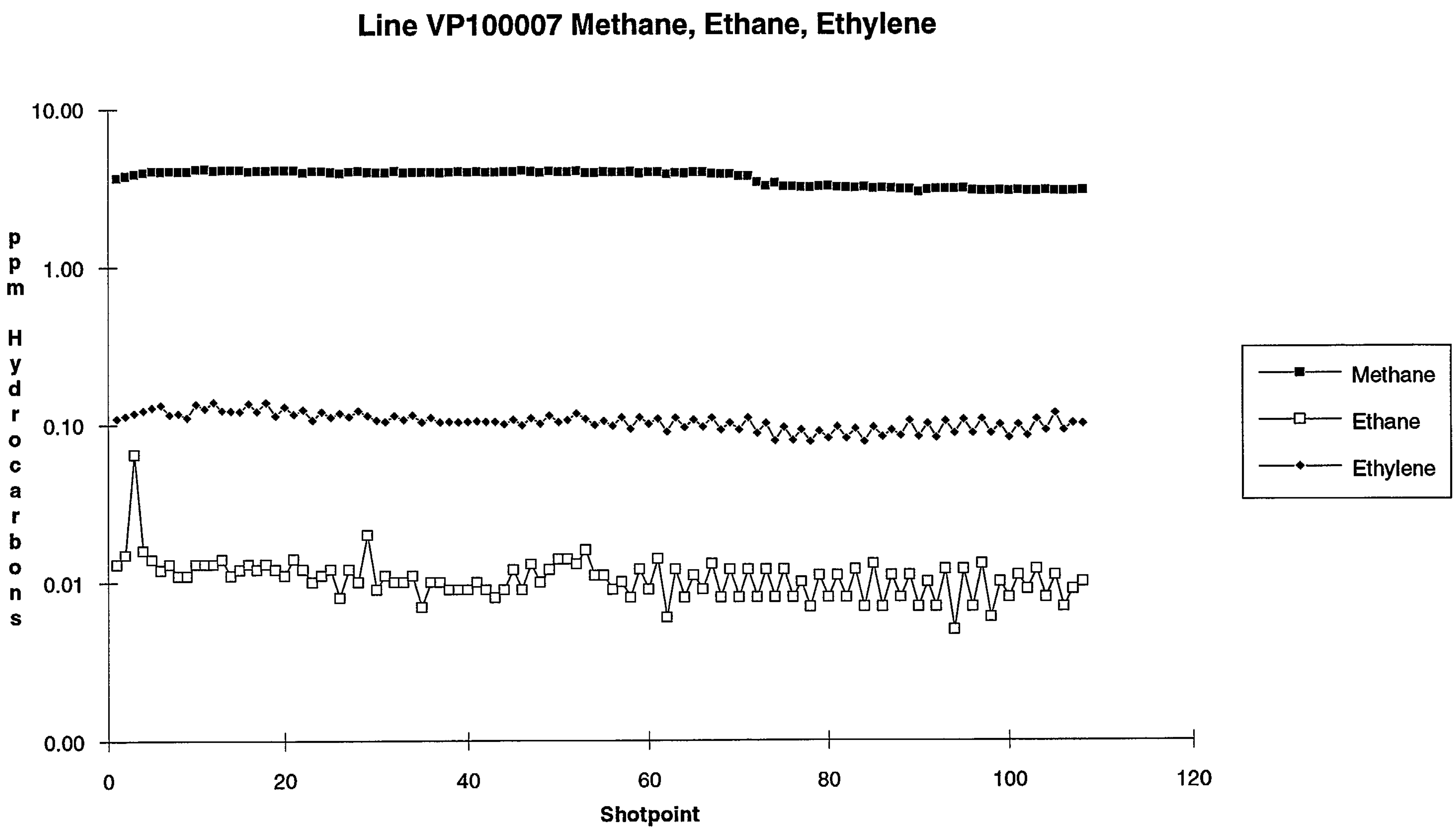
	THC	Methane	Ethane	Ethylene	Propane	Propylene	i-Butane	n-Butane	i-Pentane	n-Pentane	i-Hexane	n-Hexane	%Wetness
Mean	11.317	3.677	0.011	0.104	0.005	0.026	0.000	0.000	0.006	0.097	0.002	0.007	0.434
Std. Dev.	0.530	0.432	0.006	0.014	0.004	0.006	0.000	0.000	0.003	0.040	0.005	0.009	0.220
Minimum	9.957	2.954	0.005	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.162
Maximum	12.844	4.174	0.065	0.139	0.014	0.037	0.000	0.000	0.011	0.153	0.031	0.030	1.941

	Cond.	Temp.	F. Depth	W.Depth	Altitude
Mean	62.127	28.351	45.924	78.305	32.378
Std. Dev.	0.165	0.050	25.491	1.052	25.544
Minimum	61.830	28.270	0.900	75.900	6.700
Maximum	62.380	28.480	73.100	80.400	79.000

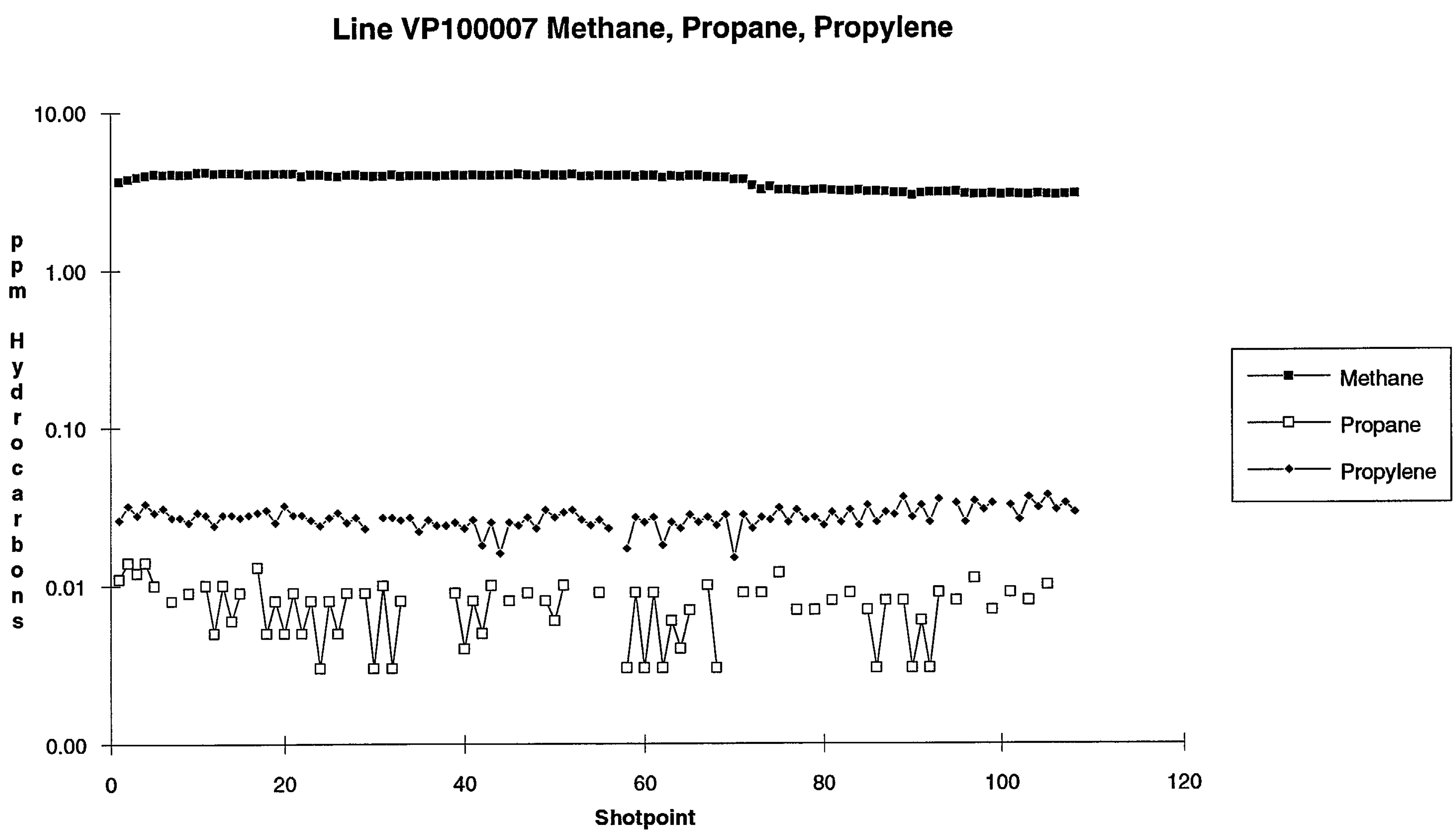
Notes

No hydrocarbon anomalies, although hydrocarbon concentrations generally lower above the thermocline.
Thermocline and halocline at approximately 35-40m below surface.

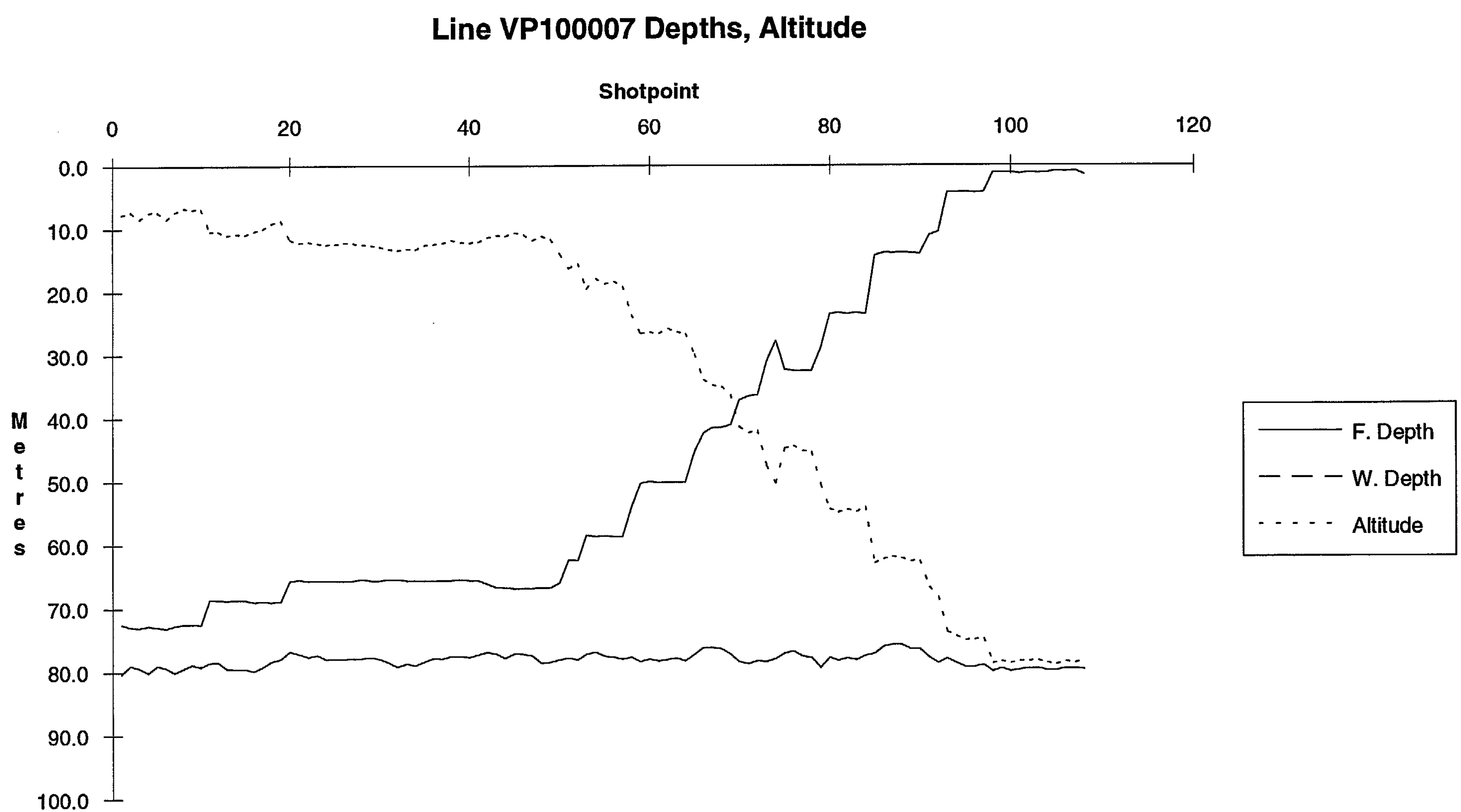

Line VP100007 THC, Methane
ppm Hydrocarbons
25.00
20.00
15.00
10.00
5.00
0.00
0
20
40
60
80
100
120
Shotpoint
THC
Methane



Line VP100007 Methane, Ethane, Ethylene
10.00
1.00
0.10
0.01
0.00
ppm Hydrocarbons
0
20
40
60
80
100
120
Shotpoint
Methane
Ethane
Ethylene



Line VP100007 Methane, Propane, Propylene
ppm Hydrocarbons
10.00
1.00
0.10
0.01
0.00
0
20
40
60
80
100
120
Shotpoint
Methane
Propane
Propylene



Line VP100007 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
Metres
F. Depth
W. Depth
Altitude

Appendix II

DHD Methodology

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

(1) The over-the-side gear includes a tow-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 tow-fish measures the depth of the tow-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 tow-fish above the seafloor allowing the operator to maintain the tow-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 tow-fish and relay CTD and sonar data from the tow-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 tow-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 tow-fish is deployed from the 'A-frame' on the port side of the R.V. *Rig Seismic*, which allows DHD data to be acquired concurrently with seismic data. Echo sounder data and GPS navigation are displayed in the laboratory and these provide clues to the locations of surface expressions of gas seeps on the seafloor. All data are recorded continuously so that any hydrocarbon anomalies in the water column can be quickly recognised and additional measurements (or samples) can be collected if appropriate.

Detector sensitivity is < 10 parts per billion in the stripped headspace sample. Calibrations were conducted on a daily basis and were within 5% 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 30m DB-1 Megabore column
n-Pentane	ppm	"
i-Hexane	ppm	"
n-Hexane	ppm	"

Water Depth	Metres	On-board 3.5 Khz and 12 Khz echo sounders
Tow-fish Altitude	Metres	Mesotech 807 altitude sonar.
Conductivity	mmhos/cm	Sea-Bird conductivity meter
Water Temperature	degrees Celsius	YSI temperature thermistor
Tow-fish Depth	Metres	Druck pressure transducer

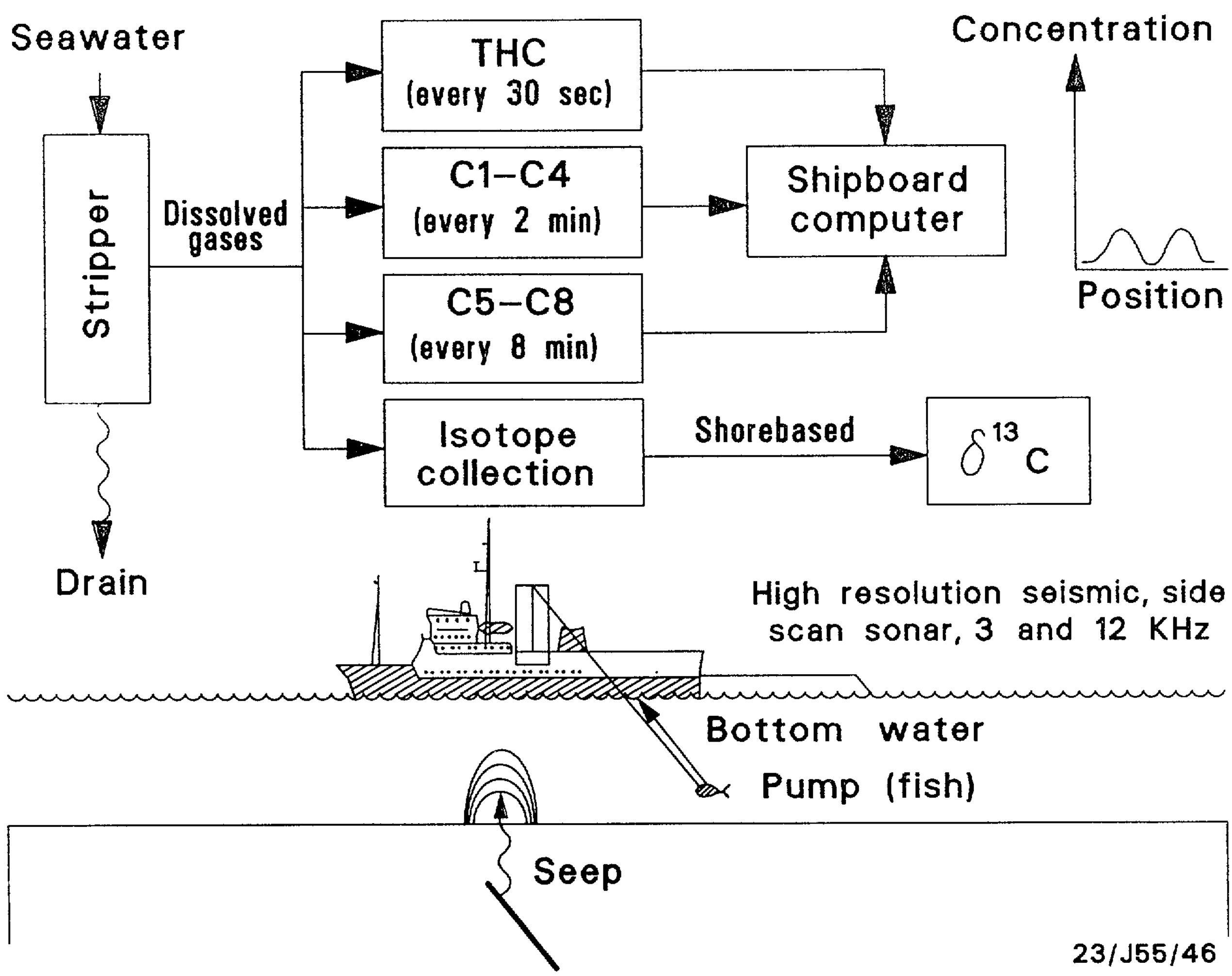


Figure II-1. Schematic of the geochemical equipment aboard Rig Seismic for the continuous profiling of hydrocarbons in seawater: the bottom-water DHD technique.

Appendix III

Interpretative Methodology

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

Light Hydrocarbons In Seawater

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

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

(2) Biological processes. Hydrocarbons are produced microbially and photochemically in seawater. In addition, during early diagenesis, a variety of hydrocarbons are produced by the activities of microbial organisms during aerobic and anaerobic destruction of organic matter which occurs primarily in the top few tens of metres of sediments. The products of these reactions include methane and minor quantities of both saturated and unsaturated hydrocarbons (Hunt 1979; Claypool & Kvenvolden

1983 and references cited therein). The presence of the unsaturated hydrocarbons, which are only produced biochemically (Primrose & Dilworth 1976; Claypool & Kvenvolden 1983), provides one criteria to distinguish between biogenic and thermogenic hydrocarbons.

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

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

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

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

Data interpretation: the mixing model

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

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

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

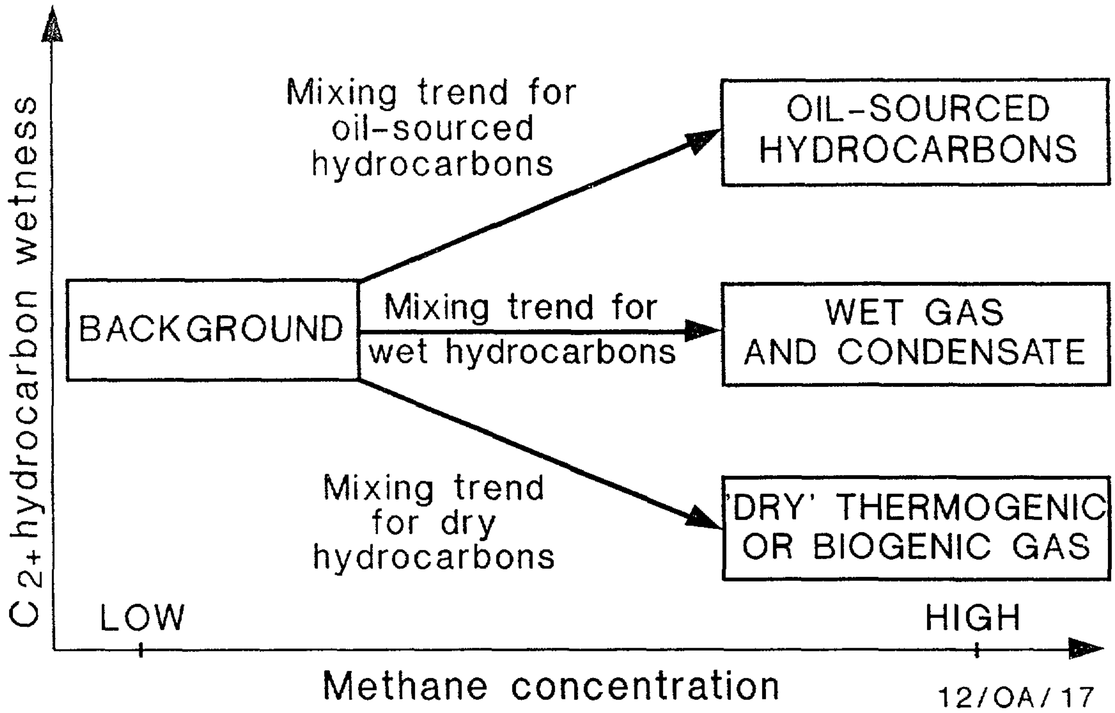


Figure III-1. Cross-plot of methane versus hydrocarbon wetness, showing the general decrease in wetness with increasing methane for gas-prone or biogenic sources. Conversely, oil-prone sources are indicated by increasing wetness with increasing wetness with increasing methane. Gas-condensate sources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

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 tow-fish above the seafloor, a shoaling of the water depth, penetration of the tow-fish above the local thermocline or combinations of these factors. In these cases, plotting the saturated hydrocarbon (methane, ethane, propane) concentrations against the tow-fish depth, seawater temperature and salinity, or against the biogenic hydrocarbons (ethylene, propylene), generally resolves apparent anomalies from those anomalies related to seepage.

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

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Appendix IV

Systems Operation Reports

The following system reports were compiled upon completion of the survey.

DHD operations (J.H. Bishop)

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

Fish/cable/winch subsystem

During mobilisation in Darwin it was noticed that there were several kinks and `bubbles' in the cable in the first few metres above the thimble (the point where the cable is attached to the fish). Consequently, it was decided to cut off the affected section of cable and reterminate. The retermination was not immediately successful, causing the submersible pump to short out, and another retermination of the pump motor connector was necessary. Further termination problems were experienced with the echo sounder/sonar resulting in at least two further reterminations of the connector. It is apparent from this that we need to develop better methods for fish terminations.

Whilst packing up the system during the transit to Port Hedland, some over-zealous tensioning of the cable on the winch caused the termination to be severed below the thimble, requiring the cable to be reterminated once more. A new thimble has been attached, but due to lack of 3- and 4-pin underwater connectors, the electrical terminations will have to wait until the next cruise.

Pump:
Another electrical short of the sub-pump on line 100/004 resulted in 1.25 hours of data acquisition being lost. On at least two occasions, the hose connecting the pump to the cable was partially or completely blown off. The partial separation resulted in reduced water flow to the gas extractor (5 l/min versus 9 l/min normally), and also caused a form of cavitation to occur in the cable, apparently the suction of the vacuum pump

pulls some gas out of solution whilst still in the cable, causing the appearance of a leak in the cable. A water flow gauge fitted to the water inlet of the gas extractor would help in identifying these problems.

Druck pressure transducer:

The depth transducer again worked well for most of the time. During line 100/002, for unknown reasons, the indicated fish depth increased from about 55m to approximately 125m without any actual change in the amount of cable deployed. The actual water depth was around 70m. The false readings lasted for about 19 hours along the line, and then returned to normal, without any intervention or changes on our part.

One other minor problem was the discrepancy between calculated altitude (water depth - fish depth) and the echo sounder altitude at depths of 60-70m or more. This was due to the transducer calibration being done in shallow waters (30-40m) prior to the start of the survey.

Sonar:

Once the problems with the cable termination were fixed, the Mesotech altitude sonar worked as well as it had during Cruise 99, that is, for most of the time, it gave a useable, albeit noisy, signal that allowed us to fly the fish 10-15m above the seabed. At other times, the sonar was over-ranging so much that no useful signal was output, hence we had to use the calculated altitude. The filtering algorithm in the data acquisition program was of some use in displaying the correct altitude, but at times the signal was so poor that no reliable altitude data was obtained. From empirical observation, it appears the behaviour of the sonar is related to the condition of the seabed, such that good signals are obtained from harder sediments, whilst soft sediments absorb the transducer pulse, causing the sonar to over-range.

Fairings:

The fairings were less of a problem than during Cruise 99, but the tendency for the fish to tow to starboard and under the hull of the vessel again limited deployment of the fish in water depths greater than 120m or so. Prior to the cruise, I found a paper in `Ocean Engineering' which describes this behaviour, known as 'kiting'. It is caused by downward compressional forces on the fairings preventing them from aligning themselves with the direction of tow, and consequently the fairings act as a hydrofoil, forcing the tow cable in one direction or another; in our case, towards the hull of the ship. The solution to the problem is to fit stacking rings to the cable every few metres so that the downward compressional forces are transferred from the fairings to the cable. We will have to develop a suitable method for doing this and spend some time prior to or during the next DHD cruise in fitting these stacking rings.

Gas extractor subsystem

Gas Extractor:

The gas extractor worked fairly well, although some problems occurred with the inlet solenoid and the level control unit. The inlet solenoid became jammed in the open position, and would not cut the inlet water supply when the high level alarm was tripped after the level control unit failed due to a faulty probe assembly. The solenoid valve was cleaned, and the probe assembly was replaced, and the gas extractor has since operated without a problem.

Gas Analysis subsystem

Gas Chromatographs:

Gases: The quality of gases obtained from CIG Darwin was better than the previous cruise, but 2 bottles of Instrument Grade Air were only half full, and at least one bottle of nitrogen caused baseline problems on the gas chromatographs until the bottle was partially bled. The sample line from the gas extractor to the methane sample valve became blocked during line 100/001A (the reshoot of line 100/001), resulting in the loss of methane and HHC data for 1.5 hours whilst the problem was identified and fixed.

One of the Mechanical TOs inadvertently caused a circuit breaker to trip which resulted in the loss of the 240v power supply to the DHD system during line 100/007. Once the system was restarted, the carrier gas flows appeared low, and these were adjusted before it was noticed that the GCs were not operating at their correct temperatures (due to loss of the 110v power supply as well as the 240v supply). The carrier gas flows were re-adjusted and the system put back online after 3 hours. Data quality for the rest of the line was down, due to poor calibration following the adjustments.

The large anomaly detected near the Petrel-1 well showed up a limitation in the THC analysis. With such large amounts of gas, the THC sample (which is normally a single peak) was chromatographically separated into at least two peaks, and the integrator method identified the 'wrong' peak. A minor change in the integrator method provided a temporary fix for the problem, but we will need to spend a little time on refining this for a permanent fix.

The calibrations of the chromatographs were checked against a standard gas of known composition (BMR Standard 'C') on a semi-regular basis, typically every 24-48 hours, during line transits and loops. Recalibration was performed when analysis of the standard showed unacceptable deviations, i.e. more than 3% from the standard.

Control and data acquisition

The acquisition software was essentially unchanged from that used for Cruise 99, and worked pretty much as expected, i.e. the known bugs are still there.

DHD Geochemistry (J.H. Bishop)

Background values for hydrocarbons were very similar to those measured on Cruises 97 and 99 (Vulcan Graben 1 and Vulcan Graben 3), with total hydrocarbons (THC) around 8-10 ppm, methane around 3-5 ppm, and C2 and C3 hydrocarbons in the range 10-100 ppb.

A brief summary of the anomalies detected is given below:

The seeps over the Tern and Petrel fields found during Cruise 99 were repeated, and although the magnitude of the seep over Petrel was greater, the compositional characteristics were very similar. As with Cruise 99, there appears to be a general lack of hydrocarbon seepage over most of the survey area, with the few exceptions outlined below:

100/001:
High levels of THC at the start of the line, decreasing during the line, probably caused by contamination from reterminating. Between Bougainville-1 and Lacrosse-1, a minor butane anomaly.

100/002:
Anomalous levels of methane and ethane, only just above background before and after Penguin-1, although no distinct anomaly over the well itself.

100/001A (reshoot):
Large butane anomaly, with minor propane, at geochemical shotpoints 510-525, occurring more-or-less at the same point as the minor butane anomaly on the original line (100/001).

100/003:
Large C1-C4 anomaly over Petrel-1, THC to 40 ppm, methane to 25 ppm, ppb levels of C2-C4.

100/004:
Methane anomaly near Curlew-1.

100/005:
Major anomaly over Petrel-1 well, methane over 250 ppm, THC estimated 350-400 ppm, with C2-C4's in range 1-7 ppm. Also smaller traces of heavier hydrocarbons (C5+).

100/006:
Methane and ethane higher than background towards end of line (prior to 100/0S1), but no distinct anomaly.

100/0S1: No anomalies.

100/0S2: No anomalies.

100/006A:
Methane and ethane higher than background at start of line (after 100/0S2), but no distinct anomaly.

100/0T1 (test) : No anomalies.

100/007:
Regional THC, methane, ethane and propane anomaly over 200 shotpoints (approx 30 miles), although low-level.

Further data processing and interpretation will be required before the significance of these anomalies can be established.

Non-Seismic Data Acquisition (N.A. Johnston)

The non-seismic data acquisition system (DAS) is based on a Hewlett-Packard 1000 F-series computer with 2 Mbyte of memory and 290 Mbyte of disk storage. This system collects navigation, bathymetry, magnetic and gravity data every 10 seconds. Data is stored onto 1600 bpi magnetic tape in blocks of 1-minute data. Tapes are changed daily at 0000 UTC.

DAS crashes occurred on days 097, 119, and twice on day 121, each resulting in the loss of about 5 minutes of data. On the last day of seismic acquisition (day 122) the DAS computer began crashing every 5 minutes. The system console reported backplane errors. The computer was stripped and all interface card slots were cleaned. The system then operated satisfactorily until Port Hedland.

Navigation

Navigation is obtained from five independent systems - three dead reckoning systems integrated into the US Navy Transit Satellite network via two Magnavox Satellite Navigators, and two systems using the NAVSTAR Global Positioning system. The DAS operated on a hierarchical system: calculating the dead reckoning position and overwriting it with the GPS positions if they are valid.

Dead reckoning:
The three dead reckoning systems are based on:

1. Magnavox MX610 Sonar Doppler and Sperry gyro compass
2. Raytheon DSN-450 Sonar Doppler and Sperry gyro compass
3. Paddle log and Sperry gyro compass

Prior to this cruise the Magnavox sonar doppler head was replaced. This system worked very well all through the cruise. The positions calculated by the Magnavox system during dead GPS periods were very good. The Raytheon system was operated for most of the cruise in 'water lock' in order to give the operators a reliable estimate of the ship's speed through the water; an essential requirement for maintaining the seismic cable at its correct depth and tension in an area prone to high current sets.

Global positioning system:

Two GPSs were used during this cruise:

1. Magnavox T-SET
2. RACAL differential system

The T-SET has been in use for about 6 years and still gives reasonable results despite its age. It was only required to be used for about 7% of the cruise due to the reliability of the RACAL system (refer to Appendix 8).

The RACAL system is a differential GPS which uses a Trimble 4000DL Differential Locator and a RACAL Skyfix data link. The data link broadcasts range corrections from a shore station in either Broome or Singapore via the MARISAT satellite communication system. The Skyfix system was found to be excellent and almost no problems were encountered due to the data link.

The navigation data from the RACAL system was fed into the DAS to give 10 second positions. The system gave between 85% and 95% differential GPS with the loss being due to poor satellite geometry.

Bathymetry

The 3.5 kHz and 12 kHz echo sounders, and the HADES program to the geochemical laboratory worked satisfactorily for the entire cruise.

Gravity

The Bodenseewerk Gravity Meter operated satisfactorily.

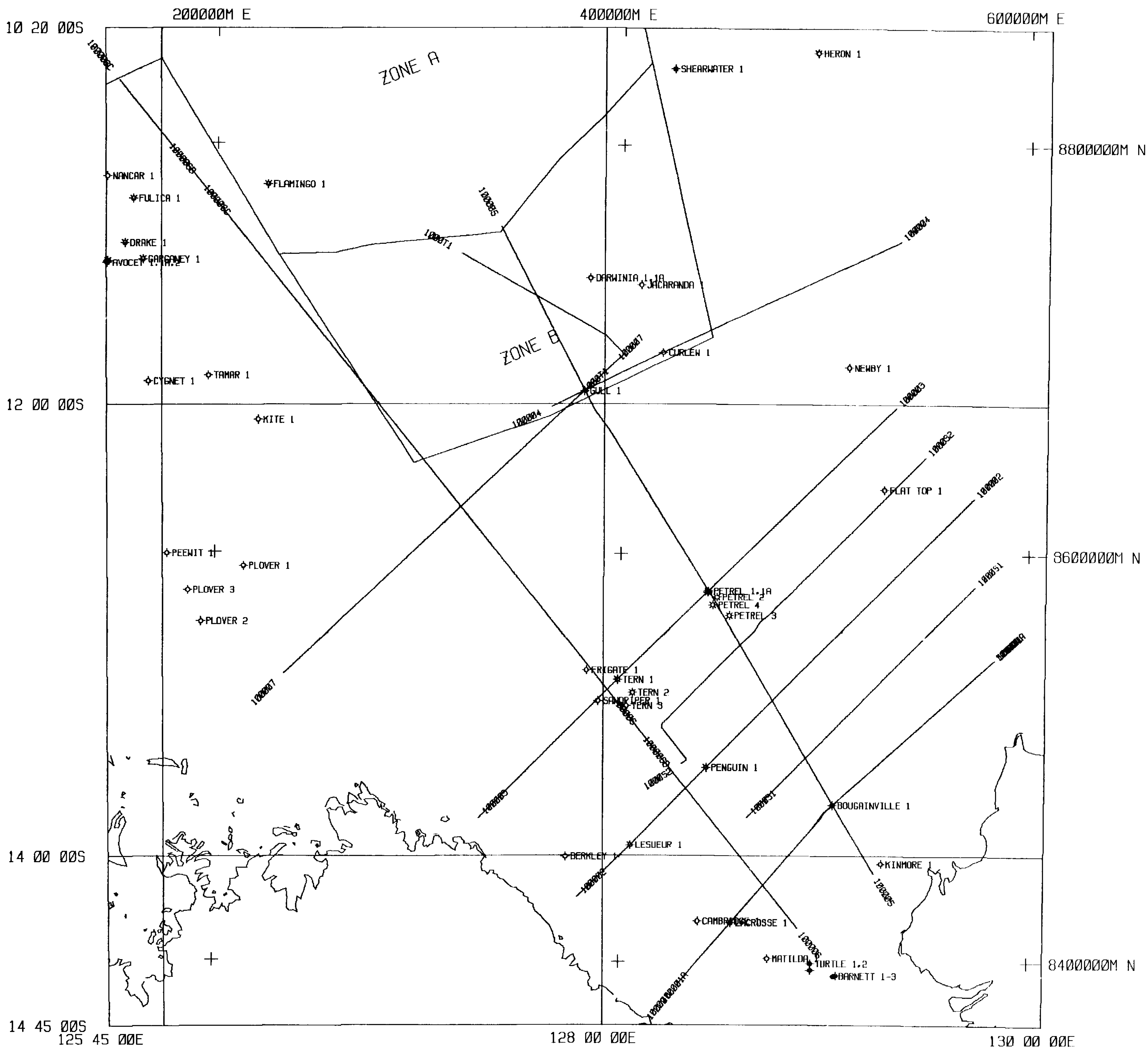
Magnetics

Magnetic data were collected with a Geometrics proton precession magnetometer. The magnetometer was only deployed from the second week of the cruise on, due to the shallow depth of the water. The noise level was of the order of 1-2 nT.

Appendix V

Enclosure 1: Map of the Bonaparte Basin showing Survey 100 lines and selected well locations.

BONAPARTE BASIN



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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 BMR SURVEY 100	
SBON100.PIC	J NEEDHAM 26/7/92

R9204703

Enclosure 2: Floppy diskettes with ASCII files of geochemical data.

See separate data files