

**Chevron Environmental Management
Company**

**Trench D Recovery System Decommissioning
Summary and Recommendation for
Replacement Well Installation**

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

July 31, 2014



Sam Miles
Staff Scientist

Rebecca K. Andresen, L.G.
Associate Vice President



Rebecca K. Andresen

**Trench D Recovery System
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Well Installation**

**Former Unocal Seattle Marketing
Terminal**

Prepared for:
Chevron Environmental Management
Company

Prepared by:
ARCADIS
1100 Olive Way,
Suite 800
Seattle,
Washington 98101
Tel 206.325.5254
Fax 206.325.8218

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2010 Summary Report	2010 Summary Report and Risk Evaluation
ARCADIS	ARCADIS U.S., Inc.
bgs	below ground surface
BNSF	Burlington Northern Santa Fe
CDF	controlled density fill
cm/sec	centimeters per second
Ecology	Washington State Department of Ecology
Emerald	Emerald Services, Inc., located at 1500 Airport Way South in Seattle, Washington
GAC	granular activated carbon
GC-FID	gas chromatography – flame ionization detector
GC/MS	gas chromatography/mass spectrometry
ITRC	Interstate Technology & Regulatory Council
LNAPL	light nonaqueous phase liquid
LNAPL assessment	LNAPL mobility and migration assessment
LO/TO	lock-out/tag-out
MDA	Major Discharge Authorization
OSP	Olympic Sculpture Park
OWS	oil-water separator
PAH	polycyclic aromatic hydrocarbon
Phase 1	February 21 to 25, 2014
Phase 2	June 9 to 13, 2014
ppm	parts per million
ROW	right-of-way
RW	recovery well



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SAM	Seattle Art Museum
SIM	selected ion monitoring
site	former Unocal Seattle Marketing Terminal, located at 3001 Elliott Avenue in Seattle, Washington
summary of work	Trench D Recovery System Decommission Summary and Recommendation for Replacement Well Installation
USEPA	United States Environmental Protection Agency
WAC	Washington Administrative Code
work plan	Trench D Recovery System and Three Piezometers Installed in 2010



1. Introduction

On behalf of Chevron Environmental Management Company, ARCADIS U.S., Inc. (ARCADIS) prepared this Trench D Recovery System Decommission Summary and Recommendation for Replacement Well Installation Report (report) to document the activities performed as described in the approved Work Plan for Decommissioning of the Trench D Recovery System and Three Piezometers Installed in 2010 (work plan; ARCADIS 2013). This report documents the work completed at the former Unocal Seattle Marketing Terminal, located at 3001 Elliott Avenue in Seattle, Washington (site) which is identified on Figure 1. A Site Plan is included as Figure 2. This report also includes a work plan for installation of replacement monitoring wells along the Trench D area.

The decommissioning work was conducted in two phases. Phase I was conducted from February 21 to 25, 2014 and included the following activities:

- Prepared the site to allow access for equipment and vehicles.
- Removed the remediation system compound and equipment.
- Attempted to locate missing piezometers and recovery wells.
- Gauged recovery wells and piezometers.
- Received variance approval for well abandonment.

Separate light nonaqueous phase liquid (LNAPL) sampling events were completed between the two phases of decommissioning work on February 26 and May 5, 2014.

Phase II was conducted from June 9 to 13, 2014 and included the following activities:

- Gauged recovery wells and piezometers.
- Vacuum extraction of fluids from each recovery well and piezometer located along Trench D.
- Decommissioning of recovery wells, piezometers, 2-inch lateral remediation system piping, and a 6-foot long by 4-foot wide recovery vault where the piping entered the former remediation system.



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- Decommissioning of piezometers installed in 2010 (PZ-61A-R, PZ-203, and PZ-204).
- Waste management.



2. Pre-Mobilization Activities

Prior to work commencement, ARCADIS coordinated access agreements with multiple stakeholders to implement the work plan (ARCADIS 2013). In April 2013, ARCADIS initiated an amended access agreement with Burlington Northern Santa Fe (BNSF); the completed agreement was received on January 7, 2014. As required by the access agreement, all work planned in the BNSF right-of-way (ROW) was coordinated with a BNSF flagger.

Although a complete utility survey was conducted in April 2013, a second utility survey was completed in February 2014 to verify potential underground utilities and to protect workers. The efforts included an updated private utility locate conducted by Geomarkout Locating Co, a utility locate performed by BNSF along the BNSF ROW in the area surrounding Trench D, and a Washington One Call public utility locate.

To access the Trench D area, vehicles with heavy payloads (greater than 20,000 pounds) were required to drive through areas managed by the City of Seattle, Port of Seattle, and the Seattle Art Museum (SAM) Olympic Sculpture Park (OSP); access agreements and permits (as necessary) were negotiated with each authority. Further planning was coordinated with SAM OSP staff to remove trees and fencing and to temporarily close key sections of pedestrian paths to set up proper access and a safe exclusion zone for work activities.

Due to safety concerns and access limitations, ARCADIS submitted a construction variance request to the Washington State Department of Ecology (Ecology) for permission to decommission the Trench D wells via pressure grouting, rather than overdrilling or perforating the well screens. This was approved on March 3, 2014.



3. Summary of Work Completed: Phase I

The first phase of decommissioning activities began on February 21, 2014 and is described in detail in Sections 3.1 through 3.5.

Phase I activities conducted in February included:

- Removed fencing to create access to the BNSF ROW to the south side of the train tracks from the off-site area (the area between the Lower Yard east of the BNSF ROW and Elliott Bay) in the SAM OSP.
- Removed the remediation system compound and equipment.
- Attempted to locate missing piezometers.
- Gauged BNSF ROW wells in Trench D.
- Received variance approval for well abandonment.

3.1 Access to Burlington Northern Santa Fe Right-of-Way

Access to the BNSF ROW required the removal of two small trees and their root balls, as well as two sections of a chain-link fence. The tree and root ball removal activities involved lock-out/tag-out (LO/TO) for electrical lines used in the irrigation system and testing irrigation lines in the site vicinity, including electrical lines used in the irrigation system. A certified electrician conducted the LO/TO and irrigation line testing, under supervision by ARCADIS and SAM representatives (who operate the irrigation system). The electrical lines were uncovered and visibly identified before the root balls were removed to assess any potential entanglements with the tree roots and irrigation system. The chain-link fence was removed in a manner that allowed it to be restored after work was complete.

3.2 Removal of System Compound and Equipment

Trench D remediation system equipment included the following components:

- Oil/water separator
- 200-gallon treatment tank
- Control boxes

- Steel equipment box
- 20-foot long by 10-foot wide fenced compound installed on a concrete slab
- 2-inch diameter PVC lateral piping leading to the recovery wells
- 6-inch diameter recovery wells (RWs)
- 1-inch diameter piezometers

Pumps and associated hosing were previously removed from the site.

In accordance with the approved work plan (ARCADIS 2013), the remediation system compound and the equipment were removed from the site for offsite disposal. The concrete pad and vault (which is set into the corner of the rectangular pad and provided the belowground access port for system piping and electrical) were left in place. As part of the system decommissioning, the King County Major Discharge Authorization (MDA) Number 529-04 was discontinued. The two inch PVC piping from the oil-water separator (OWS) was cut below grade just before it reached the sewer junction and was capped with a two inch PVC cap that was glued in place with PVC cement. A representative from King County visited the site on February 26, 2014 to inspect the permanently-capped discharge line that fed into the sewer system and to certify that it was closed. A cancellation letter for the Industrial Waste Major Discharge Authorization is included as Appendix A.

3.3 Attempt to Locate Missing Piezometers

After the system compound and all associated equipment was removed, a soil vacuum truck was used to safely remove gravel and soil to uncover the missing wells in Trench D. Previously missing wells PZ-4.5, PZ-6.5, PZ-8.5, PZ-10.5, and PZ-11.5 were uncovered during soil vacuum activities. These monitoring wells are shown on Figures 3a and 3b. Due to the presence of below-ground utilities along the trench line, soil vacuum excavations could not be conducted to the north of PZ-4.5 and to the south of RW-11. Additionally, a radio tower, signal bungalow, and gravel pad were present in the area between RW-6 and RW-5, stretching approximately 20 feet along the BNSF ROW.

3.4 Gauging of Burlington Northern Santa Fe Right-of-Way Wells

After completing soil vacuum activities, a complete gauging round of accessible piezometers and recovery wells was conducted for all known wells along Trench D. The February activities included gauging the piezometers located in the vault boxes, coincident with the recovery wells. These piezometers were presumably used

historically for gauging to measure water levels during pumping activities in the recovery wells (gauging could not be conducted in the recovery wells due to the presence of the pumps). LNAPL was detected in PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13 at thicknesses ranging from 0.53 foot (PZ-6) to 2.72 feet (PZ-11.5) during the first gauging event on February 25, 2014. Groundwater and LNAPL gauging data from the decommissioning activities are presented in Table 1. LNAPL thicknesses are shown on Figures 3a and 3b.

The LNAPL detections in the piezometers that were co-located with recovery wells (PZ-6 and PZ-13), were located in the same well box as the RW (less than 1 foot away) and in each case, no LNAPL was detected in the corresponding recovery well. The limited presence of LNAPL is evidence that the residual LNAPL is limited to the immediate area around the piezometer and the LNAPL is not migrating.

3.5 Variance Approval

On February 24, Ecology notified ARCADIS that the variance request from Washington Administrative Code (WAC) 173-160-460, requirements for decommissioning “resource protection wells” (recovery wells and piezometers), was in the final process of approval. However, the variance approval letter was required to be physically in hand on site to complete the approved decommissioning activities. Due to safety concerns with alternative methods of decommissioning (that is, puncturing well screens and/or overdrilling the RWs), the project team deferred the well decommissioning until the final approved variance letter was in hand. Consequently, once the system equipment was removed and the activities to identify missing wells were completed, the project team demobilized from the site, which concluded Phase I. Remobilization to the site was conducted in June 2014 to complete the remaining proposed work (Phase II).

4. Light Nonaqueous Phase Liquid Sample Collection

LNAPL samples were collected on February 26 and May 5, 2014. During both LNAPL sampling events, Trench D piezometers and recovery wells with LNAPL were gauged and then sampled with disposable bailers. The February event took place immediately following the end of Phase I activities, one day after conducting a complete Trench D fluid gauging round; therefore, only the wells being sampled (PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13) were gauged. On February 26, 2014, LNAPL thicknesses ranged from 0.42 foot (PZ-6) to 2.70 feet (PZ-11.5). During the May event, five wells were gauged again prior to additional LNAPL sampling activities. LNAPL thickness ranged from 0.07 foot (PZ-13) to 2.50 feet (PZ-11.5). Gauging data are presented in Table 1.

The samples collected from wells PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13 during the February event were submitted to Zymax Forensics to be analyzed for hydrocarbon range C3-C44 by gas chromatography – flame ionization detector (GC-FID), gas chromatography/mass spectrometry (GC/MS) full-scan analysis, and polycyclic aromatic hydrocarbon (PAH) by United States Environmental Protection Agency (USEPA) Method 8270M with selected ion monitoring (SIM).

During the May event, additional LNAPL sample collection was attempted at the five piezometers which had measurable thicknesses of LNAPL (PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13). However, due to the limited volume of recoverable LNAPL in the wells, samples could only be collected from three wells for further laboratory analysis. Samples of LNAPL collected from piezometers PZ-4.5, PZ-10.5, and PZ-11.5 were submitted to PTS Laboratories, Inc. to be analyzed for the fluid properties package.

5. Summary of Work Completed: Phase II

The final approved well decommissioning variance was received in hardcopy form on March 3, 2014, granted in accordance with WAC 173-160-106. A second mobilization was then scheduled but cancelled due to weather conditions and limited availability of BNSF flaggers (required to complete the work). Mobilization to complete the second phase of work was conducted on June 9, 2014. Phase II activities included:

- Final gauging of fluid levels in recovery wells and piezometers.
- Vacuum extraction of groundwater and LNAPL from each recovery well and piezometer located along Trench D.
- Decommissioning of:
 - Piezometers, recovery wells, and lateral lines with a cement slurry
 - Vault located next to the remedial compound with controlled density fill (CDF).
 - Three piezometers installed in 2010 (PZ-61A-R, PZ-203, and PZ-204).
- Waste management.

These Phase II activities are discussed in Sections 4.1 through 4.4.

5.1 Final Gauging of RWs and Piezometers

Gauging was conducted on June 9, 2014. The results of this gauging showed that the LNAPL observed in the five piezometers during the February and May 2014 gauging events had not recovered to previous thicknesses after being sampled (Table 1).

5.2 Vacuum Extraction of Groundwater and Light Nonaqueous Phase Liquid

As requested by Ecology, a liquid vacuum truck was used to remove at least one well volume of fluids from each of the accessible piezometers and recovery wells located along Trench D. The volume of each well casing was calculated prior to removal of groundwater/LNAPL during vacuum activities. The time of vacuum for each well was recorded and removal was confirmed with an oil-water interface probe. At the end of the vacuum event, a total of 353 gallons of liquid were recorded in the vacuum truck,

which compared to the calculated 309 to 329 gallons for one well volume from all of the wells. The recovered liquids were transported to Emerald Services, Inc., located at 1500 Airport Way South in Seattle, Washington (Emerald) for disposal. Bills of lading for all waste materials removed for offsite disposal are included in Appendix B.

5.3 Decommissioning

Following the liquid extraction, the recovery wells and piezometers were pressure grouted with cement slurry from the bottom of the well. Decommissioning activities were conducted by licensed drillers from Holt Services Inc. During grouting activities, recharged groundwater that was forced to the surface was captured with a vacuum truck and a secondary containment pond was used to capture any spillover. LNAPL was not observed during grouting activities or during subsequent recovery of groundwater displaced to the surface. Recovered groundwater was transported to Emerald for disposal. Waste disposal manifests are included in Appendix B. Neat cement was used to fill the well boxes and bring to grade.

The 2-inch PVC lateral lines were filled with grout in two sections: the lines were exposed at each end of Trench D and in the area between RW-6 and RW-77. The lateral lines were pressure grouted with cement slurry from the middle point between RW-6 and RW-7 in each direction (toward RW-1 to the north and RW-11 to the south) through the two lateral remedial lines. Caps with ball valves were attached on opposite ends of the lateral line, which allowed for a visual confirmation that the grout had filled the length of the line. Once the air was purged from the lines and only grout was being pushed through, the grouting was stopped and the ball valves closed, creating capped lateral lines filled with grout. Finally, the 6-foot long by 4-foot wide remediation vault located at the system compound was filled with CDF to just below the ground surface, allowing the vault lid to close flush with the surface.

Piezometers PZ-203 and PZ-204 (located in the off-site area) and PZ-61A-R (located along Elliott Avenue) were decommissioned using bentonite chips in accordance with applicable decommissioning requirements. After filling the well casings with bentonite chips, the areas were brought to grade with cement.

Following the decommissioning work, the permanent chain-linked fence was restored between the BNSF ROW and the SAM OSP. With the concurrence of SAM personnel, the trees will be replaced after the replacement monitoring wells have been installed in the vicinity of former Trench D.



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5.4 Waste Management

Recovered groundwater and/or LNAPL were removed from the site on June 9, June 12, and June 25, 2014. A total of 683 gallons of liquids was removed and disposed of at Emerald; bills of lading are included in Appendix B.

6. Light Nonaqueous Phase Liquid Mobility and Migration Assessment

Samples of LNAPL were collected from piezometers PZ-4.5, PZ-6 (collocated with RW-6), PZ-10.5, PZ-11.5, and PZ-13 (co-located with RW-13) in May and June 2014 as part of an LNAPL mobility and migration assessment (LNAPL assessment). Laboratory analyses of the LNAPL samples were used to evaluate potential mobility and migration of the LNAPL present in the Trench D area. This evaluation used the same assumptions presented in the 2010 Summary Report and Risk Evaluation (2010 Summary Report; ARCADIS 2011) and is considered an addendum to the 2010 Summary Report.

Sections 5.1 through 5.4 discuss the methods and assumptions used for this updated LNAPL assessment. Additional information is provided in the 2010 Summary Report (ARCADIS 2011).

6.1 Terminology

The Interstate Technology & Regulatory Council (ITRC) defines three conditions that characterize the potential for LNAPL movement (ITRC 2009):

1. *Immobile*. LNAPL is present at or below residual saturation and cannot move. Residual saturation is defined in the 2010 Summary Report (ARCADIS 2011).
2. *Mobile*. LNAPL is present above the residual saturation. LNAPL can potentially move within the existing LNAPL plume at a nominal rate, but the LNAPL plume footprint cannot expand.
3. *Migrating*. LNAPL is present above the residual saturation and the LNAPL plume footprint is expanding through time.

6.2 Light Nonaqueous Phase Liquid Assessment Approach

A comprehensive LNAPL assessment uses multiple lines of evidence to evaluate LNAPL mobility. The following lines of evidence were employed to assess LNAPL mobility at the site:

- LNAPL observations in monitoring wells
- LNAPL field and residual saturations
- LNAPL pore velocity calculations

- LNAPL pore entry pressure calculations

These lines of evidence are described in Appendix L of the 2010 Summary Report (ARCADS 2011).

6.3 Data

The samples collected from PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13 during the February 2014 event were submitted to Zymax Forensics to be analyzed for hydrocarbon range C3-C44 by GC-FID, GC/MS full-scan analysis, and PAH by USEPA Method 8270M with SIM.

During the May 2014 event, additional sample collection was attempted at each well where LNAPL was present in February 2014 (PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13); however, due to volume constraints, only three wells provided sufficient sample volumes for collection of samples for additional analysis. LNAPL from piezometers PZ-4.5, PZ-10.5, and PZ-11.5 were submitted to PTS Laboratories, Inc. for analysis of fluid properties.

6.4 Hydraulic Gradient and Conductivity

Site-specific data on hydraulic gradient and water hydraulic conductivity were used in the mobility calculations. The following information was used in this LNAPL assessment:

- The prevailing groundwater flow direction is west toward Puget Sound.
- The hydraulic gradient for the LNAPL-impacted area for use in the calculations was assumed to be 0.017 foot per foot, which was previously used to calculate the groundwater flux in the off-site area (ARCADIS 2011), and is based on measured data collected at the site.
- The assumed hydraulic conductivity for soil around the LNAPL-impacted wells is 15 feet per day. This is the geometric mean of the hydraulic conductivities calculated from pumping tests performed in onsite monitoring wells, as summarized in the 2010 Summary Report (ARCADIS 2011).

6.4.1 Light Nonaqueous Phase Liquid Physical Properties

LNAPL samples were previously collected from site wells MW-61A-R and PZ-61A-R (installed within 5-feet of each other) for physical properties analysis. Repeated attempts were made in 2010 to collect additional LNAPL sample from other site wells for analysis for physical properties. However, due to the small volumes of LNAPL accumulation measured in other site wells (RW-3, RW-21, and MW-30) sufficient volumes of LNAPL could not be recovered. Therefore, literature values were used in the 2010 LNAPL assessment for the physical properties of California crude oil LNAPL in the area of wells MW-30, RW-3, and RW-21.

Additional LNAPL samples were collected from piezometers PZ-4.5, PZ-6, PZ-10.5, PZ-11.5, and PZ-13 on February 25, 2014 as shown on Figure 4. However, as in 2010, the initial LNAPL sample volume that could be recovered from these piezometers in February 2014 was too small to support analysis for physical properties. Therefore, the LNAPL samples were submitted for forensic analysis to identify the product types in each of these five samples. Additional sample volume collected from three of the wells in May 2014 (PZ-4.5, PZ-10.5, and PZ-11.5) was adequate for analysis to determine physical properties.

LNAPL sample collection from piezometers was completed by ARCADIS on February 25, 2014 and subsequently submitted to Zymax of Escondido, California for analysis. The LNAPL types identified are presented in the table below.

Piezometer	Product Type Interpretation
PZ-4.5	Mixture of degraded California crude oil and degraded #3 or #4 fuel oils, refined from California crude oils
PZ-6	Degraded California crude oil
PZ-10.5	Degraded #3 or #4 fuel oils, refined from California crude oils
PZ-11.5	Degraded #3 or #4 fuel oils, refined from California crude oils
PZ-13	Degraded #3 or #4 fuel oils, refined from California crude oils

Degraded #3 and #4 fuel oils, refined from California crude oils and a mixture of the two were not identified in previous LNAPL samples collected at the site.

Appropriate LNAPL physical properties were selected from the literature based on the product types identified above for PZ-6. Fluid properties for PZ-4.5, PZ-10.5, and PZ-11.5 were analyzed by PTS and are summarized in Table 2. Fluid properties of LNAPL

in PZ-13 are an average of those measured for PZ-10.5 and PZ-11.5, because the LNAPL was interpreted to be similar. The fluid properties used were measured at either 70 or 75 degrees Fahrenheit. This approach is conservative because an LNAPL at lower site groundwater temperatures would have a higher viscosity, and would therefore be less mobile than indicated by the fluid properties and subsequent mobility calculations.

The fluid physical properties used for this analysis are presented in Table 2. The analytical laboratory reports and an e-mail summarizing the laboratory interpretation of the LNAPL are included in Appendix C. Field notes summarizing data collected during sampling are included in Appendix D.

6.4.2 Soil Petrophysical Properties

Soil properties affect how LNAPL behaves in the subsurface. The soil properties that influence LNAPL behavior can be measured in a laboratory setting through chemical and physical testing of undisturbed soil cores. Undisturbed soil cores were collected as part of the 2010 LNAPL assessment in the Elliott Avenue area. As discussed in the 2010 Summary Report (ARCADIS 2011), petrophysical tests were designated for specific intervals from each of the soil cores based on a review of the soil core photographs to characterize aquifer-matrix parameters and fluid saturations. These data were previously reported in the 2010 Summary Report (ARCADIS 2011) and are used as inputs for the van Genuchten LNAPL mobility calculations for evaluation of the 2014 Trench D LNAPL data.

6.5 Light Nonaqueous Phase Liquid Mobility and Migration Assessment Results

6.5.1 Light Nonaqueous Phase Liquid Observations in Monitoring Wells

Recovery wells located along Trench D have had fluid levels gauged semi-annually to quarterly since 2007. Prior to decommissioning, the recovery wells and piezometers located in Trench D were also gauged. Gauging data from the decommissioning activities are summarized in Table 1. The 1-inch diameter piezometers ranged in depth from 9- to 26-feet below ground surface (bgs). However, screen construction information is unknown and the LNAPL thicknesses present in the wells may be influenced by LNAPL that is not entirely within the screened interval.

LNAPL has not been observed in off-site monitoring wells located downgradient of the Trench D area (Figure 2), except for sheens briefly observed following pumping

activities in MW-205 in 2010. LNAPL has not been observed in this well since June 2011.

6.5.2 Light Nonaqueous Phase Liquid Pore Velocity Calculations

A pore velocity analysis was completed for the monitoring wells evaluated as part of the LNAPL assessment. This analysis was conducted using the same appropriate assumptions used for the wells evaluated as part of the 2010 LNAPL assessment (ARCADIS 2011). The pore velocity analysis was completed, assuming that the LNAPL is mobile; however, results indicate that the LNAPL pore velocity potential for PZ-6 (1.88×10^{-10} centimeters per second [cm/sec]) is orders of magnitude below the 1×10^{-6} cm/sec pore velocity potential criterion suggested by ASTM International (ASTM [2006]). Therefore, LNAPL at this location is considered immobile.

The calculated pore velocity potentials at piezometers PZ-4.5, PZ-10.5, PZ-11.5, and PZ-13 range from 1.6×10^{-5} to 3.5×10^{-5} cm/sec. These values exceed the ASTM standard and are considered mobile, but this does not indicate that the LNAPL is migrating. Fluid property measurements were taken at temperatures greater than site groundwater temperatures likely resulting in an overestimation of the LNAPL pore velocity potential for these piezometers. Further, the absence of LNAPL in the RW co-located with PZ-13 provides additional evidence that LNAPL in this area is not migrating. Pore velocity potentials are summarized in Table 3 and mobility worksheets are provided in Appendix E.

6.5.3 Light Nonaqueous Phase Liquid Pore Entry Pressure Calculations

LNAPL migration into pristine soil occurs when sufficient LNAPL head pressure is present in the subsurface at the fringe of the LNAPL plume to displace groundwater from the soil pores. The calculated critical LNAPL head pressures that are required for lateral LNAPL migration into saturated soil are shown in Table 4. These head pressures are converted into critical LNAPL thicknesses, which is a more easily measured indicator than head pressure. The head pressures required for plume expansion within the sandier materials at the site, expressed in LNAPL thickness units, range from approximately 0.17 to 0.29 feet for LNAPL in piezometers PZ-4.5, PZ-10.5, PZ-11.5 and PZ-13 and approximately 1.15 feet for the California crude oil LNAPL in PZ-6. The maximum LNAPL thickness observed in these piezometers is 2.72 feet, measured at well PZ-11.5. LNAPL critical thickness estimates compared to recently measured LNAPL thicknesses in monitoring wells are summarized in Table 4. LNAPL

critical thickness estimates reported in the 2010 Summary Report (ARCADIS 2011) are included in Table 4 for comparison.

These results demonstrate that sufficient LNAPL head pressure may be present within the LNAPL body in the Trench D piezometers to allow migration of LNAPL into soil that was not previously impacted by LNAPL. However, LNAPL present at the plume fringes may not have sufficient pore pressure to displace groundwater from clean soil. Furthermore, gauging conducted in May and June 2014 indicated declining thicknesses of LNAPL in these locations.

6.6 Light Nonaqueous Phase Liquid Assessment Summary and Conclusions

The findings of the LNAPL assessment are summarized below:

- LNAPL at piezometer PZ-6 is immobile and, by definition, is not migrating.
- Pore velocities of LNAPL in piezometers PZ-4, PZ-10.5, PZ-11, and PZ-13.5 exceed the ASTM mobility criteria. However, as presented, the assumptions made to complete these calculations likely lead to an overestimation of the pore velocities.
- The pore velocity potential calculated for MW-61A-R/PZ-61A-R does not imply that LNAPL is moving or will move at this velocity, only that LNAPL at this location is capable of low-velocity redistribution within the footprint of the existing LNAPL-impacted soil.
- Pore entry pressure calculations indicate that sufficient LNAPL head pressure may be present within the LNAPL body in the Trench D piezometers to allow migration of LNAPL into soil not previously impacted by LNAPL. However, LNAPL present at the plume fringes may not have sufficient pore pressure to displace groundwater from clean soil.

These conclusions are consistent with the empirical fluid-level data collected from downgradient wells installed in the off-site area, which demonstrate that LNAPL is not migrating. In addition, the lack of a contiguous LNAPL plume suggests that the footprint of the mobile LNAPL plume is minimal. To provide evidence to support these findings, replacement monitoring wells are proposed to further evaluate the presence of LNAPL, as summarized in Section 6.

7. Work Plan for Installation of Replacement Monitoring Wells

As requested by Ecology, ARCADIS proposes to install four replacement monitoring wells. Proposed locations are based on the presence of LNAPL as measured in February, May, and June 2014, and to meet the specific requests from project stakeholders. The monitoring wells are positioned to further evaluate the presence of LNAPL in the Trench D area, as well as to facilitate collection of current dissolved-phase constituent of concern data in this area. Proposed well locations were also selected based on the presence of known utilities in the Trench D area. Replacement monitoring wells are proposed adjacent to PZ-4.5, RW-7, PZ-10.5, and PZ-12.5 as shown on Figure 5.

Three wells (near PZ-4.5, RW-7, and PZ-10.5) will be installed to an approximate total depth of 15 feet below bgs. A fourth replacement well is proposed west of former piezometer PZ-12.5, along the OSP footpath. This well is not proposed adjacent to the former piezometer due to the presence of known utilities in the Trench D area. Because there is no seawall obstructing groundwater flow in this area, the proposed location along the footpath is adequate for evaluating conditions downgradient of the Trench D area. This well is anticipated to be installed to a depth of approximately 40 feet bgs.

The proposed replacement wells will be installed using a small-footprint hollow-stem auger drill rig. Monitoring well locations will be cleared to a minimum depth of approximately 8 feet bgs to assure clearance of any potential underground utilities. Soil samples will be collected during installation of the borings on 5-foot centers using split-spoon samplers. The soil samples will be logged in the field according to the Unified Soil Classification System, and a portion of each sample will be screened in the field with a photo ionization detector. Visual observations for the presence of LNAPL will be recorded.

Upon reaching the proposed depth of each monitoring well location, the wells will be constructed with 10 feet of 2-inch-diameter Schedule 40 polyvinyl chloride (PVC) with 0.020-inch slotted well screen and completed with 2-inch-diameter Schedule 40 blank PVC riser. Each well will have a sand pack of 10/20 silica sand from the total depth of the well to at least 1 foot above the screened interval. Above each sand pack will be at least a 6-inch seal of hydrated bentonite and each well will be completed to the surface with concrete, a flush-mount traffic-rated well monument, and locking well cap.



**Trench D Recovery System
Decommissioning Summary
and Recommendation for
Replacement Well Installation**

Former Unocal Seattle
Marketing Terminal

After installation, each monitoring well will be developed via surge and purge methods using bailers. A disposable bailer will be surged along the entire length of the well screen and a minimum of 10 pore volumes of water will be removed from each well. The monitoring wells will be surveyed by a surveyor, licensed in the state of Washington, for horizontal location and vertical elevation of the well casing. The proposed replacement wells will be incorporated into a quarterly groundwater monitoring program.



**Trench D Recovery System
Decommissioning Summary
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Former Unocal Seattle
Marketing Terminal

8. Schedule

Scheduling for the proposed well installations will be initiated upon receipt of approval from Ecology. ARCADIS will work with SAM to identify an acceptable date to minimize disruption to OSP activities and will procure appropriate vehicle access as necessary. A BNSF flagger will be required for the well installations.



Trench D Recovery System Decommissioning Summary and Recommendation for Replacement Well Installation

Former Unocal Seattle
Marketing Terminal

9. References

ARCADIS U.S., Inc. 2011. 2010 Summary Report and Risk Evaluation. February 1, 2011.

ARCADIS U.S., Inc. 2013. Work Plan for Decommissioning of the Trench D Recovery System and Three Piezometers Installed in 2010. May 31, 2013.

ASTM International. 2006. Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface. Document: E 2531-06.

Interstate Technology & Regulatory Council. 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.



Tables

Table 1
 Summary of Groundwater Elevation Data Decommissioning Event 2014
 Former Unocal Seattle Marketing Terminal
 3001 Elliott Avenue
 Seattle, Washington

Well Number	Date Measured	Time Measured (hr:min)	Top of Casing ^{1,5}	Depth to Groundwater ² (feet)	Total Depth (feet)	Depth to LNAPL ^{2,3} (feet)	LNAPL Thickness ³ (feet)	Groundwater Elevation ⁴ (feet)	Gauging Notes
RW-1	2/25/2014	12:00	14.2	7.80	20.15	--	--	6.40	--
	5/5/2014	8:45		7.30	--	--	--	6.90	--
	6/9/2014	11:32		9.20	--	--	--	5.00	--
RW-2	2/25/2014	11:52	14.3	7.54	19.70	--	--	6.76	--
	5/5/2014	8:55		7.00	--	--	--	7.30	--
	6/9/2014	11:25		9.00	--	--	--	5.30	--
RW-3	2/25/2014	11:45	14.3	7.67	18.45	--	--	6.63	--
	5/5/2014	9:04		7.50	--	--	--	6.80	--
	6/9/2014	11:17		9.40	--	--	--	4.90	--
RW-5	2/25/2014	11:35	13.9	7.43	21.80	--	--	6.47	--
	5/5/2014	9:27		7.23	--	--	--	6.67	--
	6/9/2014	11:08		8.71	--	--	--	5.19	--
RW-6	2/25/2014	11:25	13.9	6.95	18.00	--	--	6.95	--
	5/5/2014	9:36		7.02	--	--	--	6.88	--
	6/9/2014	11:00		8.30	--	--	--	5.60	--
RW-7	2/25/2014	11:15	14.2	7.40	20.00	--	--	6.80	--
	5/5/2014	9:46		7.40	--	--	--	6.80	--
	6/9/2014	10:53		8.68	--	--	--	5.52	--
RW-8	2/25/2014	11:00	13.9	7.00	21.50	--	--	6.90	--
	5/5/2014	10:04		7.11	--	--	--	6.79	--
	6/9/2014	10:43		8.41	--	--	--	5.49	--
RW-9	2/25/2014	10:50	14.1	6.28	46.82	--	--	7.82	--
	5/5/2014	10:18		6.70	--	--	--	7.40	--
	6/9/2014	10:31		9.04	--	--	--	5.06	--
RW-10	2/25/2014	10:38	14.3	7.07	25.00	--	--	7.23	--
	5/5/2014	10:33		7.22	--	--	--	7.08	--
	6/9/2014	10:23		9.04	--	--	--	5.26	--
RW-11	2/25/2014	10:30	14.1	7.40	23.00	--	--	6.70	--
	5/5/2014	10:45		7.51	--	--	--	6.59	--
	6/9/2014	10:17		8.80	--	--	--	5.30	--
RW-13	2/25/2014	10:20	14.1	8.66	24.16	--	--	5.44	Sheen on measuring tape
	5/5/2014	11:00		7.65	--	--	--	6.45	--
	6/9/2014	10:00		9.05	--	--	--	5.05	--
PZ-1	2/25/2014	12:00	NS	8.66	20.35	--	--	--	no cap on PZ
	5/5/2014	8:50		8.13	--	--	--	--	--
	6/9/2014	--		NG	--	--	--	--	--
PZ-2	2/25/2014	11:52	NS	8.14	12.17	--	--	--	no cap on PZ
	5/5/2014	8:59		7.71	--	--	--	--	--
	6/9/2014	--		NG	--	--	--	--	--
PZ-3	2/25/2014	11:45	NS	NG	NG	--	--	--	cap cannot be removed
	5/5/2014	9:08		NG	--	--	--	--	cap cannot be removed
	6/9/2014	--		NG	--	--	--	--	cap cannot be removed

Table 1
Summary of Groundwater Elevation Data Decommissioning Event 2014
Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Well Number	Date Measured	Time Measured (hr:min)	Top of Casing ^{1,5}	Depth to Groundwater ² (feet)	Total Depth (feet)	Depth to LNAPL ^{2,3} (feet)	LNAPL Thickness ³ (feet)	Groundwater Elevation ⁴ (feet)	Gauging Notes
PZ-4.5	2/25/2014	13:15	NS	10.15	19.10	8.40	1.75	--	well box in very poor condition
	2/26/2014	--		8.15	--	unable to determine		--	--
	5/5/2014	9:21		10.30	--	8.51	1.79	--	--
	6/9/2014	--		NG	--	NG	NG	--	--
PZ-5	2/25/2014	11:35	NS	8.62	22.03	--	--	--	no cap on PZ
	5/5/2014	9:31		8.43	--	--	--	--	--
	6/9/2014	--		NG	--	--	--	--	--
PZ-6	2/25/2014	11:25	NS	8.15	21.75	7.62	0.53	--	--
	2/26/2014	--		8.15	--	7.73	0.42	--	--
	5/5/2014	9:40		7.97	--	7.70	0.27	--	--
	6/9/2014	--		NG	--	NG	NG	--	--
PZ-6.5	2/25/2014	12:20	NS	6.86	17.90	--	--	--	--
	5/5/2014	9:51		6.88	--	--	--	--	--
	6/9/2014	10:57		10.25	--	--	--	--	--
PZ-7	2/25/2014	Not found in well box							
	5/5/2014	Not found in well box							
	6/9/2014	Found buried below TOC for the RW well during decommissioning activities							
PZ-7.5	2/25/2014	11:10	NS	6.09	9.12	--	--	--	--
	5/5/2014	9:57		6.14	--	--	--	--	--
	6/9/2014	10:49		DRY	--	--	--	--	--
PZ-8	2/25/2014	11:00	NS	7.30	9.33	--	--	--	no cap on PZ
	5/5/2014	10:08		7.37	--	--	--	--	--
	6/9/2014	10:45		8.60	--	--	--	--	--
PZ-8.5	2/25/2014	12:10	NS	6.77	9.60	--	--	--	no cap on PZ, well box poor
	5/5/2014	10:13		6.90	--	--	--	--	--
	6/9/2014	10:40		7.79	--	--	--	--	--
PZ-9	2/25/2014	10:50	NS	7.03	45.37	--	--	--	no cap on PZ
	5/5/2014	10:25		7.37	--	--	--	--	--
	6/9/2014	10:34		9.90	--	--	--	--	--
PZ-9.5	2/25/2014	10:45	NS	9.06	26.20	--	--	--	--
	5/5/2014	10:28		7.44	--	--	--	--	--
	6/9/2014	10:28		9.41	--	--	--	--	--
PZ-10	2/25/2014	10:38	NS	8.25	24.25	--	--	--	no cap on PZ
	5/5/2014	10:36		8.33	--	--	--	--	--
	6/9/2014	10:25		10.13	--	--	--	--	--
PZ-10.5	2/25/2014	12:40	NS	10.70	19.00	8.20	2.50	--	--
	2/26/2014	--		10.82	--	8.26	2.56	--	--
	5/5/2014	10:41		10.30	--	8.29	2.01	--	--
	6/9/2014	10:22		11.55	--	9.98	1.57	--	--

Table 1
 Summary of Groundwater Elevation Data Decommissioning Event 2014
 Former Unocal Seattle Marketing Terminal
 3001 Elliott Avenue
 Seattle, Washington

Well Number	Date Measured	Time Measured (hr:min)	Top of Casing ^{1,5}	Depth to Groundwater ² (feet)	Total Depth (feet)	Depth to LNAPL ^{2,3} (feet)	LNAPL Thickness ³ (feet)	Groundwater Elevation ⁴ (feet)	Gauging Notes	
PZ-11	2/25/2014	10:30	NS	8.30	21.80	--	--	--	--	
	5/5/2014	10:48		8.38	--	--	--	--	--	
	6/9/2014	10:15		9.90	--	--	--	--	--	
PZ-11.5	2/25/2014	12:05	NS	10.50	18.70	7.78	2.72	--	--	
	2/26/2014	--		10.50	--	7.80	2.70	--	--	
	5/5/2014	10:52		10.34	--	7.84	2.50	--	--	
	6/9/2014	10:20		9.89	--	9.70	0.19	--	--	
PZ-13	2/25/2014	10:00	NS	Could not measure accurately due to LNAPL						--
	2/26/2014	--		9.95	--	8.73	1.22	--	--	
	5/5/2014	11:03		8.75	--	8.68	0.07	--	--	
	6/9/2014	10:01		10.20	--	10.1	0.10	--	--	

Notes:

¹Well casing elevations listed in feet above mean sea level.

²Below top of casing.

³Light non-aqueous phase liquid

⁴Elevation referenced to city of Seattle datum.

⁵Survey by OTAK 5/27/08.

NS = Not Surveyed

NG=Not Gauged

"--" = not measured or not obtainable

PZ=Piezometer

RW=Remedial Well

**Table 2
Laboratory Fluid Physical Properties**

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Parameter	Units	Value					
		RW-3, RW-21, MW-30, PZ-4.5	PZ-4.5 ³	PZ-10.5 ³	PZ-11.5 ³	PZ-13 ⁴	MW-61A-R ³
LNAPL Type Description		California Crude ¹	Mixture of degraded CA crude oil and degraded #3 or #4 fuel oils, refined from CA crude oils ⁵	Degraded #3 or #4 fuel oils, refined from CA crude oils ⁵	Degraded #3 or #4 fuel oils, refined from CA crude oils ⁵	Degraded #3 or #4 fuel oils, refined from CA crude oils	Diesel #2 ⁶
LNAPL Density	g/cm ³	0.85	0.88	0.86	0.85	0.85	0.85
LNAPL Viscosity	g/cm-s	340	0.0963	0.0481	0.0365	0.0423	0.0363
Groundwater Density ¹	g/cm ³	0.9989	0.9983	0.9982	0.9984	0.9983	0.9989
Groundwater Viscosity ¹	g/cm-s	0.013	0.016	0.0113	0.0102	0.0108	0.013
Air-Groundwater Interfacial (Surface) Tension ¹	Dyne/cm	61.8	69.4	63.3	68.3	65.8	61.8
Air-LNAPL Interfacial Tension	Dyne/cm	37	26.7	26.3	25.5	25.9	27.5
LNAPL-Water Interfacial Tension	Dyne/cm	25 ²	8	8.3	7.5	7.9	21.4

Notes:

- 1: LNAPL properties obtained from API database at 15 degrees Celsius.
- 2: LNAPL property unavailable for California Crude, general crude oil property from the API database used.
- 3: LNAPL properties measured at 70 or 75 degrees Fahrenheit.
- 4: LNAPL properties are an average of the PZ-10.5 and PZ-11.5.
- 5: Used site sample collected on May 5, 2014.
- 6: Used site sample collected at MW-61A-R on June 4th, 2010.

Acronyms and Abbreviations:

LNAPL = light nonaqueous phase liquid
g/cm³ = grams per cubic centimeter
g/cm-s = grams per centimeter per second
Dyne/cm = Dynes per centimeter

Table 3
LNAPL Velocity Under Site-Specific LNAPL Accumulation

Former Unocal Seattle Marketing Terminal
 3001 Elliott Avenue
 Seattle, Washington

Well	Soil type	Gradient	LNAPL Saturation (%Pv)	Hydraulic Conductivity (ft/day)	LNAPL Type	LNAPL Velocity (cm/s)	Notes
PZ-4.5	Medium grained sand	0.017	9.7 ¹	15	Mixture of Degraded CA Crude Oil and #3 or #4 Fuel Oil	1.38 x 10 ⁻⁵	
PZ-6	Medium grained sand	0.017	9.7 ¹	15	CA Crude	1.88 x 10 ⁻¹⁰	
PZ-10.5	Medium grained sand	0.017	9.7 ¹	15	#3 or #4 Fuel Oil	2.05 x 10 ⁻⁵	
PZ-11.5	Medium grained sand	0.017	9.7 ¹	15	#3 or #4 Fuel Oil	3.51 x 10 ⁻⁵	
PZ-13	Medium grained sand	0.017	9.7 ¹	15	#3 or #4 Fuel Oil	1.56 x 10 ⁻⁵	
RW-3	Medium grained sand	0.014	4.3001 ¹	0.5	CA Crude	7.65 x 10 ⁻¹³	3
RW-21	Medium grained sand	0.025	4.3001 ¹	0.3	CA Crude	8.43 x 10 ⁻¹³	3
MW-30	Medium grained sand	0.012	4.3001 ¹	1.4	CA Crude	1.40 x 10 ⁻¹²	3
PZ-61A-R (15.65)	Medium grained sand	0.015	9.9 ²	12.5	Diesel #2	5.60 x 10 ⁻⁶	3
PZ-61A-R (15.25)	Medium grained sand	0.015	10.7 ²	12.5	Diesel #2	6.21 x 10 ⁻⁶	3

Notes:

- 1: LNAPL Saturation Estimated Based on Maximum Recent LNAPL Thickness in Wells
- 2: Laboratory Determined LNAPL Saturation Results (Pore Fluid Saturation Test)
- 3: Previously reported in the 2010 Summary Report (ARCADIS 2011)

CA = California

%Pv = Percent pore volume

ft/day = feet per day

LNAPL = Light nonaqueous phase liquid

cm/s = centimeters per second

Table 4
Summarized Results of Critical LNAPL Thickness Calculations Based on Brooks-Corey Capillary Model

Former Unocal Seattle Marketing Terminal
 3001 Elliott Avenue
 Seattle, Washington

Sample/Well ID	Displacement Head Pressure	Critical LNAPL Thickness	Recently Observed LNAPL Thickness	Notes
	h_d (cm H ₂ O)	$b_{o(crit)}$ (ft)	(ft)	
PZ-4.5	17.6 ¹	0.29 ⁴	1.79	
PZ-6	17.6 ¹	1.15 ³	0.53	
PZ-10.5	17.6 ¹	0.26 ⁴	2.56	
PZ-11.5	17.6 ¹	0.17 ⁴	2.72	
PZ-13	17.6 ¹	0.21 ⁴	1.22	
PZ-61A-R (17.3-17.5)	17.6 ¹	1.04 ²	0.52	5
RW-3	17.6 ¹	1.15 ³	0.01	5
RW-21	17.6 ¹	1.15 ³	0.02	5
MW-30	17.6 ¹	1.15 ³	0.02	5

Notes:

- 1: Based on soil properties and the Brooks-Corey Fit to Air Water Capillary Drainage data from PZ-61A-R (17.3-17.5 ft bgs).
- 2: Critical LNAPL Thickness Based on Displacement Head Pressure and LNAPL Properties from MW-61A-R (Diesel #2).
- 3: Critical LNAPL Thickness Based on Displacement Head Pressure and Literature LNAPL Properties for California Crude Oil.
- 4: Calculated from properties of samples collected collected on May 5, 2014.
- 5: Previously reported in the 2010 Summary Report (ARCADIS 2011)

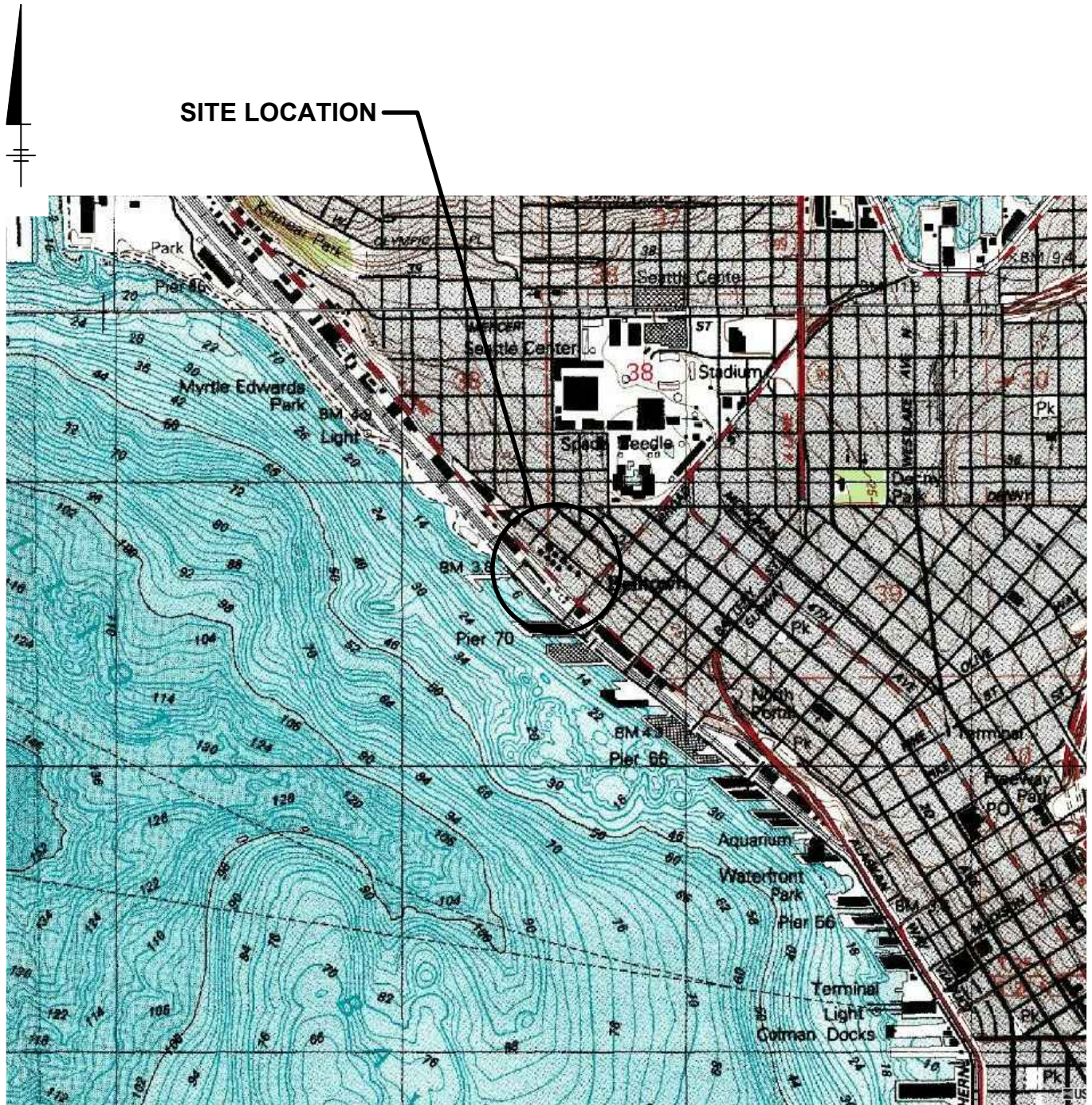
ft = feet

LNAPL = Light nonaqueous phase liquid

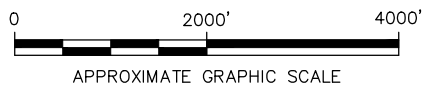
cm H₂O = centimeters of water

Figures

CITY:(Reqd) DIV:(GROUP:(Reqd) DB:(Reqd) LD:(Opt) PIC:(Reqd) PM:(Reqd) TM:(Opt) LYR:(Opt)ON="OFF"-REF-
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SOURCE: TOPOGRAPHIC IMAGE DOWNLOADED FROM MICROSOFT TERRASERVER, MAP DATE 7/1/83, (www.terraserver-usa.com)



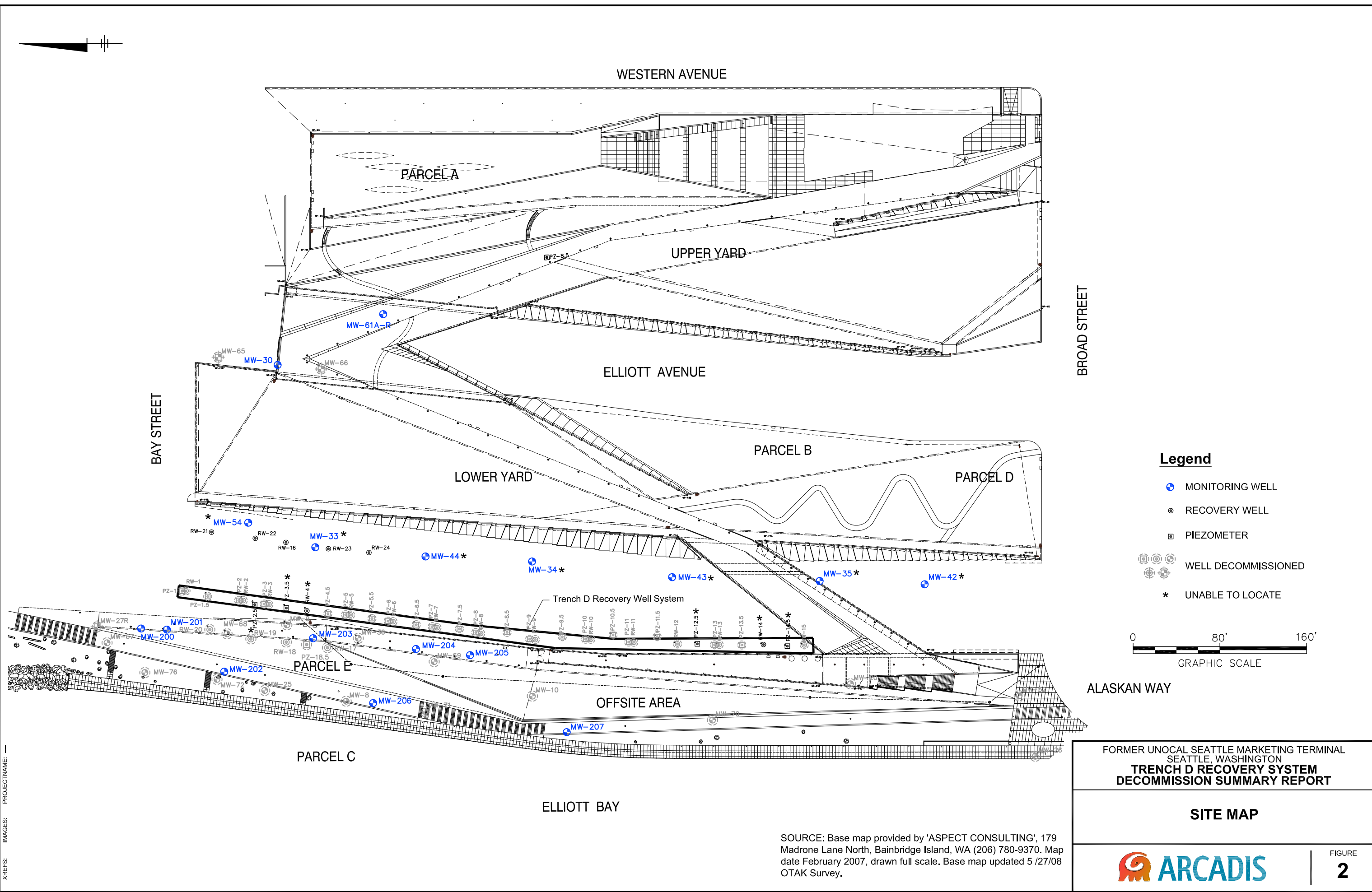
FORMER UNOCAL SEATTLE MARKETING TERMINAL
SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
DECOMMISSION SUMMARY REPORT**

SITE LOCATION MAP



FIGURE
1

CITY: SYRACUSE DIV/GROUP: 141 DB: JAR GWS LD(Ort) PIC: J. VOGELY PM: R. ANDRESEN TM: R. ANDRESEN LVR: ONE OFF-REF
 G:\ENVCAD\TAMPACT\B0045363 Seattle Terminal\005.0003\Trench D\B0045363.dwg LAYOUT: 2 SAVED: 7/17/2014 7:13 PM ACADVER: 18.1S (LMS TECH) PAGESETUP: PDF-BL PLOTSTYLETABLE: PLT-FULL-CTB PLOTTED: 7/18/2014 2:07 PM BY: RICHARDS, JIM
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FORMER UNOCAL SEATTLE MARKETING TERMINAL
 SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
 DECOMMISSION SUMMARY REPORT**

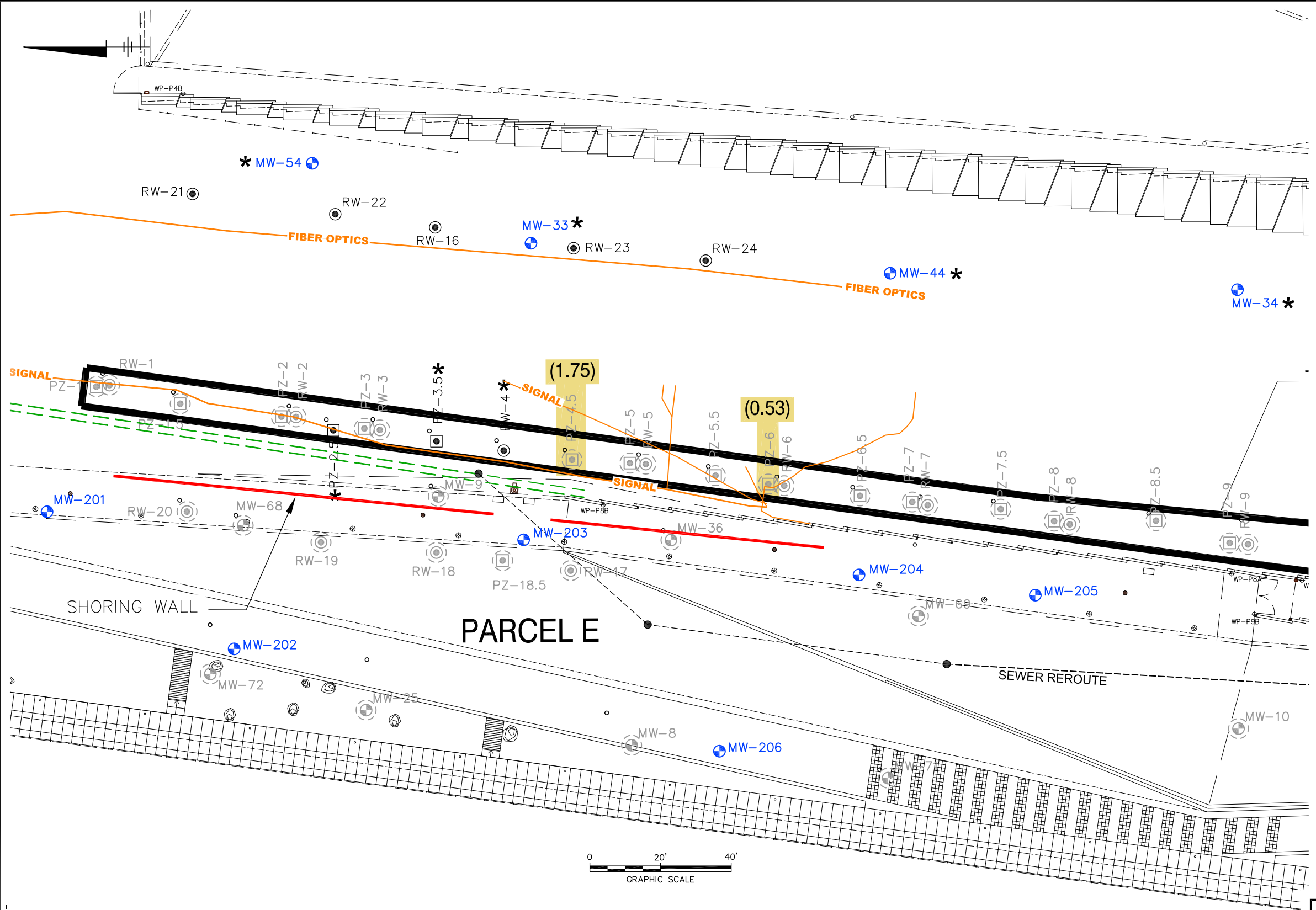
SITE MAP

SOURCE: Base map provided by 'ASPECT CONSULTING', 179 Madrone Lane North, Bainbridge Island, WA (206) 780-9370. Map date February 2007, drawn full scale. Base map updated 5 /27/08 OTAK Survey.

 **ARCADIS**

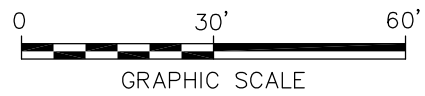
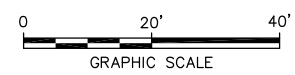
FIGURE
2

CITY: SYRACUSE DIV/GROUP: 141 DB: JAR GMS LD(Ont) PIC: J. VOGELY PM: R. ANDRESEN TM: R. ANDRESEN LVR: ONE OFF-REF
 G:\ENVCAD\TAMPACT\B0045363 Seattle Terminal\0005.0003\Trench D\B0045363B03.dwg LAYOUT: 3A SAVED: 7/24/2014 10:40 AM ACADVER: 18.1S (LMS TECH) PAGES: 18 PLOTSTYLETABLE: PLT\FULL.CTB PLOTTED: 7/24/2014 4:32 PM BY: RICHARDS, JIM
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Legend

- MONITORING WELL
- RECOVERY WELL
- PIEZOMETER
- WELL DECOMMISSIONED
- * UNABLE TO LOCATE
- (0.53) LNAPL THICKNESS MEASURED ON 2/25/14 AND 2/26/14.
- SIGNAL RAILROAD SIGNAL LINE
- FIBER OPTICS FIBER OPTICS LINE
- - - SEWER LINE
- LNAPL DETECTED - 2014



PARCEL C

PARCEL E

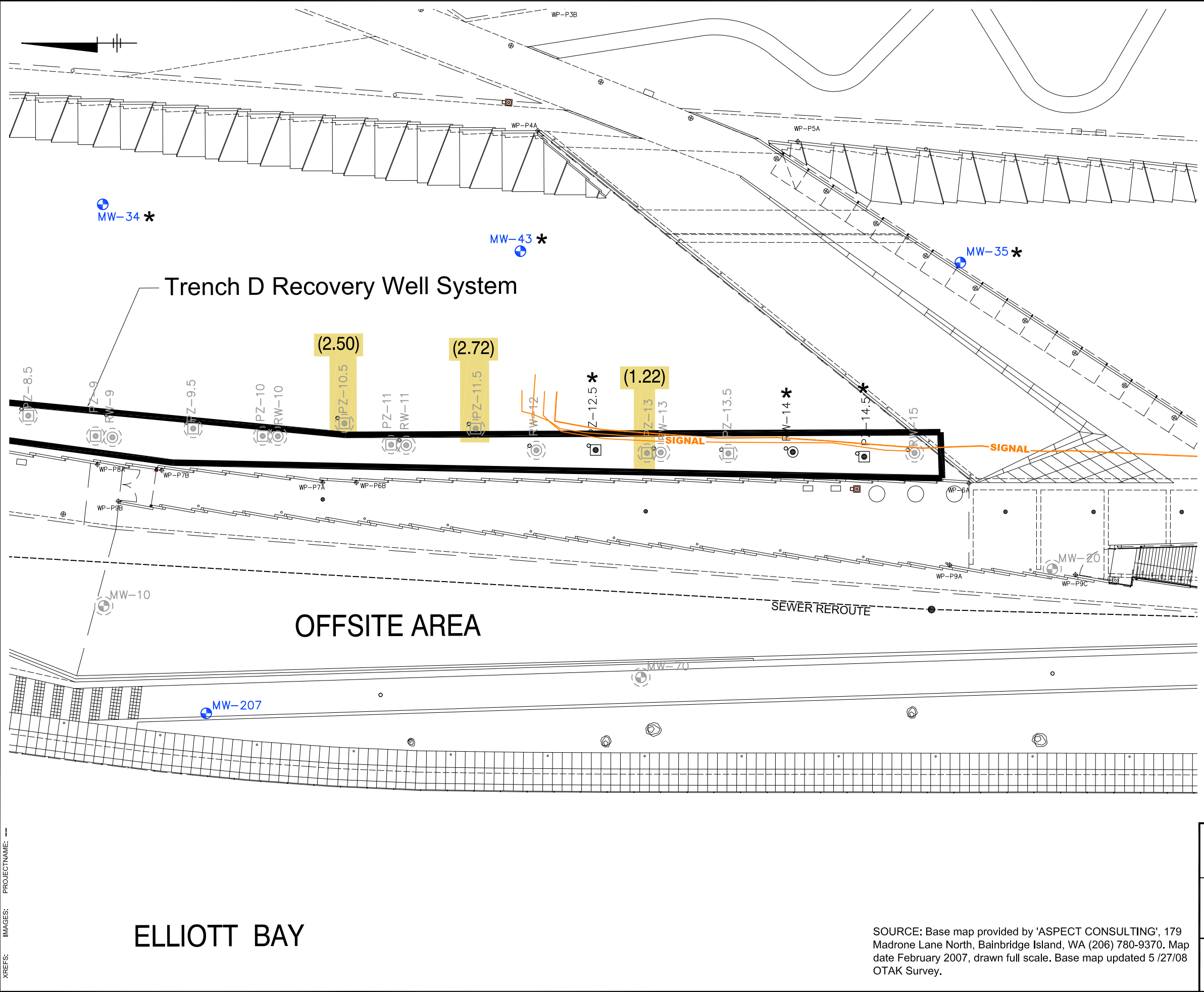
FORMER UNOCAL SEATTLE MARKETING TERMINAL
 SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
 DECOMMISSION SUMMARY REPORT**

**TRENCH D MAP WITH
 LNAPL THICKNESS - NORTH END**

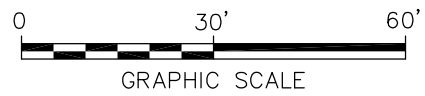
FIGURE
3a

SOURCE: Base map provided by 'ASPECT CONSULTING', 179 Madrone Lane North, Bainbridge Island, WA (206) 780-9370. Map date February 2007, drawn full scale. Base map updated 5 /27/08 OTAK Survey.

CITY: SYRACUSE DIV/GROUP: 141 DB: IAR GMS LD(Ort) PIC: J. VOGELY PM: R. ANDRESEN TM: R. ANDRESEN LVR: ONE OFF-REF
 G:\ENVCAD\TAMPAACT\B0045363 Seattle Terminal\005.00031 Trench D\B0045363B03.dwg LAYOUT: 3B SAVED: 7/18/2014 4:28 PM ACADVER: 18.15 (LMS TECH) PAGESETUP: PDF-BL PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 7/24/2014 10:39 AM BY: RICHARDS, JIM
 XREFS: IMAGES: PROJECTNAME: --



- Legend**
- MONITORING WELL
 - RECOVERY WELL
 - PIEZOMETER
 - WELL DECOMMISSIONED
 - * UNABLE TO LOCATE
 - (0.53) LNAPL THICKNESS MEASURED ON 2/25/14 AND 2/26/14.
 - RAILROAD SIGNAL LINE
 - FIBER OPTICS LINE
 - SEWER LINE
 - LNAPL DETECTED - 2014



ELLIOTT BAY

OFFSITE AREA

Trench D Recovery Well System

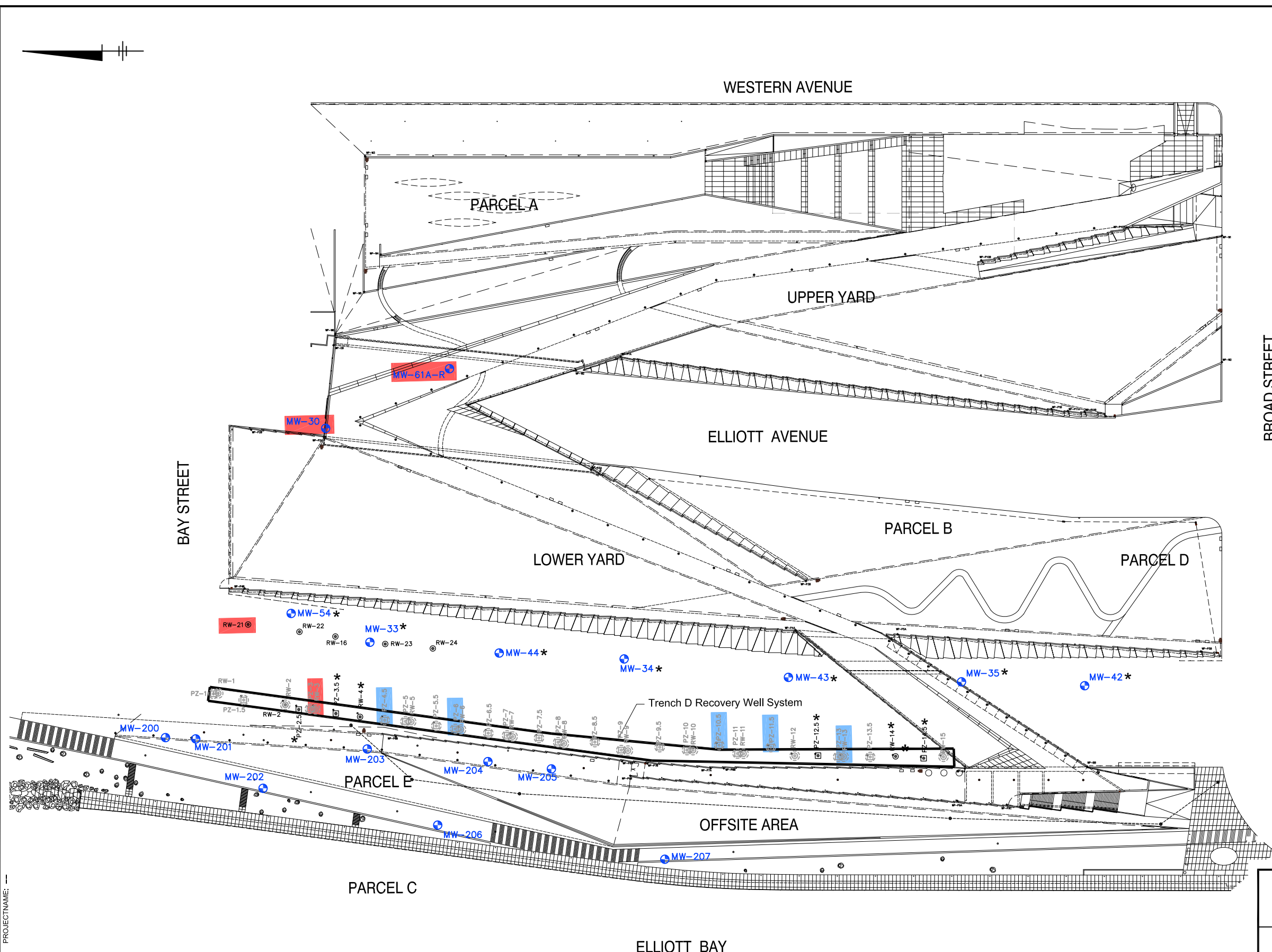
FORMER UNOCAL SEATTLE MARKETING TERMINAL
 SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
 DECOMMISSION SUMMARY REPORT**

**TRENCH D MAP WITH
 LNAPL THICKNESS - SOUTH END**

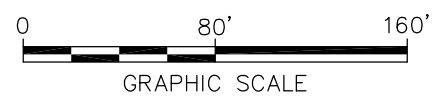
FIGURE
3b

SOURCE: Base map provided by 'ASPECT CONSULTING', 179 Madrone Lane North, Bainbridge Island, WA (206) 780-9370. Map date February 2007, drawn full scale. Base map updated 5 /27/08 OTAK Survey.

CITY: SYRACUSE DIV/GROUP: 141 DB: IAR GMS LD(Ort) PIC: J. VOGELY PM: R. ANDRESEN TM: R. ANDRESEN LYR: ONE OFF-REF
 G:\ENVCAD1\TAMPACT\B0045363 Seattle Terminal\0005.0003\Trench D\B0045363B02.dwg LAYOUT: 4. SAVED: 7/24/2014 10:22 AM. ACADVER: 18.1 S (LMS TECH) PAGES: 18. PLOTSTYLETABLE: PLTFULLCTB PLOTTED: 7/24/2014 10:23 AM BY: RICHARDS, JIM
 XREFS: IMAGES: PROJECTNAME: --



- Legend**
- ⊕ MONITORING WELL
 - ⊙ RECOVERY WELL
 - PIEZOMETER
 - * UNABLE TO LOCATE
 - LNAPL LIGHT NONAQUEOUS PHASE LIQUID
 - LNAPL SAMPLE COLLECTED AND ANALYZED IN 2010
 - LNAPL SAMPLE COLLECTED AND ANALYZED IN 2014



FORMER UNOCAL SEATTLE MARKETING TERMINAL
 SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
 DECOMMISSION SUMMARY REPORT**

LNAPL SAMPLING SUMMARY MAP


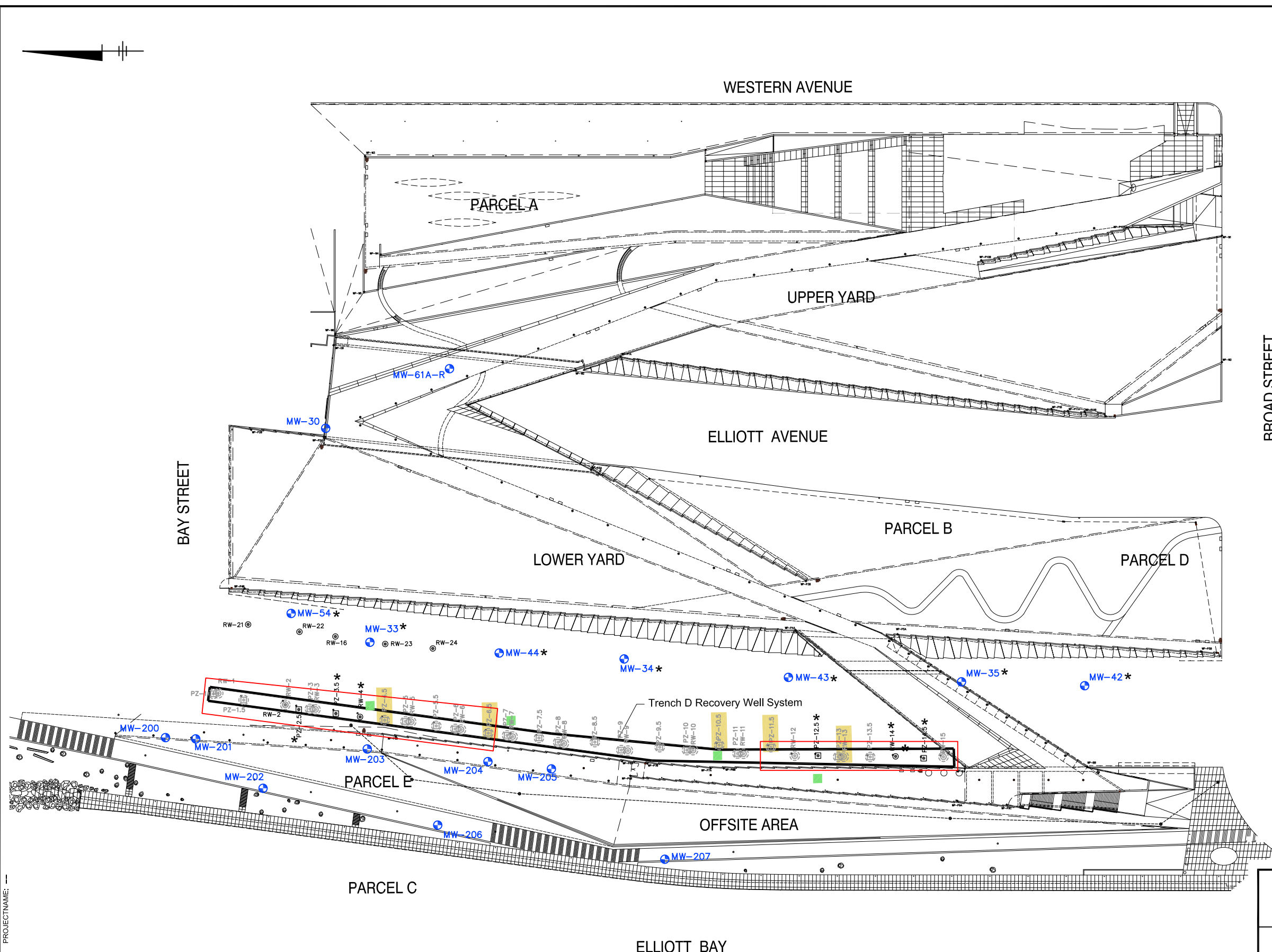


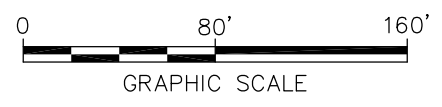
FIGURE
4

SOURCE: Base map provided by 'ASPECT CONSULTING', 179 Madrone Lane North, Bainbridge Island, WA (206) 780-9370. Map date February 2007, drawn full scale. Base map updated 5/27/08 OTAK Survey.

CITY: SYRACUSE DIV/GROUP: 141 DB: JAR GWS LD(Ort) PIC: J. VOGELY PM: R. ANDRESEN TM: R. ANDRESEN LVR: ONE OFF-REF
 G:\ENVCAD\TAMP\ACT\B00045363 Seattle Terminal\0005.000031 Trench D\B0045363B02.dwg LAYOUT: 5. SAVED: 7/17/2014 7:21 PM ACADVER: 18.1S (LMS TECH) PAGES: 18 PAGES: 18 PLOT: 7/18/2014 2:18 PM BY: RICHARDS, JIM
 XREFS: IMAGES: PROJECTNAME: --



- Legend**
- ⊕ MONITORING WELL
 - ⊙ RECOVERY WELL
 - ⊠ PIEZOMETER
 - * UNABLE TO LOCATE
 - LNAPL LIGHT NONAQUEOUS PHASE LIQUID
 - PROPOSED WELL LOCATIONS
 - LNAPL DETECTED - 2014
 - ▭ UTILITIES PRESENT (SEE FIGURES 3a & 3b)



FORMER UNOCAL SEATTLE MARKETING TERMINAL
 SEATTLE, WASHINGTON
**TRENCH D RECOVERY SYSTEM
 DECOMMISSION SUMMARY REPORT**

PROPOSED WELL LOCATIONS MAP



FIGURE
5

SOURCE: Base map provided by 'ASPECT CONSULTING', 179 Madrone Lane North, Bainbridge Island, WA (206) 780-9370. Map date February 2007, drawn full scale. Base map updated 5 /27/08 OTAK Survey.



Appendix A

Discharge Permit Closure



King County

Wastewater Treatment Division
Industrial Waste Program
Department of Natural Resources and Parks
130 Nickerson Street, Suite 200
Seattle, WA 98109-1658
206-263-3000 Fax 206-263-3001
TTY Relay: 711

April 7, 2014

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Kim Jolitz
Chevron Environmental Management Company
6111 Bollinger Canyon Road
San Ramon, CA 94583

Cancellation of Industrial Waste Major Discharge Authorization No. 529-04
Effective February 26, 2014

Dear Mr. Stelling:

The King County Industrial Waste Program has reviewed your February 28, 2014, letter requesting cancellation of your Major Discharge Authorization No. 529-04 for wastewater discharges from the Chevron Environmental Management Company (DA529) facility located at 3001 Elliott Avenue, Seattle, Washington.

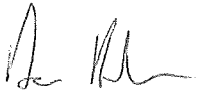
You made this request because the groundwater remediation system has been removed and the sewer connection capped. You do not need to submit any further documentation under the terms of this permit.

On February 26, 2014, I met with Ross LaGrandeur of ARCADIS at your permitted facility and confirmed that your company has ceased operating at this site.

This Major Discharge Authorization is cancelled, effective February 28, 2014, with the understanding that industrial wastewater will not be discharged to the sewer system at this facility. In the future, if you decide to discharge process water from this operation, you must submit a new permit application.

If you have any questions concerning this cancellation, please call Dave Haberman at 206-263-3007.

Sincerely,



Dave Haberman
Industrial Waste Compliance Investigator

cc: Todd Keithahn, K.C. Wtd (Interceptor Discharge)
Kristin Painter, King County

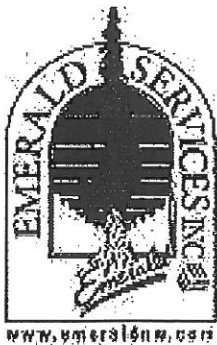


Appendix B

Bills of Lading

WASTE DOCUMENTATION FROM
FORMER UNOCAL SEATTLE MARKETING TERMINAL
3001 ELLIOT AVENUE, SEATTLE, WA
130045363

WELL PURGE WATER FOR DECOMMISSION
6-9-14



CERTIFICATE OF DISPOSAL

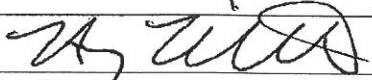
On June 9th, 2014 the Emerald Recycling facility located at 1500 Airport Way S., Seattle WA 98134, received a shipment from:

**Chevron EMC
3001 Elliot Ave
Seattle, WA**

On Manifest Number: 64844

Manifest Line	1A
Profile Number	G00707
Process	Waste Water
Date of Process:	6/10/2014

I certify, on behalf of the above listed treatment facility, that to the best of my knowledge, the above described waste or material was managed in compliance with all applicable laws, regulations, permits, and licenses on the date listed above.

	7/8/14
Facility Representative	Date of Issue



7843 E. MARGINAL WAY SOUTH
 SEATTLE, WASHINGTON 98108
 PH. (206) 832-3000
 FAX (206) 832-3080
 24 HOUR EMERGENCY PHONE: 1-888-832-3008

214006

64844

BILL OF LADING AND GALLONAGE TICKET

SHIPPER NAME CLEAR CREEK CONT.	CONTACT	JOB # 70462
ADDRESS 1001 ELLIOT AVE (PARK)	PHONE#	LOAD # 1
CITY, STATE, ZIP SEATTLE WA.	DISPATCH	DATE 6-9-14
CARRIER E.S.I.	PHONE# 206-832-3552	DOCUMENT # 784
CONSIGNEE EMERALD RECYCLING INC.	CONTACT	787
ADDRESS 1500 AIRPORT WAY S.	PHONE#	PRODUCT TYPE LIP
CITY, STATE, ZIP SEATTLE WA. 98134		EST. GALLONS 1211
U.S. DOT DESCRIPTION		
A	NON-REGULATED MATERIAL BY DOT.	# 7
B		TYPE TT
C		QTY. 353
D		

A. WPQ # _____ DISP. CODE: **600707** C. WPQ # _____ DISP. CODE: _____
 B. WPQ # _____ DISP. CODE: _____ D. WPQ # _____ DISP. CODE: _____

DISPOSAL

WASH. OUT: YES () NO () DUMP DELAY TIME _____

E. WATER _____ GALLONS LOCATION _____ TEST _____ TIME IN _____ TIME OUT _____
 F. SOLIDS _____ GALLONS LOCATION _____ TEST _____ DISP. CODE _____

_____ % SUSPENDED SOLIDS BY CENTRIFUGE _____ GALS SEDIMENT

G. OIL/DIESEL/GAS _____ GALLONS LOCATION _____ TEST _____ DISP. CODE _____

H. PCB'S _____ B.S.&W. _____ API _____ LAB. Y / N _____

Shipper's Certification: I hereby declare that the contents of this consignment are fully and accurately described above by proper shipping name and are classified, packaged, marked and labeled, and are in all respects in proper condition for transport by highway, vessel and rail according to international and national government regulations and this material is not regulated as a hazardous waste in accordance with Part 261 or 40 CFR Part 761.

X **SEANAS MITCHELL CN**
 BEHALF OF CLEAR CREEK CONT.
 SHIPPER (PRINT NAME)
 X **LEE HODF**
 CARRIER - DRIVER 1 (PRINT NAME)
 X _____
 CARRIER - DRIVER 2 (PRINT NAME)
 X _____
 CONSIGNEE (PRINT NAME)

X **Seanas Mitchell**
 SIGNATURE
 X **Lee Hoff**
 SIGNATURE
 X _____
 SIGNATURE
 X _____
 SIGNATURE

DATE: **6-9-14**
 DATE: **6-9-14**
 DATE: _____
 DATE: _____

CUSTOMER

WASTE DOCUMENTATION FROM
FORMER UNOCAL SEATTLE MARKETING TERMINAL
3001 ELLIOT AVENUE, SEATTLE, WA
B0045363
WELL PURGE WATER FOR DECOMMISSION
6-12-14

* CALLED CLEARCREEK
ABOUT SENDING US
SIGNED, ACCURATE FORM
7-10-14 JAL-



CERTIFICATE OF DISPOSAL

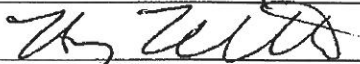
On June 12th, 2014 the Emerald Recycling facility located at 1500 Airport Way S., Seattle WA 98134, received a shipment from:

**Chevron EMC
3001 Elliot Ave
Seattle, WA**

On Manifest Number: 03907

Manifest Line	1
Profile Number	G00707
Process	Waste Water
Date of Process:	6/13/2014

I certify, on behalf of the above listed treatment facility, that to the best of my knowledge, the above described waste or material was managed in compliance with all applicable laws, regulations, permits, and licenses on the date listed above.

	7/8/14
Facility Representative	Date of Issue



SERVICES FACILITIES
1500 AIRPORT WAY
SEATTLE, WA 98134

214006

03907

BILL OF LADING AND GALLONAGE REPORT

CUSTOMER Clear Creek / Chevron DATE 6-12-14

JOB LOCATION Seattle

DRIVER _____ EQUIP _____

JOB NO _____ DOCUMENT NO _____

PRODUCT COG707 EST. GALS 2,000

PRODUCT _____ EST. GALS _____

PRODUCT _____ EST. GALS _____

DRUMS _____ NO _____

DRUMS _____ NO _____

PROFILE # _____ EST SOLIDS _____

WASH OUT: YES NO TIME IN _____ TIME OUT _____

WATER 2,000 GAL LOCATION F-P15 08 CODE COG707 WTP-A

SOLIDS _____ GAL LOCATION _____ CODE _____

_____ % SUSPENDED SOLIDS BY CENTRIFUGE + _____ GALS. SEDIMENT

OIL/DIESEL _____ GAL LOCATION _____ CODE _____

HOC'S _____ PCB'S _____ B.S.&W _____ API _____ LAB: YES NO

GAS _____ GAL LOCATION _____

BUNKER FUEL _____ GAL LOCATION _____

OTHER _____

THIS MATERIAL IS NOT REGULATED UNDER WAC-173-303 OR 40CFR PART 261 AND 40CFR PART 761

[Signature]
FACILITY REPRESENTATIVE

[Signature]
DRIVERS SIGNATURE

WASTE DOCUMENTATION FROM
FORMER UNOCAL SEATTLE MARKETING TERMINAL
3001 ELLIOT AVENUE, SEATTLE, WA ~~2~~

800 453 63

GWM NON HAZ WATER PICKUP

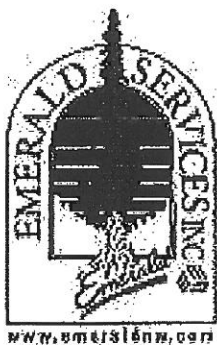
6-25-14

ANY FURTHER INFORMATION NEEDED PLEASE
CALL SEAMAS MCGUIRE-

339-222-7873 / Seamas.mcguire@arcadis-us.com

THANKS!





CERTIFICATE OF DISPOSAL

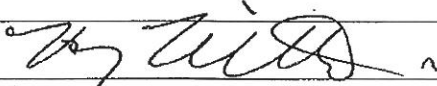
On June 25th, 2014 the Emerald Recycling facility located at 1500 Airport Way S., Seattle WA 98134, received a shipment from:

**Chevron EMC
3001 Elliot Ave
Seattle, WA**

On Manifest Number: 3019

Manifest Line	1
Profile Number	G00707
Process	Waste Water
Date of Process:	6/26/2014

I certify, on behalf of the above listed treatment facility, that to the best of my knowledge, the above described waste or material was managed in compliance with all applicable laws, regulations, permits, and licenses on the date listed above.

	7/8/14
Facility Representative	Date of Issue

Report # 22343

DRUM RECEIPT REPORT



Date 06/25/2014
 Name of Transporter Clear Creek Contractors
 Origin of Load Chevron EMC
 Name of Driver Tom Doods
 Load Number 062514-01

Total Number Airport Way Drums 1

(Document Size, if other than 55-gal)

- Used Oil / Alternative Fuel (G00505, G02903, G02907) _____
- Used Oil w/ Gasoline (G02902) _____
- Gasoline/Diesel <90% Water (G02901) _____
- Oily Water or Process Water (G00501, G00502, G02095, G04701) _____
- Oil Filters/Metal Cased Fuel Filters (G04714, G04715, G04713) _____
- Petroleum Cont. Solids (G03201, G03202, G03203, G03204, G04704, G04711) _____
- PPE and Oily Debris (G00504) _____
- Emulsified /Water Soluble Coolant (G04710) _____
- Petroleum Grease (G04716) _____
- Non-Petroleum Grease (G04717) _____
- Latex Rinse Water (G00506) _____
- Process Water (G04703) _____
- Off-spec Oil (G03000) _____
- Aqueous Brake Wash (G00700, G00800) _____
- Concrete Comp/Latex/Alkali Resist Skins (G05400, G00507, G00600) _____
- Empty Drums (G00602) _____
- Other Decon water G00707 1
- Other _____

Total # of Transfer Facility Drums _____

[Signature]
 Facility Signature

[Signature]
 Driver Signature



3919 88th Street
Marysville, WA 98270

Ph. (425) 252-5800
Fx. (425) 252-1093



JOB # <i>214006</i>	JOB NAME <i>Olympic Sculpture Park</i>	SITE ADDRESS <i>3001 Elliott Ave</i>	
GENERATOR NAME <i>Chevron EMC</i>		GENERATOR MAILING ADDRESS <i>Rebecca Anderson</i>	GENERATOR CONTACT INFORMATION <i>1100 Olive Way Suite 600 Seattle, WA 98101</i>

PUMP & RINSE / CLEANING CERTIFICATE

DATE	SIZE & DIMENSIONS OF TANK OR STRUCTURE	DESCRIBE CONTENTS	PUMP/RINSE		LIQUID QTY	SOLIDS QTY
			YES	NO		
			CLEANED			
			YES	NO		
			CLEANED			
			YES	NO		
			CLEANED			
			YES	NO		

NOTES

WORK PERFORMED BY

WORKER SIGNATURE

LIQUID / SOLIDS BILL OF LADING

DATE <i>6/25/14</i>	TRUCK # <i>34</i>	DRIVER <i>Tom Dodds</i>	LIQUID DESCRIPTION AND QUANTITY <i>Weld decommissioning water</i>	SOLID DESCRIPTION AND QUANTITY
	TRLR #	DISPOSAL/RECYCLING FACILITY	LIQUID PROFILE # <i>G00707</i>	SOLIDS PROFILE #
NOTES <i>one 30 GALLON DRUM</i>			GENERATOR'S SIGNATURE CONFIRMS THIS MATERIAL IS NOT REGULATED UNDER WAC-173-303 OR 40CFR PART 261 & 40CFR PART 760	
			GENERATOR SIGNATURE <i>Tom Dodds</i>	
			DRIVER SIGNATURE <i>Tom Dodds</i>	
			FACILITY SIGNATURE <i>Antonio Pedraza</i>	

James McQueen ON BEHALF OF CHEVRON EMC

UST CORRECTIVE ACTION CERTIFICATION

I certify that the petroleum contaminated debris and media that fail the test for Toxicity Characteristic Waste codes D018-D043 is exempt under 40CFR 261.4 and is subject to the corrective action regulation under 40 CFR 280.

GENERATOR NAME

GENERATOR SIGNATURE

DATE

DISPOSAL CERTIFICATE

DATE	TRUCK #	DRIVER	ITEM(S) DESCRIPTION
	TRLR #	DISPOSAL/RECYCLING FACILITY	
NOTES			DRIVER SIGNATURE
			FACILITY SIGNATURE



Appendix C

LNAPL Analytical Reports

May 9, 2014

Mr. Samuel Miles
ARCADIS
1100 Olive Way, Suite 800
Seattle, WA 98101

RE: Former Unocal Seattle Marketing Terminal
Project Number: B0045363.00006

Dear Samuel,

Enclosed are analytical results for five product samples ID PZ-13, PZ-11.5, PZ-10.5, PZ-6, and PZ-4.5 submitted to Zymax on April 25, 2014. Per your request, the following analyses were performed on the samples submitted:

1. C3-C44 whole oil analysis by high resolution GC-FID
2. GC/MS full scan analysis
3. Extended PAHs analysis

The project was performed at ZymaX forensics as Laboratory No.43576.

Please call us at 760-781-3338 ext 201 or email me at shantan.lu@zymaxusa.com if you have any questions regarding the analytical results.

Respectfully,
ZymaX Forensics/Pace analytical



Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry



600 S Andreason Dr. Ste. B
Escondido, California 92029

tel 760.781.3338
fax 760.781.3339

*Samples will be disposed of
after 30 days unless requested otherwise

CHAIN of CUSTODY

report to Samuel Miles (Samuel.miles@arcadis-us.com)	tel (206) 853-7428	fax 206-325-8218	ANALYSIS REQUESTED										Turnaround Time				
company ARCADIS-US	proj Former Unocal Seattle Marketing Terminal		GC-C44 Oil by GC-FID	GC/MS Full Scan Analysis	PAH by SIM EPA 8270M											ASAP <input type="checkbox"/> 1 wk <input type="checkbox"/>	
address 1100 Olive Way, Suite 800, Seattle, WA 98101	proj # B0045363.00006															48hr <input type="checkbox"/> 2 wk <input type="checkbox"/>	
	sampler Ross Lagrandeur															72hr <input type="checkbox"/> STD <input checked="" type="checkbox"/>	
Zymax use only	SAMPLE DESCRIPTION	Date Sampled	Time	Matrix	Preserve												Remarks
43576-1	PZ-13	2-25-14	1240	LNAPL	UN	✓	✓	✓									2
-2	PZ-11.5	2-25-14	1305	LNAPL	UN	✓	✓	✓									2
-3	PZ-10.5	2-25-14	1330	LNAPL	UN	✓	✓	✓									2
-4	PZ-6	2-25-14	1415	LNAPL	UN	✓	✓	✓									1
-5	PZ-4.5	2-25-14	1500	LNAPL	UN	✓	✓	✓									2

Bill To: Same as Above <input type="checkbox"/> OR	Relinquished by: <u>Seamas McGuire</u>	Received by:
Company: <u>ARCADIS-US</u>	Signature: _____	Signature: _____
Address: <u>ATTN: ACCOUNTS PAYABLE</u>	Print: <u>Seamas McGuire</u>	Print: _____
<u>630 PLAZA DRIVE, SUITE 600</u>	Company: <u>ARCADIS-US</u>	Company: _____
<u>HIGHLANDS RANCH, CO 80129</u>	Date: <u>4/25/2014</u> Time: <u>1500</u>	Date: _____ Time: _____
Sample integrity upon receipt:	Relinquished by:	Received by Zymax:
Samples received intact <input checked="" type="checkbox"/>	Signature: _____	Signature: <u>Che-Ying Hsu</u>
Samples received cold <input type="checkbox"/>	Print: _____	Print: <u>Zymax Forensics</u>
Custody seals <input type="checkbox"/>	Company: _____	Company: <u>Zymax Forensics</u>
Correct container types <input checked="" type="checkbox"/>	Date: _____ Time: _____	Date: <u>4/25/14</u> Time: <u>12:10</u>
PO#: _____		
Quote yes <input type="checkbox"/> no <input type="checkbox"/>		

Email to:
Samuel.miles@arcadis-us.com
Seamas.mcguire@arcadis-us.com

Extended PAHs Analysis

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-1
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-13
Analyzed: 4/30/2014
Method: 8270M

CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Benzothiophene	25.0	ND
C1 Benzothiophenes	25.0	70.1
C2 Benzothiophenes	25.0	70.8
C3 Benzothiophenes	25.0	134.0
C4 Benzothiophenes	25.0	122.1
Naphthalene	25.0	ND
1-Methylnaphthalene	25.0	ND
2-Methylnaphthalene	25.0	ND
C2 Naphthalenes	25.0	962.6
C3 Naphthalenes	25.0	1284.3
C4 Naphthalenes	25.0	1270.5
Biphenyl	25.0	ND
Acenaphthylene	25.0	ND
Dibenzofuran	25.0	ND
Acenaphthene	25.0	237.8
Fluorene	25.0	189.9
C1 Fluorenes	25.0	202.3
C2 Fluorenes	25.0	89.9
C3 Fluorenes	25.0	118.9
Anthracene	25.0	60.2
Phenanthrene	25.0	149.9
C1 Phenanthrenes/Anthracenes	25.0	256.8
C2 Phenanthrenes/Anthracenes	25.0	319.2
C3 Phenanthrenes/Anthracenes	25.0	255.4
C4 Phenanthrenes/Anthracenes	25.0	115.3

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

MSD 10
43576-1PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-1
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-13
Analyzed: 4/30/2014
Method: 8270M

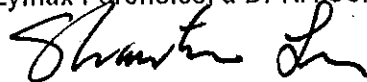
CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Dibenzothiophene	25.0	31.7
C1 Dibenzothiophenes	25.0	91.5
C2 Dibenzothiophenes	25.0	107.3
C3 Dibenzothiophenes	25.0	92.0
C4 Dibenzothiophenes	25.0	41.2
Fluoranthene	25.0	138.0
Pyrene	25.0	104.0
C1 Pyrenes/Fluoranthenes	25.0	98.1
C2 Pyrenes/Fluoranthenes	25.0	97.6
C3 Pyrenes/Fluoranthenes	25.0	49.4
Benzo(a)anthracene	25.0	ND
Chrysene	25.0	ND
C1 Chrysenes	25.0	53.7
C2 Chrysenes	25.0	43.0
C3 Chrysenes	25.0	ND
C4 Chrysenes	25.0	ND
Benzo(b)fluroanthene	25.0	ND
Benzo(k)fluoranthene	25.0	ND
Benzo(e)pyrene	25.0	ND
Benzo(a)pyrene	25.0	ND
Perylene	25.0	ND
Indeno(1,2,3-c,d)pyrene	25.0	ND
Dibenz(a,h)anthracene	25.0	ND
Benzo(g,h,i)perylene	25.0	ND

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director, Forensic Geochemistry

MSD 10
43576-1PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-2
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-11.5
Analyzed: 4/30/2014
Method: 8270M

CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Benzothiophene	25.0	ND
C1 Benzothiophenes	25.0	69.1
C2 Benzothiophenes	25.0	128.1
C3 Benzothiophenes	25.0	235.9
C4 Benzothiophenes	25.0	131.8
Naphthalene	25.0	ND
1-Methylnaphthalene	25.0	ND
2-Methylnaphthalene	25.0	ND
C2 Naphthalenes	25.0	2020.8
C3 Naphthalenes	25.0	1745.6
C4 Naphthalenes	25.0	1280.8
Biphenyl	25.0	ND
Acenaphthylene	25.0	ND
Dibenzofuran	25.0	35.7
Acenaphthene	25.0	678.6
Fluorene	25.0	707.8
C1 Fluorenes	25.0	299.5
C2 Fluorenes	25.0	102.0
C3 Fluorenes	25.0	139.4
Anthracene	25.0	190.9
Phenanthrene	25.0	595.0
C1 Phenanthrenes/Anthracenes	25.0	452.1
C2 Phenanthrenes/Anthracenes	25.0	394.6
C3 Phenanthrenes/Anthracenes	25.0	292.9
C4 Phenanthrenes/Anthracenes	25.0	114.6

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

MSD 10
43576-2PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-2
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-11.5
Analyzed: 4/30/2014
Method: 8270M

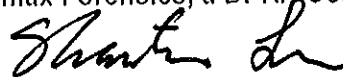
CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Dibenzothiophene	25.0	124.3
C1 Dibenzothiophenes	25.0	120.8
C2 Dibenzothiophenes	25.0	118.9
C3 Dibenzothiophenes	25.0	83.1
C4 Dibenzothiophenes	25.0	53.4
Fluoranthene	25.0	341.6
Pyrene	25.0	204.2
C1 Pyrenes/Fluoranthenes	25.0	174.6
C2 Pyrenes/Fluoranthenes	25.0	117.2
C3 Pyrenes/Fluoranthenes	25.0	58.3
Benzo(a)anthracene	25.0	40.9
Chrysene	25.0	39.6
C1 Chrysenes	25.0	75.9
C2 Chrysenes	25.0	47.5
C3 Chrysenes	25.0	ND
C4 Chrysenes	25.0	ND
Benzo(b)fluroanthene	25.0	ND
Benzo(k)fluoranthene	25.0	ND
Benzo(e)pyrene	25.0	ND
Benzo(a)pyrene	25.0	ND
Perylene	25.0	ND
Indeno(1,2,3-c,d)pyrene	25.0	ND
Dibenz(a,h)anthracene	25.0	ND
Benzo(g,h,i)perylene	25.0	ND

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director, Forensic Geochemistry

MSD 10
43576-2PAH.xls
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Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-3
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-10.5
Analyzed: 4/30/2014
Method: 8270M

CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Benzothiophene	25.0	ND
C1 Benzothiophenes	25.0	77.2
C2 Benzothiophenes	25.0	123.8
C3 Benzothiophenes	25.0	229.9
C4 Benzothiophenes	25.0	199.7
Naphthalene	25.0	ND
1-Methylnaphthalene	25.0	ND
2-Methylnaphthalene	25.0	ND
C2 Naphthalenes	25.0	1737.1
C3 Naphthalenes	25.0	1801.7
C4 Naphthalenes	25.0	1373.0
Biphenyl	25.0	ND
Acenaphthylene	25.0	ND
Dibenzofuran	25.0	ND
Acenaphthene	25.0	214.2
Fluorene	25.0	286.9
C1 Fluorenes	25.0	286.3
C2 Fluorenes	25.0	122.4
C3 Fluorenes	25.0	149.7
Anthracene	25.0	58.2
Phenanthrene	25.0	214.6
C1 Phenanthrenes/Anthracenes	25.0	347.7
C2 Phenanthrenes/Anthracenes	25.0	430.9
C3 Phenanthrenes/Anthracenes	25.0	334.7
C4 Phenanthrenes/Anthracenes	25.0	137.6

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

MSD 10
43576-3PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-3
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-10.5
Analyzed: 4/30/2014
Method: 8270M

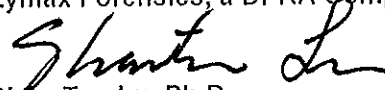
CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Dibenzothiophene	25.0	64.0
C1 Dibenzothiophenes	25.0	117.1
C2 Dibenzothiophenes	25.0	146.7
C3 Dibenzothiophenes	25.0	121.3
C4 Dibenzothiophenes	25.0	62.0
Fluoranthene	25.0	70.6
Pyrene	25.0	53.5
C1 Pyrenes/Fluoranthenes	25.0	79.5
C2 Pyrenes/Fluoranthenes	25.0	119.5
C3 Pyrenes/Fluoranthenes	25.0	66.9
Benzo(a)anthracene	25.0	ND
Chrysene	25.0	ND
C1 Chrysenes	25.0	62.9
C2 Chrysenes	25.0	51.9
C3 Chrysenes	25.0	ND
C4 Chrysenes	25.0	ND
Benzo(b)fluroanthene	25.0	ND
Benzo(k)fluoranthene	25.0	ND
Benzo(e)pyrene	25.0	ND
Benzo(a)pyrene	25.0	ND
Perylene	25.0	ND
Indeno(1,2,3-c,d)pyrene	25.0	ND
Dibenz(a,h)anthracene	25.0	ND
Benzo(g,h,i)perylene	25.0	ND

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director, Forensic Geochemistry

MSD 10
43576-3PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-4
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-6
Analyzed: 4/30/2014
Method: 8270M

CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Benzothiophene	25.0	ND
C1 Benzothiophenes	25.0	69.2
C2 Benzothiophenes	25.0	70.8
C3 Benzothiophenes	25.0	205.4
C4 Benzothiophenes	25.0	192.4
Naphthalene	25.0	ND
1-Methylnaphthalene	25.0	ND
2-Methylnaphthalene	25.0	ND
C2 Naphthalenes	25.0	920.5
C3 Naphthalenes	25.0	1413.4
C4 Naphthalenes	25.0	1448.8
Biphenyl	25.0	ND
Acenaphthylene	25.0	ND
Dibenzofuran	25.0	28.6
Acenaphthene	25.0	209.8
Fluorene	25.0	159.2
C1 Fluorenes	25.0	261.5
C2 Fluorenes	25.0	143.9
C3 Fluorenes	25.0	256.9
Anthracene	25.0	55.9
Phenanthrene	25.0	145.0
C1 Phenanthrenes/Anthracenes	25.0	424.6
C2 Phenanthrenes/Anthracenes	25.0	617.9
C3 Phenanthrenes/Anthracenes	25.0	566.2
C4 Phenanthrenes/Anthracenes	25.0	234.6

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

MSD 10
43576-4PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-4
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-6
Analyzed: 4/30/2014
Method: 8270M

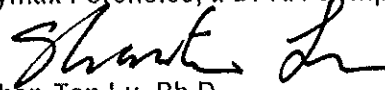
CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Dibenzothiophene	25.0	35.9
C1 Dibenzothiophenes	25.0	156.5
C2 Dibenzothiophenes	25.0	228.5
C3 Dibenzothiophenes	25.0	190.7
C4 Dibenzothiophenes	25.0	131.3
Fluoranthene	25.0	136.0
Pyrene	25.0	102.8
C1 Pyrenes/Fluoranthenes	25.0	168.7
C2 Pyrenes/Fluoranthenes	25.0	255.3
C3 Pyrenes/Fluoranthenes	25.0	135.3
Benzo(a)anthracene	25.0	ND
Chrysene	25.0	31.3
C1 Chrysenes	25.0	112.9
C2 Chrysenes	25.0	103.6
C3 Chrysenes	25.0	52.4
C4 Chrysenes	25.0	44.0
Benzo(b)fluroanthene	25.0	ND
Benzo(k)fluoranthene	25.0	ND
Benzo(e)pyrene	25.0	ND
Benzo(a)pyrene	25.0	ND
Perylene	25.0	ND
Indeno(1,2,3-c,d)pyrene	25.0	ND
Dibenz(a,h)anthracene	25.0	ND
Benzo(g,h,i)perylene	25.0	ND

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director, Forensic Geochemistry

MSD 10
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STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-5
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-4.5
Analyzed: 4/30/2014
Method: 8270M

CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Benzothiophene	25.0	ND
C1 Benzothiophenes	25.0	59.6
C2 Benzothiophenes	25.0	135.3
C3 Benzothiophenes	25.0	216.8
C4 Benzothiophenes	25.0	162.1
Naphthalene	25.0	ND
1-Methylnaphthalene	25.0	ND
2-Methylnaphthalene	25.0	ND
C2 Naphthalenes	25.0	2074.1
C3 Naphthalenes	25.0	1522.0
C4 Naphthalenes	25.0	1261.8
Biphenyl	25.0	ND
Acenaphthylene	25.0	ND
Dibenzofuran	25.0	ND
Acenaphthene	25.0	108.3
Fluorene	25.0	195.6
C1 Fluorenes	25.0	257.3
C2 Fluorenes	25.0	133.5
C3 Fluorenes	25.0	187.4
Anthracene	25.0	39.5
Phenanthrene	25.0	303.0
C1 Phenanthrenes/Anthracenes	25.0	506.8
C2 Phenanthrenes/Anthracenes	25.0	584.1
C3 Phenanthrenes/Anthracenes	25.0	462.7
C4 Phenanthrenes/Anthracenes	25.0	186.6

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

MSD 10
43576-5PAH.xls
STL

Client: Samuel Miles
ARCADIS
1100 Olive Way Suite 800
Seattle, WA 98101

Lab Number: 43576-5
Collected: 2/25/2014
Received: 4/25/2014
Matrix: Product

Project: Former Unocal Seattle Marke
Project Number: B0045363.00006
Collected by: Ross Lagrandeur

Sample Description:
PZ-4.5
Analyzed: 4/30/2014
Method: 8270M

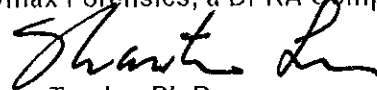
CONSTITUENT	PQL* mg/kg	RESULT** mg/kg
Dibenzothiophene	25.0	62.2
C1 Dibenzothiophenes	25.0	149.6
C2 Dibenzothiophenes	25.0	228.3
C3 Dibenzothiophenes	25.0	145.4
C4 Dibenzothiophenes	25.0	100.7
Fluoranthene	25.0	40.1
Pyrene	25.0	38.3
C1 Pyrenes/Fluoranthenes	25.0	121.0
C2 Pyrenes/Fluoranthenes	25.0	202.2
C3 Pyrenes/Fluoranthenes	25.0	110.3
Benz(a)anthracene	25.0	ND
Chrysene	25.0	ND
C1 Chrysenes	25.0	99.0
C2 Chrysenes	25.0	82.5
C3 Chrysenes	25.0	41.3
C4 Chrysenes	25.0	26.8
Benzo(b)fluroanthene	25.0	ND
Benzo(k)fluoranthene	25.0	ND
Benzo(e)pyrene	25.0	ND
Benzo(a)pyrene	25.0	ND
Perylene	25.0	ND
Indeno(1,2,3-c,d)pyrene	25.0	ND
Dibenz(a,h)anthracene	25.0	ND
Benzo(g,h,i)perylene	25.0	ND

*PQL - Practical Quantitation Limit

**Results listed as ND would have been reported if present at or above the listed PQL.

Note: Analyzed in the Selected Ion Monitoring (SIM) mode.

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director, Forensic Geochemistry

MSD 10
43576-5PAH.xls
STL

C3-C44 Whole Oil Analysis (ASTM D3328)

1. Gasoline Range PIANO Distribution
2. Whole Chromatogram
3. Expanded Chromatogram(in 3 pages)
4. Quantitation Report with Peak areas

5/5/2014

ZymaX ID 43576-1
Sample ID PZ-13

Evaporation

n-Pentane / n-Heptane 0.00
2-Methylpentane / 2-Methylheptane 0.00

Waterwashing

Benzene / Cyclohexane 0.00
Toluene / Methylcyclohexane 0.00
Aromatics / Total Paraffins (n+iso+cyc) 0.74
Aromatics / Naphthenes 7.68

Biodegradation

(C4 - C8 Para + Isopara) / C4 - C8 Olefins 658.46
3-Methylhexane / n-Heptane 0.00
Methylcyclohexane / n-Heptane 0.00
Isoparaffins + Naphthenes / Paraffins 6.22

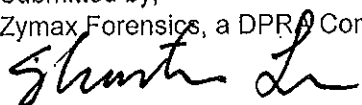
Octane rating

2,2,4,-Trimethylpentane / Methylcyclohexane 0.00

Relative percentages - Bulk hydrocarbon composition as PIANO

% Paraffinic 7.84
% Isoparaffinic 43.25
% Aromatic 41.99
% Naphthenic 5.47
% Olefinic 1.45

Submitted by,
Zymax Forensics, a DPR Company



Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

5/5/2014

ZymaX ID	43576-1	
Sample ID	PZ-13	
	Relative Area %	
1	Propane	0.00
2	Isobutane	0.00
3	Isobutene	0.00
4	Butane/Methanol	0.00
5	trans-2-Butene	0.00
6	cis-2-Butene	0.00
7	3-Methyl-1-butene	0.00
8	Isopentane	0.00
9	1-Pentene	0.00
10	2-Methyl-1-butene	0.00
11	Pentane	0.00
12	trans-2-Pentene	0.00
13	cis-2-Pentene/t-Butanol	0.00
14	2-Methyl-2-butene	0.00
15	2,2-Dimethylbutane	0.00
16	Cyclopentane	0.00
17	2,3-Dimethylbutane/MTBE	0.00
18	2-Methylpentane	0.00
19	3-Methylpentane	0.00
20	Hexane	0.00
21	trans-2-Hexene	0.00
22	3-Methylcyclopentene	0.00
23	3-Methyl-2-pentene	0.00
24	cis-2-Hexene	0.00
25	3-Methyl-trans-2-pentene	0.00
26	Methylcyclopentane	0.00
27	2,4-Dimethylpentane	0.21
28	Benzene	0.00
29	5-Methyl-1-hexene	0.07
30	Cyclohexane	0.00
31	2-Methylhexane/TAME	0.00
32	2,3-Dimethylpentane	1.42
33	3-Methylhexane	0.09
34A	1-trans-3-Dimethylcyclopentane	0.45
34B	1-cis-3-Dimethylcyclopentane	0.30
35	2,2,4-Trimethylpentane	1.04
I.S. #1	à,à,à-Trifluorotoluene	0.00

5/5/2014

ZymaX ID		43576-1
Sample ID		PZ-13
		Relative Area %
36	n-Heptane	0.00
37	Methylcyclohexane	0.00
38	2,5-Dimethylhexane	0.17
39	2,4-Dimethylhexane	0.85
40	2,3,4-Trimethylpentane	1.30
41	Toluene/2,3,3-Trimethylpentane	0.81
42	2,3-Dimethylhexane	1.56
43	2-Methylheptane	0.00
44	4-Methylheptane	0.00
45	3,4-Dimethylhexane	0.60
46A	3-Ethyl-3-methylpentane	2.86
46B	1,4-Dimethylcyclohexane	1.88
47	3-Methylheptane	0.00
48	2,2,5-Trimethylhexane	1.77
49	n-Octane	5.91
50	2,2-Dimethylheptane	1.16
51	2,4-Dimethylheptane	1.55
52	Ethylcyclohexane	2.84
53	2,6-Dimethylheptane	13.10
54	Ethylbenzene	4.06
55	m+p Xylenes	2.61
56	4-Methyloctane	0.56
57	2-Methyloctane	0.00
58	3-Ethylheptane	2.58
59	3-Methyloctane	1.81
60	o-Xylene	0.00
61	1-Nonene	1.38
62	n-Nonane	0.86
I.S.#2	p-Bromofluorobenzene	0.00
63	Isopropylbenzene	0.19
64	3,3,5-Trimethylheptane	4.02
65	2,4,5-Trimethylheptane	3.71
66	n-Propylbenzene	4.49
67	1-Methyl-3-ethylbenzene	0.00
68	1-Methyl-4-ethylbenzene	1.37
69	1,3,5-Trimethylbenzene	5.33
70	3,3,4-Trimethylheptane	1.93

5/5/2014

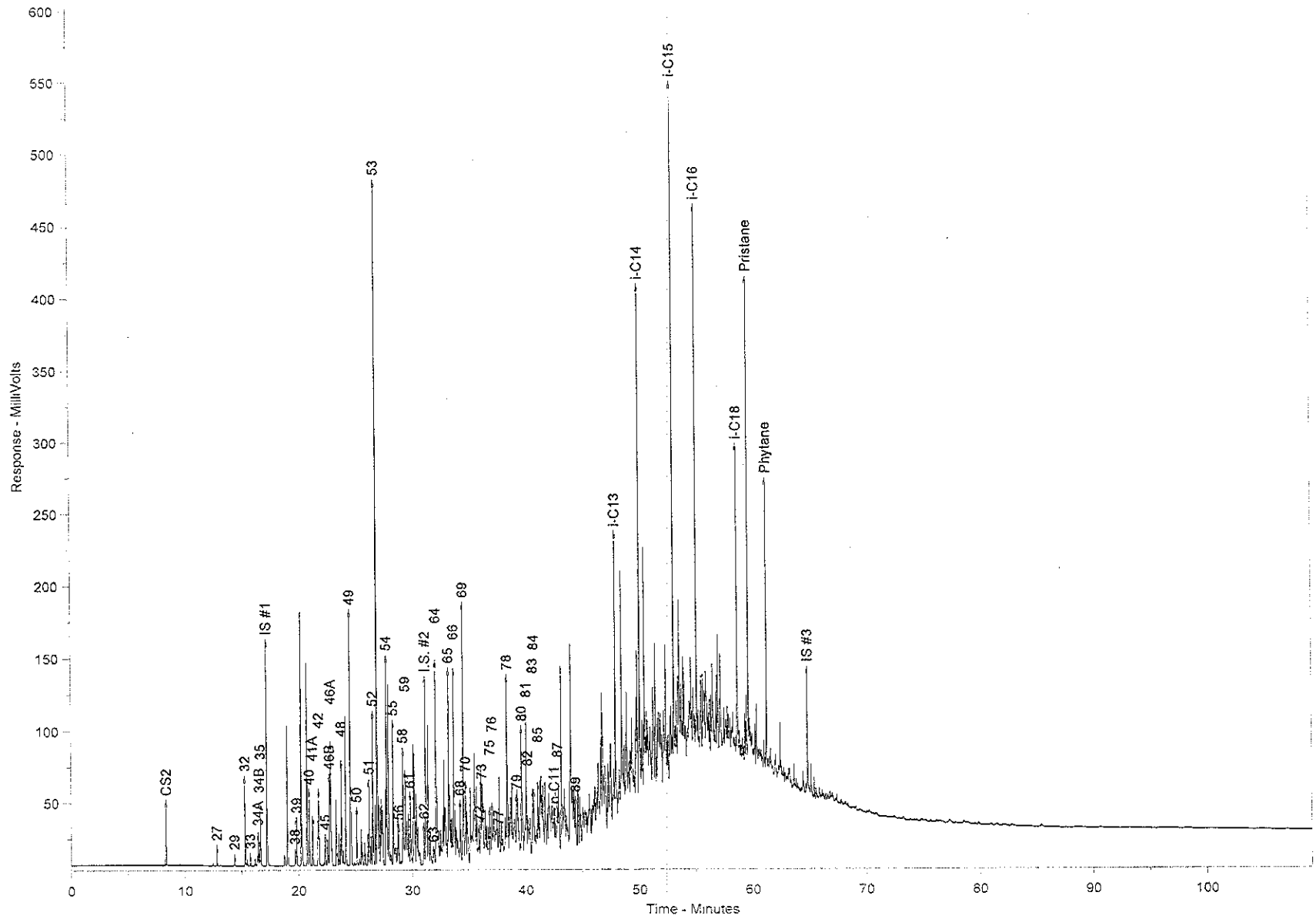
ZymaX ID
Sample ID43576-1
PZ-13

		Relative Area %
71	1-Methyl-2-ethylbenzene	0.00
72	3-Methylnonane	0.96
73	1,2,4-Trimethylbenzene	1.65
74	Isobutylbenzene	0.00
75	sec-Butylbenzene	1.28
76	n-Decane	1.08
77	1,2,3-Trimethylbenzene	0.42
78	Indan	5.04
79	1,3-Diethylbenzene	1.12
80	1,4-Diethylbenzene	3.87
81	n-Butylbenzene	3.07
82	1,3-Dimethyl-5-ethylbenzene	0.95
83	1,4-Dimethyl-2-ethylbenzene	1.74
84	1,3-Dimethyl-4-ethylbenzene	1.15
85	1,2-Dimethyl-4-ethylbenzene	1.18
86	Undecene	0.00
87	1,2,4,5-Tetramethylbenzene	0.43
88	1,2,3,5-Tetramethylbenzene	0.00
89	1,2,3,4-Tetramethylbenzene	1.25
90	Naphthalene	0.00
91	2-Methyl-naphthalene	0.00
92	1-Methyl-naphthalene	0.00

Chrom Perfect Chromatogram Report

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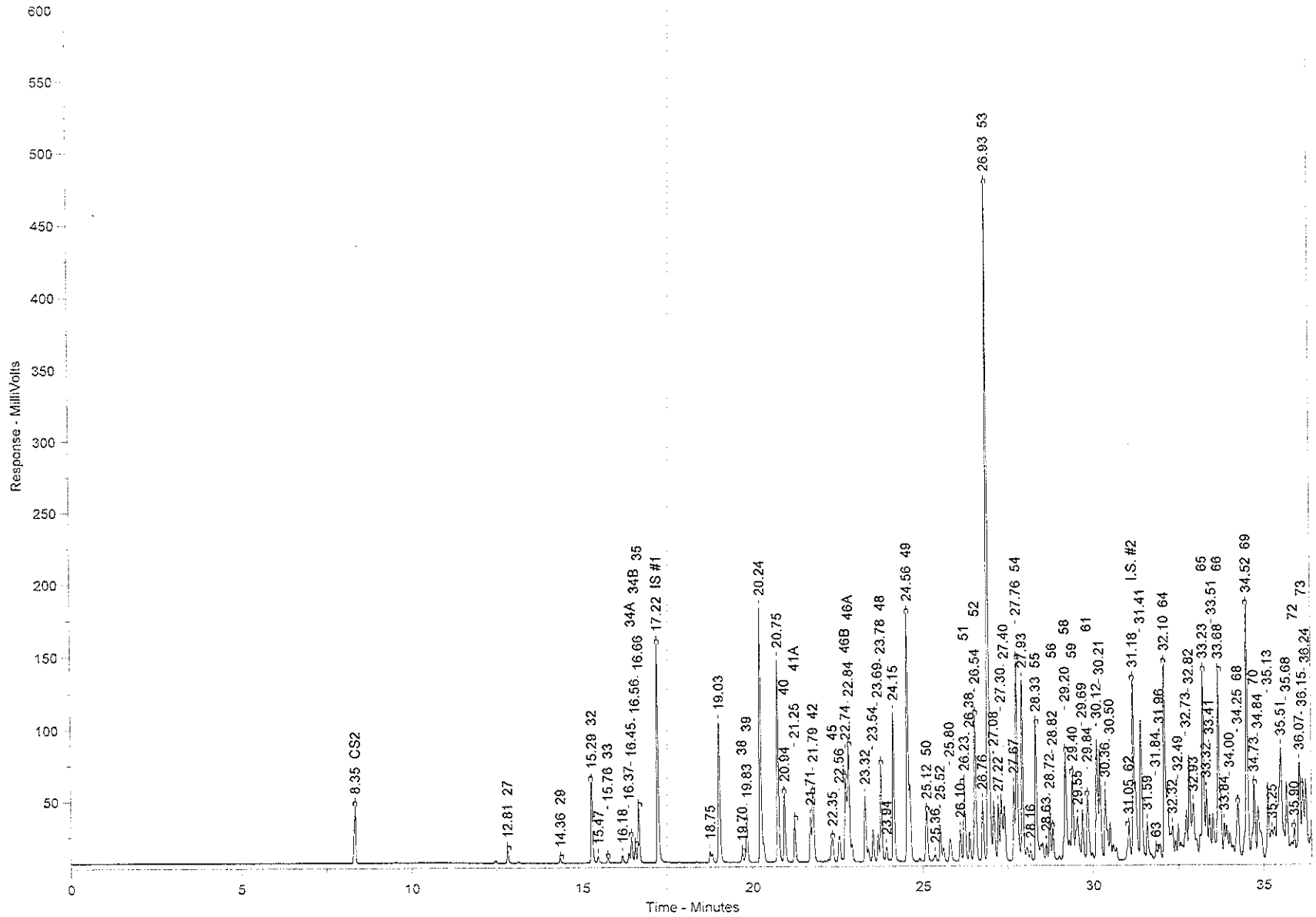
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Chrom Perfect Chromatogram Report

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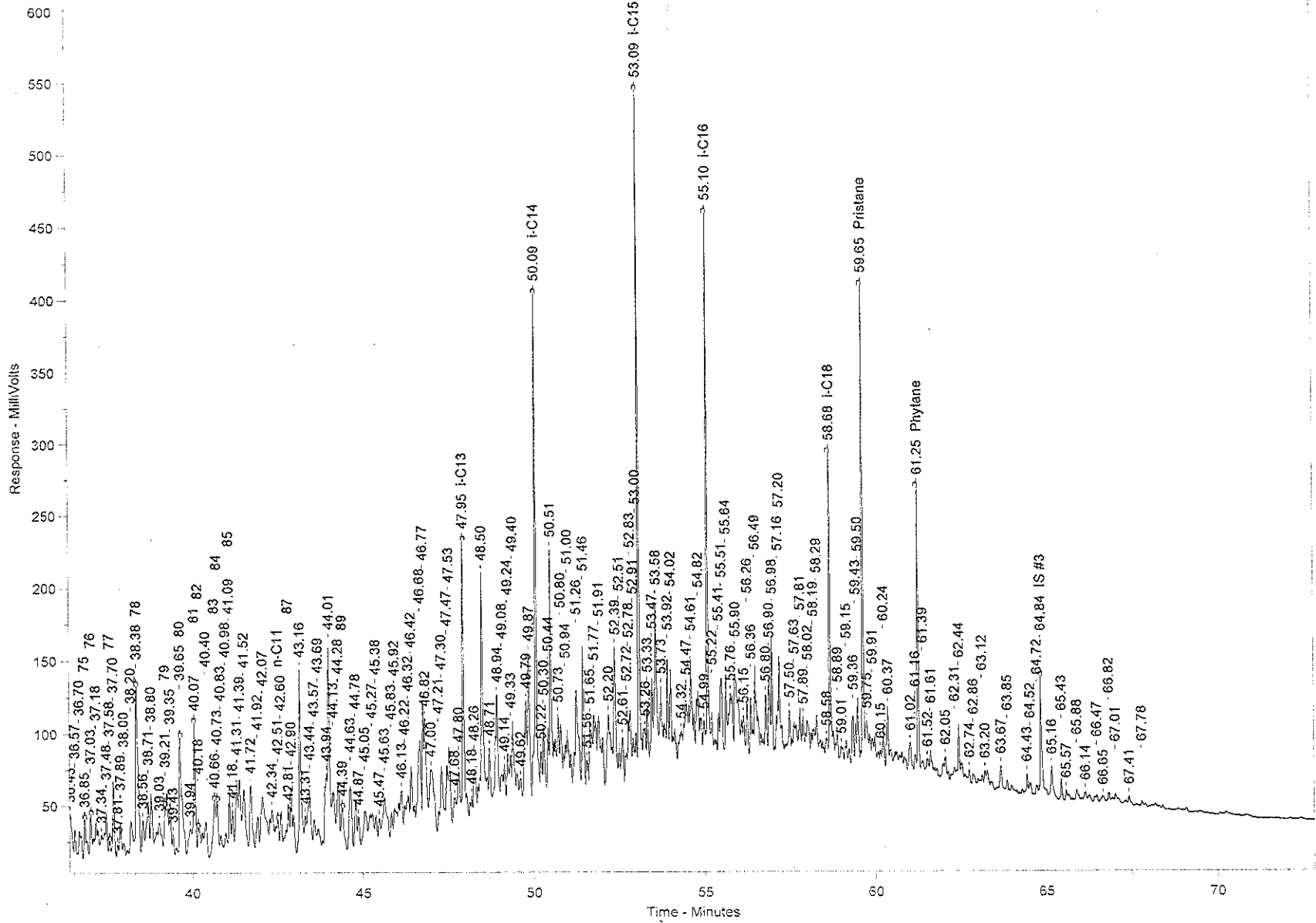
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Chrom Perfect Chromatogram Report

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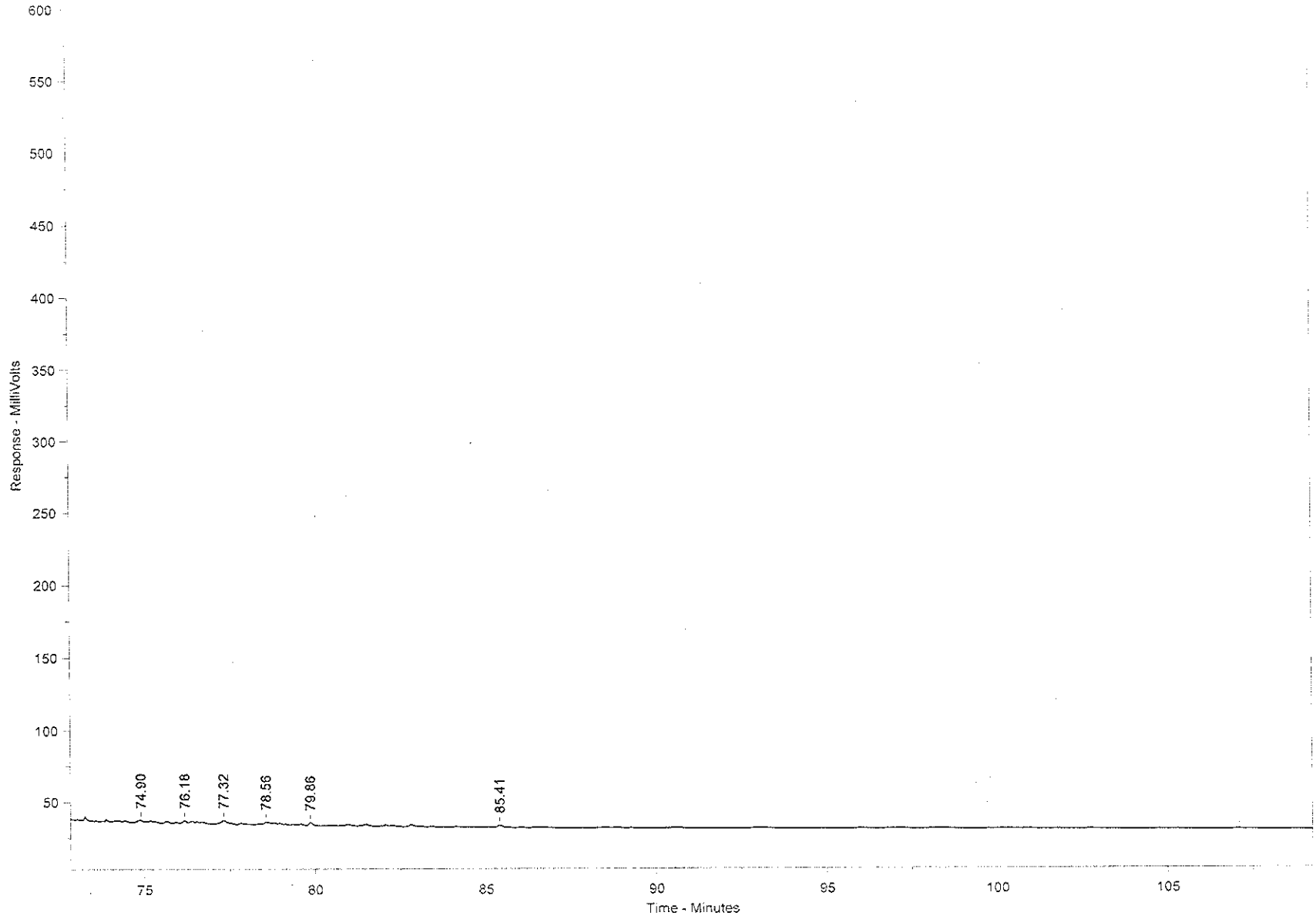
43576-1 [PZ-13] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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43576-1 [PZ-13] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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Acquisition Port = DP#

Heading 1 =

Heading 2 =

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Date Taken (end) = 5/7/2014 2:37:54 PM

Method File Name = C:\CPSpirit\C344.met

Method Version = 44

Calibration File Name = C:\CPSpirit\2014\May14\050514.0006.BND

Calibration Version = 10

Peak Name	Ret. Time	Area %	Area
CS2	8.35	0.2290	130211.30
27	12.81	0.0476	27068.99
29	14.36	0.0167	9494.92
32	15.29	0.3184	181005.10
	15.47	0.0268	15258.95
33	15.76	0.0202	11492.11
	16.18	0.0299	17018.87
	16.37	0.0381	21637.71
34A	16.45	0.1012	57553.77
34B	16.56	0.0660	37512.09
35	16.66	0.2322	132011.40
IS #1	17.22	0.8559	486621.80
	18.75	0.0411	23374.15
	19.03	0.5851	332619.60
38	19.70	0.0388	22041.46
39	19.83	0.1892	107565.00
	20.24	1.0792	613562.20
	20.75	0.8176	464854.30
40	20.94	0.2901	164950.10
41A	21.25	0.1812	103030.70
	21.71	0.1731	98400.71
42	21.79	0.3479	197800.80
45	22.35	0.1350	76743.48
	22.56	0.1450	82435.27
46B	22.74	0.4212	239440.20
46A	22.84	0.6406	364190.10
	23.32	0.2695	153217.70
	23.54	0.1264	71846.19
	23.69	0.1027	58410.89
48	23.78	0.3954	224802.00
	23.94	0.0652	37085.25
	24.15	0.6142	349212.80
49	24.56	1.3216	751387.30
50	25.12	0.2595	147554.90
	25.36	0.0326	18543.47
	25.52	0.1193	67836.89
	25.80	0.1308	74343.88
	26.10	0.1247	70921.09
51	26.23	0.3477	197683.40
	26.38	0.1216	69132.38
52	26.54	0.6354	361263.20
	26.76	0.2567	145942.70
53	26.93	2.9309	1666306.00
	27.08	0.2937	166976.90
	27.22	0.2251	127999.00
	27.30	0.3297	187424.70
	27.40	0.2463	140039.30
	27.67	0.2940	167160.50
54	27.76	0.9078	516109.60
	27.93	0.7146	406249.90
	28.16	0.0394	22428.08
55	28.33	0.5830	331434.60
	28.63	0.0625	35548.74
	28.72	0.2181	123998.40
56	28.82	0.1258	71536.68

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
58	29.20	0.5770	328018.40
59	29.40	0.4046	230010.90
	29.55	0.3014	171336.30
	29.69	0.1886	107233.40
61	29.84	0.3082	175192.20
	30.12	0.5573	316816.80
	30.21	0.4623	262827.50
	30.36	0.3357	190852.00
	30.50	0.1035	58858.57
62	31.05	0.1914	108820.60
I.S. #2	31.18	1.1024	626739.40
	31.41	0.6999	397920.20
	31.59	0.1881	106931.70
63	31.84	0.0427	24270.28
	31.96	0.0963	54723.09
64	32.10	0.8992	511200.00
	32.32	0.1050	59700.94
	32.49	0.0741	42139.59
	32.73	0.1548	88017.45
	32.82	0.3505	199246.70
	32.93	0.1894	107663.90
65	33.23	0.8290	471289.80
	33.32	0.2446	139048.50
	33.41	0.1597	90816.03
	33.51	0.1746	99261.87
66	33.68	1.0045	571070.60
	33.84	0.0597	33936.57
	34.00	0.0409	23257.52
68	34.25	0.3063	174152.30
69	34.52	1.1922	677796.70
70	34.73	0.4322	245710.90
	34.84	0.3921	222927.50
	35.13	0.3426	194792.60
	35.25	0.1845	104880.00
	35.51	1.0552	599934.20
	35.68	0.4006	227742.10
72	35.90	0.2141	121701.20
	36.07	0.5344	303810.00
73	36.15	0.3691	209846.10
	36.24	0.3908	222170.80
	36.43	0.3945	224265.70
	36.57	0.1771	100665.80
	36.70	0.2298	130656.60
75	36.85	0.2856	162383.10
76	37.03	0.2405	136739.70
	37.18	0.1744	99154.13
	37.34	0.1661	94423.99
	37.48	0.3566	202722.50
77	37.58	0.0929	52791.51
	37.70	0.3932	223556.70
	37.81	0.0689	39174.50
	37.89	0.1993	113287.60
	38.00	0.1020	58000.68
	38.20	0.2814	159961.90
78	38.38	1.1280	641315.30
	38.56	0.2273	129206.10
	38.71	0.4062	230953.20
	38.80	0.3512	199685.60
	39.03	0.5200	295655.60
79	39.21	0.2504	142362.20
	39.35	0.2583	146833.10
	39.43	0.1051	59765.85
80	39.65	0.8651	491835.70
	39.94	0.2390	135868.80
81	40.07	0.6873	390743.80
82	40.18	0.2131	121147.20
	40.40	0.3444	195794.30

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
83	40.66	0.3890	221157.30
84	40.73	0.2563	145737.30
	40.83	0.1167	66373.67
	40.98	0.1257	71471.46
85	41.09	0.2649	150589.90
	41.18	0.1853	105371.30
	41.31	0.4135	235109.80
	41.39	0.3630	206347.20
	41.52	0.4501	255872.60
	41.72	0.3815	216878.20
	41.92	0.1700	96667.27
	42.07	0.5664	321985.80
	42.34	0.2909	165363.80
n-C11	42.51	0.0946	53801.02
	42.60	0.1097	62343.61
87	42.81	0.0958	54461.24
	42.90	0.1471	83637.15
	43.16	0.9182	522047.10
	43.31	0.1784	101446.70
	43.44	0.4822	274117.30
	43.57	0.1920	109153.30
	43.69	0.1659	94324.89
	43.94	0.4850	275730.70
	44.01	0.9276	527382.80
	44.13	0.4444	252681.40
	44.28	0.4399	250122.00
89	44.39	0.2790	158611.90
	44.63	0.3943	224157.60
	44.78	0.2373	134886.10
	44.87	0.1293	73494.41
	45.05	0.3032	172354.40
	45.27	0.3560	202413.60
	45.38	0.1314	74683.43
	45.47	0.1122	63772.50
	45.63	0.4969	282505.10
	45.83	0.1266	71982.34
	45.92	0.2497	141934.90
	46.13	0.2964	168529.40
	46.22	0.1450	82439.39
	46.32	0.2792	158718.40
	46.42	0.3761	213807.30
	46.68	0.7857	446698.60
	46.77	0.5019	285331.50
	46.82	0.6010	341681.60
	47.00	0.7062	401475.90
	47.21	0.0736	41831.03
	47.30	0.4245	241353.60
	47.47	0.3049	173362.40
	47.53	0.3923	223018.30
	47.68	0.1909	108504.20
	47.80	0.3817	217014.20
i-C13	47.95	1.2998	738981.40
	48.18	0.1560	88705.54
	48.26	0.3198	181801.40
	48.50	1.5361	873320.90
	48.71	0.3384	192362.10
	48.94	0.9380	533298.40
	49.08	0.2451	139326.30
	49.14	0.2378	135218.50
	49.24	0.2900	164895.80
	49.33	0.2523	143415.60
	49.40	0.4898	278480.90
	49.62	0.1676	95297.71
	49.79	0.7207	409752.10
	49.87	0.7239	411582.80
i-C14	50.09	2.1098	1199500.00
	50.22	0.2345	133320.60

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	50.30	0.3749	213146.60
	50.44	0.3145	178797.60
	50.51	1.4071	799989.60
	50.73	0.3791	215533.10
	50.80	0.3678	209088.80
	50.94	0.1936	110088.90
	51.00	0.5289	300686.70
	51.26	0.9271	527060.70
	51.46	0.6430	365556.70
	51.56	0.1510	85859.73
	51.65	0.2279	129569.50
	51.77	0.7369	418967.50
	51.91	0.5149	292738.20
	52.20	0.7009	398452.70
	52.39	0.7046	400571.10
	52.51	0.1403	79755.68
	52.61	0.2140	121685.80
	52.72	0.1316	74804.86
	52.78	0.2069	117607.70
	52.83	0.2368	134626.40
	52.91	0.1689	96010.74
	53.00	0.1421	80762.64
i-C15	53.09	2.0564	1169092.00
	53.26	0.2440	138700.00
	53.33	0.1940	110277.60
	53.47	0.3232	183765.10
	53.58	0.7888	448469.50
	53.73	0.3373	191766.00
	53.92	0.2438	138594.80
	54.02	0.2484	141205.80
	54.32	0.2266	128840.70
	54.47	0.5812	330430.60
	54.61	0.5148	292681.30
	54.82	0.3655	207786.50
	54.99	0.1467	83393.49
i-C16	55.10	1.5145	861021.10
	55.22	0.1102	62634.38
	55.41	0.1185	67387.33
	55.51	0.3793	215648.60
	55.64	0.2591	147311.80
	55.76	0.3466	197034.70
	55.90	0.7059	401337.90
	56.15	0.2619	148908.50
	56.26	0.1939	110242.30
	56.36	0.2701	153554.10
	56.49	0.5270	299624.40
	56.80	0.2288	130083.40
	56.90	0.2816	160090.50
	56.98	0.3570	202954.60
	57.16	0.2122	120637.30
	57.20	0.3729	211997.50
	57.50	0.1326	75363.66
	57.63	0.0343	19496.09
	57.81	0.1141	64842.41
	57.89	0.0974	55348.51
	58.02	0.1472	83701.66
	58.19	0.0512	29080.79
	58.29	0.1117	63483.25
	58.58	0.0862	48983.76
i-C18	58.68	1.0704	608537.80
	58.89	0.0784	44600.88
	59.01	0.0768	43634.93
	59.15	0.0730	41478.65
	59.36	0.2034	115611.80
	59.43	0.1043	59317.06
	59.50	0.2080	118264.60
Pristane	59.65	1.3171	748832.50

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	59.75	0.1262	71736.70
	59.91	0.0332	18879.18
	60.15	0.0285	16182.63
	60.24	0.1390	79019.73
	60.37	0.2040	115977.00
	61.02	0.1564	88898.27
	61.16	0.0592	33663.62
Phytane	61.25	0.8393	477181.10
	61.39	0.0550	31288.66
	61.52	0.0605	34400.50
	61.61	0.0949	53980.81
	62.05	0.1236	70284.75
	62.31	0.0549	31224.61
	62.44	0.1385	78740.73
	62.74	0.0306	17419.13
	62.86	0.0577	32783.75
	63.12	0.0205	11630.89
	63.20	0.0251	14266.93
	63.67	0.0969	55071.73
	63.85	0.0347	19735.77
	64.43	0.0622	35369.12
	64.52	0.0550	31242.05
	64.72	0.0512	29083.28
IS #3	64.84	0.5480	311540.70
	65.16	0.1883	107075.50
	65.43	0.0759	43129.89
	65.57	0.0687	39068.36
	65.88	0.0567	32254.58
	66.14	0.0321	18246.20
	66.47	0.0508	28863.15
	66.65	0.0419	23840.38
	66.82	0.0309	17560.49
	67.01	0.0218	12370.05
	67.41	0.0316	17979.55
	67.78	0.0155	8802.82
	74.90	0.0324	18417.27
	76.18	0.0228	12961.37
	77.32	0.0549	31219.49
	78.56	0.0183	10417.62
	79.86	0.0312	17747.72
	85.41	0.0349	19847.46

Total Area = 5.685273E+07

Total Height = 1.418453E+07

Total Amount = 0

5/5/2014

ZymaX ID 43576-2
Sample ID PZ-11.5

Evaporation

n-Pentane / n-Heptane 0.00
2-Methylpentane / 2-Methylheptane 0.00

Waterwashing

Benzene / Cyclohexane 0.00
Toluene / Methylcyclohexane 0.00
Aromatics / Total Paraffins (n+iso+cyc) 0.69
Aromatics / Naphthenes 4.53

Biodegradation

(C4 - C8 Para + Isopara) / C4 - C8 Olefins 176.93
3-Methylhexane / n-Heptane 0.00
Methylcyclohexane / n-Heptane 0.00
Isoparaffins + Naphthenes / Paraffins 7.47

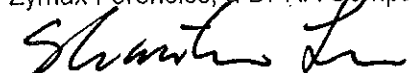
Octane rating

2,2,4,-Trimethylpentane / Methylcyclohexane 0.00

Relative percentages - Bulk hydrocarbon composition as PIANO

% Paraffinic 6.89
% Isoparaffinic 42.61
% Aromatic 40.04
% Naphthenic 8.83
% Olefinic 1.63

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

5/5/2014

ZyMaX ID	43576-2	
Sample ID	PZ-11.5	
	Relative	
	Area %	
1	Propane	0.00
2	Isobutane	0.00
3	Isobutene	0.00
4	Butane/Methanol	0.00
5	trans-2-Butene	0.00
6	cis-2-Butene	0.00
7	3-Methyl-1-butene	0.00
8	Isopentane	0.20
9	1-Pentene	0.00
10	2-Methyl-1-butene	0.00
11	Pentane	0.00
12	trans-2-Pentene	0.00
13	cis-2-Pentene/t-Butanol	0.00
14	2-Methyl-2-butene	0.00
15	2,2-Dimethylbutane	0.00
16	Cyclopentane	0.00
17	2,3-Dimethylbutane/MTBE	0.42
18	2-Methylpentane	0.54
19	3-Methylpentane	0.50
20	Hexane	0.00
21	trans-2-Hexene	0.00
22	3-Methylcyclopentene	0.00
23	3-Methyl-2-pentene	0.00
24	cis-2-Hexene	0.00
25	3-Methyl-trans-2-pentene	0.12
26	Methylcyclopentane	0.00
27	2,4-Dimethylpentane	0.68
28	Benzene	0.00
29	5-Methyl-1-hexene	0.15
30	Cyclohexane	0.00
31	2-Methylhexane/TAME	0.18
32	2,3-Dimethylpentane	2.82
33	3-Methylhexane	0.43
34A	1-trans-3-Dimethylcyclopentane	1.09
34B	1-cis-3-Dimethylcyclopentane	0.80
35	2,2,4-Trimethylpentane	0.84
I.S. #1	à,à,à-Trifluorotoluene	0.00

5/5/2014

ZymaX ID	43576-2	
Sample ID	PZ-11.5	
	Relative	
	Area %	
36	n-Heptane	0.00
37	Methylcyclohexane	0.00
38	2,5-Dimethylhexane	0.87
39	2,4-Dimethylhexane	0.98
40	2,3,4-Trimethylpentane	1.09
41	Toluene/2,3,3-Trimethylpentane	0.53
42	2,3-Dimethylhexane	1.74
43	2-Methylheptane	0.00
44	4-Methylheptane	0.72
45	3,4-Dimethylhexane	0.00
46A	3-Ethyl-3-methylpentane	2.14
46B	1,4-Dimethylcyclohexane	1.89
47	3-Methylheptane	0.00
48	2,2,5-Trimethylhexane	1.93
49	n-Octane	5.01
50	2,2-Dimethylheptane	1.20
51	2,4-Dimethylheptane	1.32
52	Ethylcyclohexane	5.05
53	2,6-Dimethylheptane	9.04
54	Ethylbenzene	3.67
55	m+p Xylenes	3.24
56	4-Methyloctane	0.69
57	2-Methyloctane	0.00
58	3-Ethylheptane	2.40
59	3-Methyloctane	1.28
60	o-Xylene	0.00
61	1-Nonene	1.37
62	n-Nonane	0.69
I.S.#2	p-Bromofluorobenzene	0.00
63	Isopropylbenzene	0.26
64	3,3,5-Trimethylheptane	4.11
65	2,4,5-Trimethylheptane	4.10
66	n-Propylbenzene	3.87
67	1-Methyl-3-ethylbenzene	0.00
68	1-Methyl-4-ethylbenzene	1.22
69	1,3,5-Trimethylbenzene	4.52
70	3,3,4-Trimethylheptane	1.62

5/5/2014

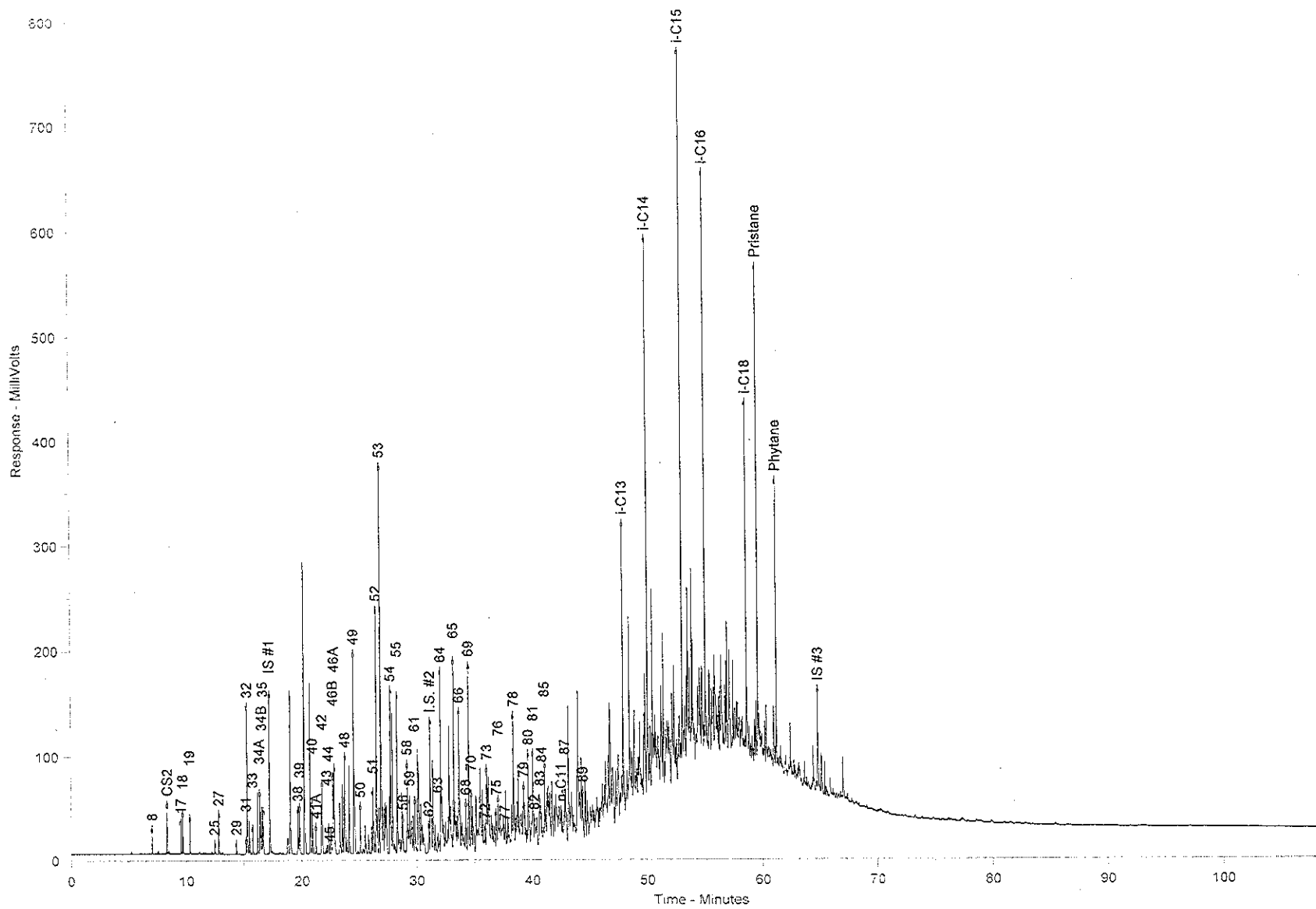
ZymaX ID
Sample ID43576-2
PZ-11.5

		Relative Area %
71	1-Methyl-2-ethylbenzene	0.00
72	3-Methylnonane	0.79
73	1,2,4-Trimethylbenzene	2.18
74	Isobutylbenzene	0.00
75	sec-Butylbenzene	1.23
76	n-Decane	1.19
77	1,2,3-Trimethylbenzene	0.37
78	Indan	4.22
79	1,3-Diethylbenzene	2.32
80	1,4-Diethylbenzene	3.29
81	n-Butylbenzene	2.43
82	1,3-Dimethyl-5-ethylbenzene	0.86
83	1,4-Dimethyl-2-ethylbenzene	1.48
84	1,3-Dimethyl-4-ethylbenzene	0.65
85	1,2-Dimethyl-4-ethylbenzene	1.63
86	Undecene	0.00
87	1,2,4,5-Tetramethylbenzene	0.65
88	1,2,3,5-Tetramethylbenzene	0.00
89	1,2,3,4-Tetramethylbenzene	1.40
90	Naphthalene	0.00
91	2-Methyl-naphthalene	0.00
92	1-Methyl-naphthalene	0.00

Chrom Perfect Chromatogram Report

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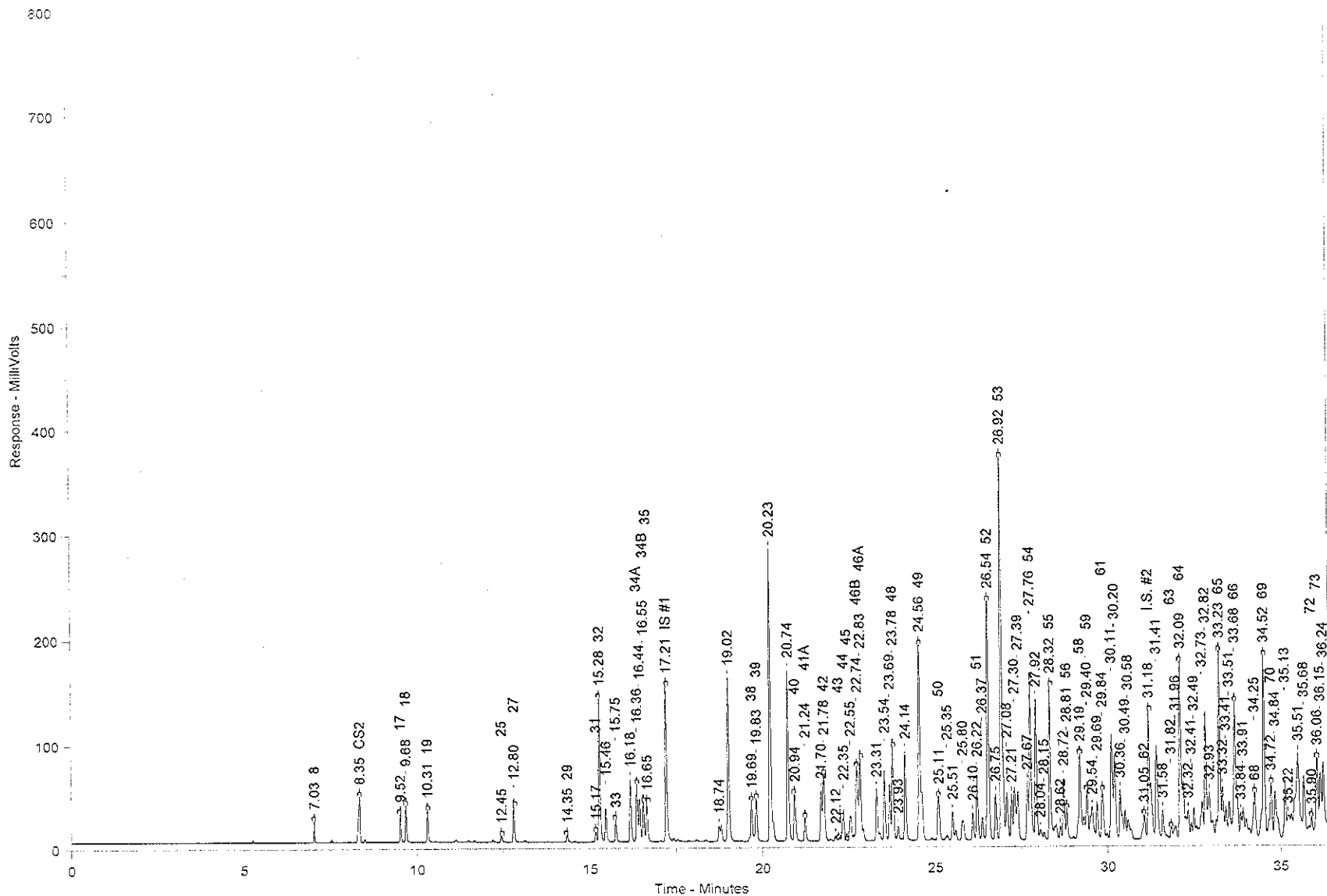
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Chrom Perfect Chromatogram Report

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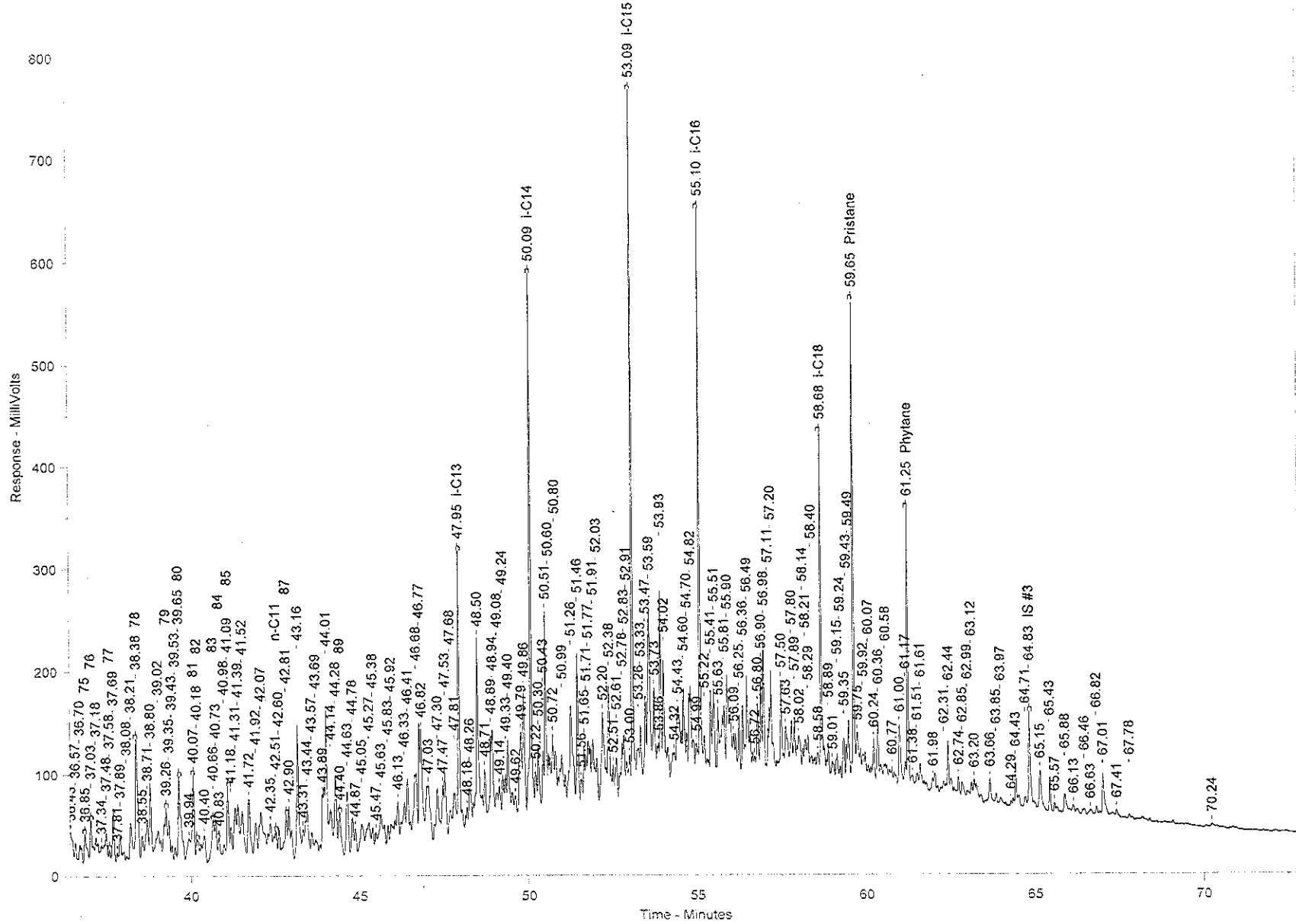
43576-2 [PZ-11.5] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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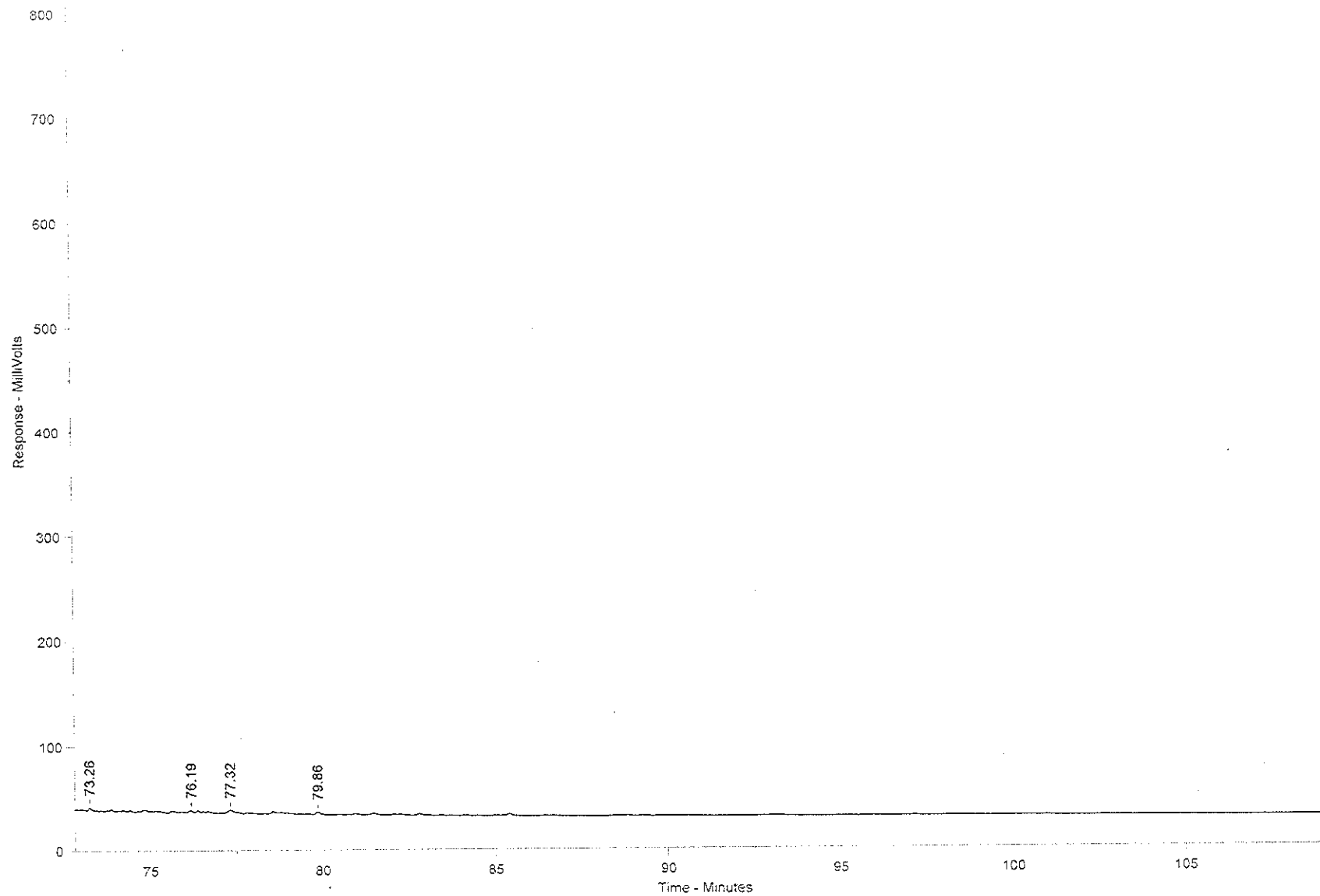
43576-2 [PZ-11.5] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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43576-2 [PZ-11.5] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

Sample Name = 43576-2 [PZ-11.5] [600+400CS2] + IS F-090913-1

Instrument = Instrument 1
 Heading 1 =
 Heading 2 =

Acquisition Port = DP#

Raw File Name = C:\CPSpirit\2014\May14\050514.0007.RAW
 Method File Name = C:\CPSpirit\C344.met
 Calibration File Name = C:\CPSpirit\2014\May14\050514.0007.BND

Date Taken (end) = 5/7/2014 4:44:28 PM
 Method Version = 44
 Calibration Version = 10

Peak Name	Ret. Time	Area %	Area
8	7.03	0.0423	31500.19
CS2	8.35	0.2086	155333.50
17	9.52	0.0872	64904.71
18	9.68	0.1119	83301.01
19	10.31	0.1033	76920.90
25	12.45	0.0251	18721.64
27	12.80	0.1408	104840.50
29	14.35	0.0308	22910.27
31	15.17	0.0377	28094.04
32	15.28	0.5853	435858.50
	15.46	0.1432	106647.80
33	15.75	0.0891	66387.38
	16.18	0.2523	187865.10
34A	16.36	0.2258	168141.60
	16.44	0.1766	131529.10
34B	16.55	0.1659	123528.20
35	16.65	0.1738	129416.50
IS #1	17.21	0.6311	469968.20
	18.74	0.0291	21645.39
	19.02	0.7179	534668.50
38	19.69	0.1799	133980.50
39	19.83	0.2044	152260.80
	20.23	1.2914	961766.80
	20.74	0.7309	544311.80
40	20.94	0.2264	168635.30
41A	21.24	0.1104	82196.69
	21.70	0.2019	150352.20
42	21.78	0.3613	269102.20
	22.12	0.0215	15997.37
44	22.35	0.1489	110883.30
	22.55	0.1413	105219.80
46B	22.74	0.3936	293143.60
46A	22.83	0.4447	331215.00
	23.31	0.2575	191778.60
	23.54	0.2911	216804.90
	23.69	0.2318	172626.20
48	23.78	0.4011	298728.30
	23.93	0.0674	50171.17
	24.14	0.3925	292307.10
49	24.56	1.0409	775176.30
50	25.11	0.2502	186307.80
	25.35	0.0318	23685.64
	25.51	0.1243	92591.61
	25.80	0.1329	98961.48
	26.10	0.1153	85832.52
51	26.22	0.2736	203759.60
	26.37	0.0989	73688.14
52	26.54	1.0494	781509.40
	26.75	0.2112	157302.30
53	26.92	1.8768	1397726.00
	27.08	0.2439	181662.50
	27.21	0.1860	138529.60
	27.30	0.2751	204876.80
	27.39	0.2300	171278.10
	27.67	0.2362	175870.00

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
54	27.76	0.7614	567009.70
	27.92	0.5879	437860.80
	28.04	0.0592	44056.15
	28.15	0.0339	25280.88
55	28.32	0.6726	500873.80
	28.62	0.0560	41683.93
	28.72	0.2581	192244.50
	28.81	0.1435	106901.30
56	29.19	0.4987	371387.30
58	29.40	0.2655	197735.20
59	29.54	0.2618	194944.60
	29.69	0.1709	127308.70
61	29.84	0.2837	211258.00
	30.11	0.5466	407094.90
	30.20	0.4051	301725.80
	30.36	0.3029	225580.50
	30.49	0.1263	94073.77
	30.58	0.1547	115238.80
62	31.05	0.1428	106322.60
	31.18	0.8121	604793.30
I.S. #2	31.41	0.4734	352571.50
	31.58	0.1113	82858.43
63	31.82	0.0549	40852.20
	31.96	0.0771	57399.41
64	32.09	0.8527	635045.80
	32.32	0.1169	87072.99
	32.41	0.0501	37296.62
	32.49	0.1526	113666.20
	32.73	0.1974	147017.10
	32.82	0.5497	409352.00
65	32.93	0.2363	175956.40
	33.23	0.8510	633785.90
	33.32	0.1970	146729.80
	33.41	0.1229	91509.68
	33.51	0.1557	115979.00
66	33.68	0.8044	599049.40
	33.84	0.0654	48741.93
	33.91	0.0837	62357.44
68	34.25	0.2540	189171.60
69	34.52	0.9384	698863.90
70	34.72	0.3359	250154.40
	34.84	0.3316	246924.10
72	35.13	0.2724	202859.70
	35.22	0.1586	118150.60
	35.51	0.8444	628831.80
	35.68	0.3315	246917.00
	35.90	0.1636	121873.00
	36.06	0.4535	337737.30
	73	36.15	0.3392
75	36.24	0.4416	328870.50
	36.43	0.2740	204030.60
	36.57	0.1372	102153.40
	36.70	0.1720	128090.40
	36.85	0.2545	189502.00
	37.03	0.2470	183984.90
	76	37.18	0.1349
77	37.34	0.1321	98359.62
	37.48	0.1595	118777.90
	37.58	0.0772	57489.66
	37.69	0.2997	223201.70
	37.81	0.0573	42666.30
78	37.89	0.1710	127352.50
	38.08	0.0534	39788.26
	38.21	0.2894	215530.00
	38.38	0.8758	652206.50
	38.55	0.1809	134712.70
	38.71	0.3316	246919.40

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	38.80	0.4185	311649.80
	39.02	0.3752	279396.70
79	39.26	0.4825	359305.40
	39.35	0.2037	151672.40
	39.43	0.0821	61176.02
	39.53	0.0792	58992.78
80	39.65	0.6836	509099.80
	39.94	0.2054	152994.80
81	40.07	0.5056	376559.90
82	40.18	0.1789	133225.10
	40.40	0.2701	201161.20
83	40.66	0.3080	229401.00
	40.73	0.2006	149358.90
84	40.83	0.1359	101201.90
	40.98	0.0944	70271.75
85	41.09	0.3393	252701.90
	41.18	0.1469	109399.00
	41.31	0.3292	245151.40
	41.39	0.3034	225968.70
	41.52	0.3638	270924.50
	41.72	0.3692	274975.00
	41.92	0.2029	151078.90
	42.07	0.4864	362271.60
	42.35	0.2602	193789.90
n-C11	42.51	0.0919	68422.46
	42.60	0.0867	64561.36
87	42.81	0.1349	100438.20
	42.90	0.1328	98893.88
	43.16	0.7440	554074.90
	43.31	0.1489	110893.80
	43.44	0.4156	309513.30
	43.57	0.1560	116174.60
	43.69	0.1484	110551.50
	43.89	0.2444	181986.10
	44.01	0.7214	537218.90
	44.14	0.3725	277396.90
	44.28	0.4837	360247.50
89	44.40	0.2905	216363.90
	44.63	0.3942	293568.50
	44.78	0.1905	141842.50
	44.87	0.1112	82784.34
	45.05	0.2615	194753.60
	45.27	0.3069	228563.50
	45.38	0.1154	85969.84
	45.47	0.0844	62868.72
	45.63	0.3135	233501.70
	45.83	0.1058	78822.71
	45.92	0.1956	145641.30
	46.13	0.2691	200405.20
	46.33	0.3967	295426.50
	46.41	0.4522	336774.40
	46.68	0.6807	506953.70
	46.77	0.4496	334827.20
	46.82	0.6082	452962.00
	47.03	0.6573	489548.30
	47.30	0.4387	326728.20
	47.47	0.2643	196815.20
	47.53	0.3349	249420.80
	47.68	0.1826	135981.90
	47.81	0.3535	263275.30
i-C13	47.95	1.3151	979428.30
	48.18	0.1484	110491.00
	48.26	0.2997	223174.00
	48.50	1.4301	1065052.00
	48.71	0.3044	226714.70
	48.89	0.4434	330216.80
	48.94	0.4620	344072.60

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	49.08	0.2243	167030.00
	49.14	0.1948	145077.70
	49.24	0.2437	181463.60
	49.33	0.2363	175948.30
	49.40	0.4598	342428.20
	49.62	0.1480	110251.30
	49.79	0.6540	487094.60
	49.86	0.6420	478083.80
i-C14	50.09	2.2786	1696988.00
	50.22	0.2194	163380.00
	50.30	0.3433	255643.10
	50.43	0.2876	214151.00
	50.51	0.8551	636813.10
	50.60	0.3987	296910.60
	50.72	0.4214	313868.90
	50.80	0.4515	336273.60
	50.99	0.4804	357764.50
	51.26	0.9535	710091.40
	51.46	0.6811	507209.50
	51.56	0.1426	106200.40
	51.65	0.2059	153378.10
	51.71	0.1885	140390.90
	51.77	0.4813	358419.70
	51.91	0.4689	349197.70
	52.03	0.1856	138238.60
	52.20	0.7618	567342.20
	52.38	0.6597	491323.10
	52.51	0.1255	93433.49
	52.61	0.2044	152205.60
	52.78	0.3224	240075.00
	52.83	0.2411	179562.80
	52.91	0.1429	106441.90
	53.00	0.1872	139397.90
i-C15	53.09	2.3408	1743269.00
	53.26	0.3167	235830.20
	53.33	0.2629	195781.80
	53.47	0.4226	314735.10
	53.59	1.1586	862860.40
	53.73	0.5588	416150.90
	53.86	0.2317	172543.40
	53.93	0.6537	486836.60
	54.02	0.5841	435011.10
	54.32	0.2284	170107.90
	54.43	0.7374	549205.40
	54.60	0.3816	284221.70
	54.70	0.1287	95813.76
	54.82	0.5495	409201.70
	54.99	0.1469	109422.10
i-C16	55.10	1.7284	1287167.00
	55.22	0.1052	78312.54
	55.41	0.2536	188865.70
	55.51	0.3769	280704.40
	55.63	0.2224	165640.70
	55.81	0.5436	404817.60
	55.90	0.7867	585875.40
	56.09	0.2856	212714.30
	56.25	0.2024	150752.80
	56.36	0.2274	169325.50
	56.49	0.5593	416520.40
	56.72	0.0455	33916.66
	56.80	0.2661	198153.50
	56.90	0.3440	256226.30
	56.98	0.4458	332040.30
	57.11	0.1116	83093.04
	57.20	0.5731	426829.10
	57.50	0.3740	278563.80
	57.63	0.2694	200656.80

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	57.80	0.2045	152265.90
	57.89	0.1938	144357.00
	58.02	0.1850	137794.60
	58.14	0.0494	36773.05
	58.21	0.1316	97999.70
	58.29	0.1250	93106.13
	58.40	0.0384	28626.67
	58.58	0.0687	51147.53
i-C18	58.68	1.2354	920072.30
	58.89	0.1191	88694.44
	59.01	0.0803	59816.17
	59.15	0.1113	82861.19
	59.24	0.0426	31719.17
	59.35	0.1857	138268.30
	59.43	0.0991	73794.77
	59.49	0.2024	150749.20
Pristane	59.65	1.4709	1095430.00
	59.75	0.1441	107341.50
	59.92	0.0348	25942.49
	60.07	0.0254	18944.97
	60.24	0.1554	115709.10
	60.36	0.2345	174607.70
	60.58	0.1326	98789.25
	60.77	0.0317	23586.88
	61.00	0.3228	240367.90
	61.17	0.1011	75271.16
Phytane	61.25	0.8974	668331.20
	61.38	0.0645	48068.13
	61.51	0.0552	41120.67
	61.61	0.1123	83645.09
	61.98	0.0248	18492.86
	62.31	0.0606	45142.54
	62.44	0.1412	105130.60
	62.74	0.0516	38399.59
	62.85	0.0743	55333.54
	62.99	0.0347	25837.73
	63.12	0.0610	45430.97
	63.20	0.1388	103355.00
	63.66	0.1069	79647.13
	63.85	0.0323	24040.19
	63.97	0.0341	25401.48
	64.29	0.0135	10035.44
	64.43	0.1059	78869.87
	64.71	0.0553	41150.96
IS #3	64.83	0.4968	369957.20
	65.15	0.2520	187672.90
	65.43	0.1183	88102.74
	65.57	0.0262	19527.84
	65.88	0.1236	92037.07
	66.13	0.0341	25370.86
	66.46	0.0453	33710.81
	66.63	0.0500	37212.15
	66.82	0.0481	35829.66
	67.01	0.2660	198086.70
	67.41	0.0449	33428.59
	67.78	0.0156	11651.48
	70.24	0.0144	10753.73
	73.26	0.0225	16779.11
	76.19	0.0207	15438.62
	77.32	0.0613	45621.98
	79.86	0.0288	21430.04

Total Area = 7.447366E+07

Total Height = 1.906022E+07

Total Amount = 2

5/5/2014

ZymaX ID 43576-3
Sample ID PZ-10.5

Evaporation

n-Pentane / n-Heptane 0.00
2-Methylpentane / 2-Methylheptane 2.82

Waterwashing

Benzene / Cyclohexane 0.00
Toluene / Methylcyclohexane 0.00
Aromatics / Total Paraffins (n+iso+cyc) 0.83
Aromatics / Naphthenes 5.66

Biodegradation

(C4 - C8 Para + Isopara) / C4 - C8 Olefins 156.92
3-Methylhexane / n-Heptane 0.00
Methylcyclohexane / n-Heptane 0.00
Isoparaffins + Naphthenes / Paraffins 5.82

Octane rating

2,2,4,-Trimethylpentane / Methylcyclohexane 0.00

Relative percentages - Bulk hydrocarbon composition as PIANO

% Paraffinic 7.85
% Isoparaffinic 37.84
% Aromatic 44.69
% Naphthenic 7.90
% Olefinic 1.72

Submitted by,
Zymax Forensics, a DPRA Company



Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

5/5/2014

ZymaX ID		43576-3
Sample ID		PZ-10.5
		Relative Area %
1	Propane	0.00
2	Isobutane	0.00
3	Isobutene	0.00
4	Butane/Methanol	0.00
5	trans-2-Butene	0.00
6	cis-2-Butene	0.00
7	3-Methyl-1-butene	0.00
8	Isopentane	0.18
9	1-Pentene	0.00
10	2-Methyl-1-butene	0.00
11	Pentane	0.06
12	trans-2-Pentene	0.00
13	cis-2-Pentene/t-Butanol	0.00
14	2-Methyl-2-butene	0.00
15	2,2-Dimethylbutane	0.00
16	Cyclopentane	0.00
17	2,3-Dimethylbutane/MTBE	0.31
18	2-Methylpentane	0.21
19	3-Methylpentane	0.18
20	Hexane	0.00
21	trans-2-Hexene	0.00
22	3-Methylcyclopentene	0.00
23	3-Methyl-2-pentene	0.00
24	cis-2-Hexene	0.00
25	3-Methyl-trans-2-pentene	0.13
26	Methylcyclopentane	0.20
27	2,4-Dimethylpentane	0.47
28	Benzene	0.00
29	5-Methyl-1-hexene	0.15
30	Cyclohexane	0.00
31	2-Methylhexane/TAME	0.00
32	2,3-Dimethylpentane	2.18
33	3-Methylhexane	0.00
34A	1-trans-3-Dimethylcyclopentane	0.70
34B	1-cis-3-Dimethylcyclopentane	0.26
35	2,2,4-Trimethylpentane	0.24
I.S. #1	à,à,à-Trifluorotoluene	0.00

5/5/2014

ZymaX ID		43576-3
Sample ID		PZ-10.5
		Relative
		Area %
36	n-Heptane	0.00
37	Methylcyclohexane	0.00
38	2,5-Dimethylhexane	0.74
39	2,4-Dimethylhexane	0.82
40	2,3,4-Trimethylpentane	0.71
41	Toluene/2,3,3-Trimethylpentane	0.21
42	2,3-Dimethylhexane	1.48
43	2-Methylheptane	0.08
44	4-Methylheptane	0.00
45	3,4-Dimethylhexane	0.69
46A	3-Ethyl-3-methylpentane	1.71
46B	1,4-Dimethylcyclohexane	1.80
47	3-Methylheptane	0.00
48	2,2,5-Trimethylhexane	1.19
49	n-Octane	5.00
50	2,2-Dimethylheptane	1.23
51	2,4-Dimethylheptane	1.35
52	Ethylcyclohexane	4.95
53	2,6-Dimethylheptane	8.44
54	Ethylbenzene	3.70
55	m+p Xylenes	3.35
56	4-Methyloctane	0.67
57	2-Methyloctane	0.00
58	3-Ethylheptane	0.61
59	3-Methyloctane	1.24
60	o-Xylene	0.00
61	1-Nonene	1.45
62	n-Nonane	0.80
I.S.#2	p-Bromofluorobenzene	0.00
63	Isopropylbenzene	0.27
64	3,3,5-Trimethylheptane	5.92
65	2,4,5-Trimethylheptane	4.72
66	n-Propylbenzene	4.64
67	1-Methyl-3-ethylbenzene	0.00
68	1-Methyl-4-ethylbenzene	1.61
69	1,3,5-Trimethylbenzene	4.52
70	3,3,4-Trimethylheptane	1.90

5/5/2014

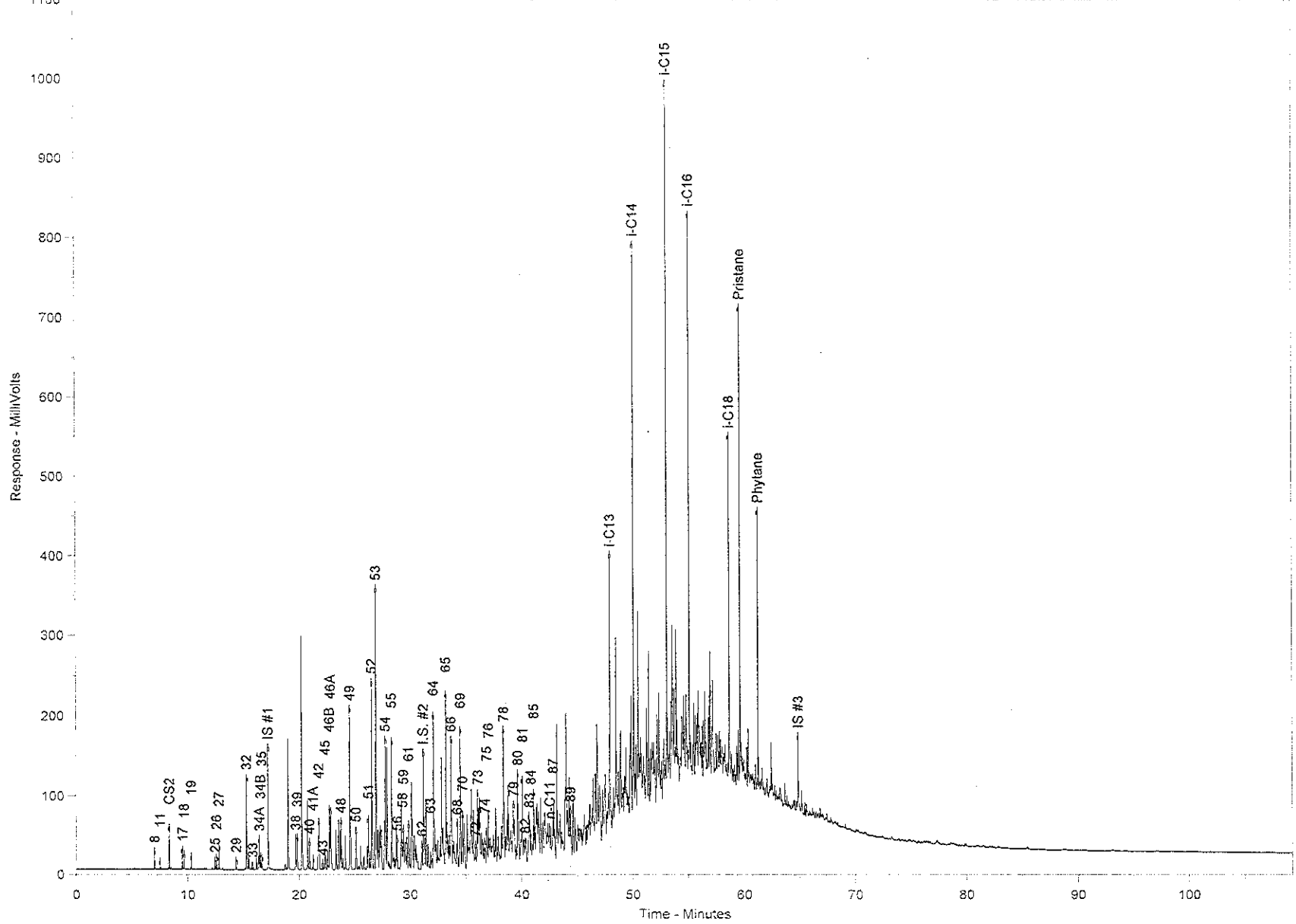
ZymaX ID
Sample ID43576-3
PZ-10.5

		Relative Area %
71	1-Methyl-2-ethylbenzene	0.00
72	3-Methylnonane	0.56
73	1,2,4-Trimethylbenzene	2.55
74	Isobutylbenzene	0.95
75	sec-Butylbenzene	1.49
76	n-Decane	2.00
77	1,2,3-Trimethylbenzene	0.00
78	Indan	5.40
79	1,3-Diethylbenzene	1.73
80	1,4-Diethylbenzene	4.09
81	n-Butylbenzene	2.83
82	1,3-Dimethyl-5-ethylbenzene	0.45
83	1,4-Dimethyl-2-ethylbenzene	1.89
84	1,3-Dimethyl-4-ethylbenzene	0.83
85	1,2-Dimethyl-4-ethylbenzene	1.76
86	Undecene	0.00
87	1,2,4,5-Tetramethylbenzene	0.69
88	1,2,3,5-Tetramethylbenzene	0.00
89	1,2,3,4-Tetramethylbenzene	1.71
90	Naphthalene	0.00
91	2-Methyl-naphthalene	0.00
92	1-Methyl-naphthalene	0.00

Chrom Perfect Chromatogram Report

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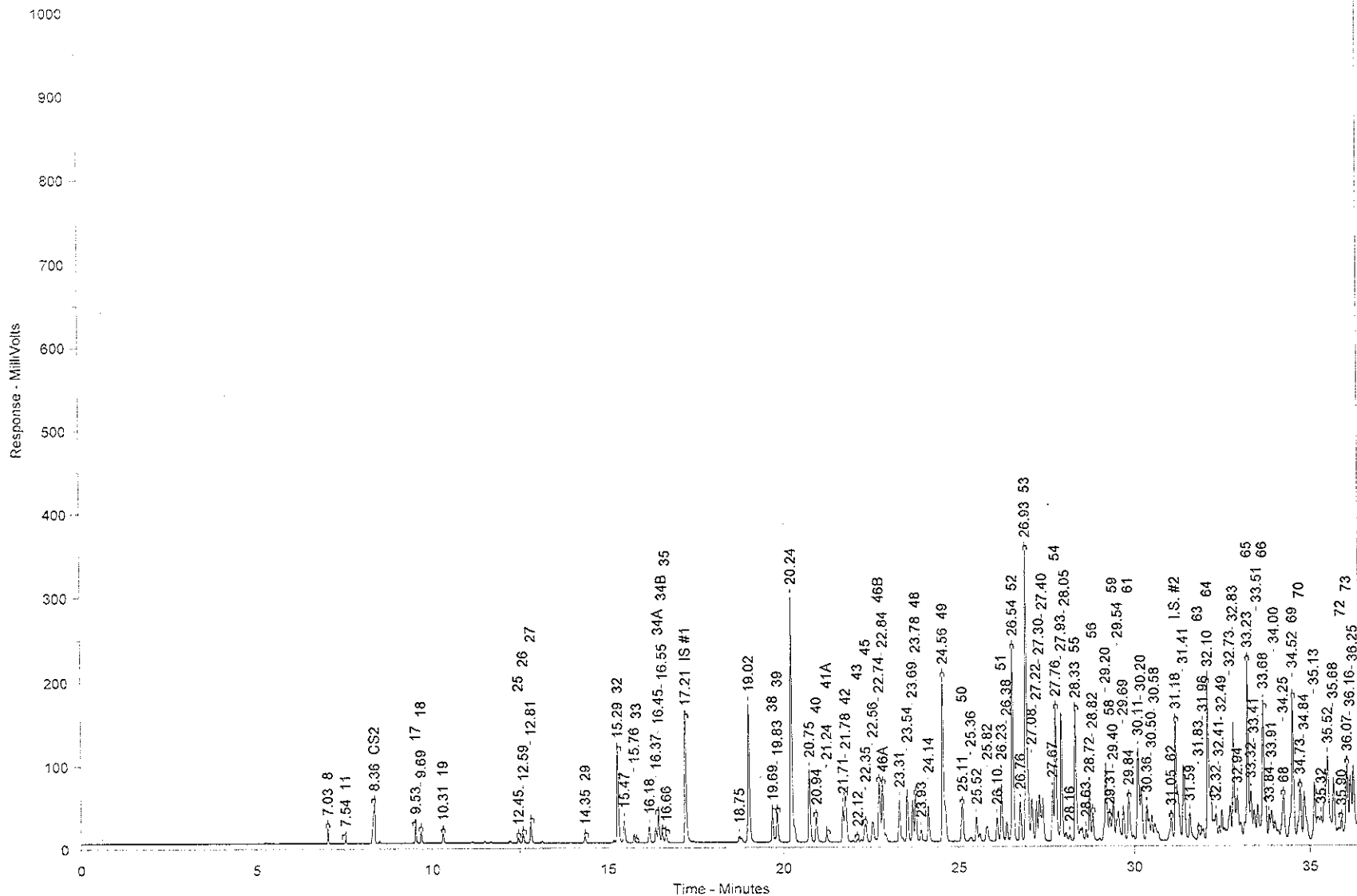
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Chrom Perfect Chromatogram Report

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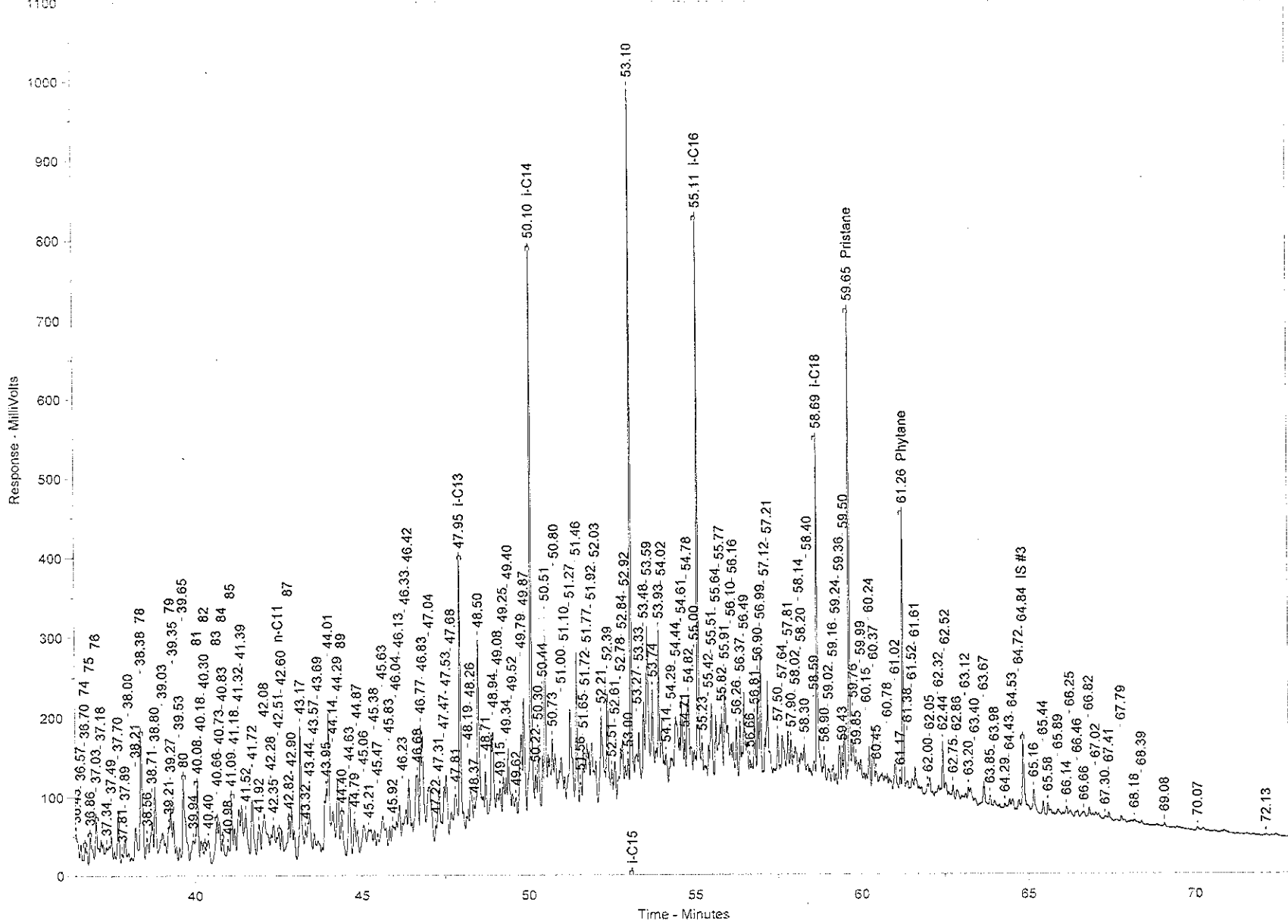
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Chrom Perfect Chromatogram Report

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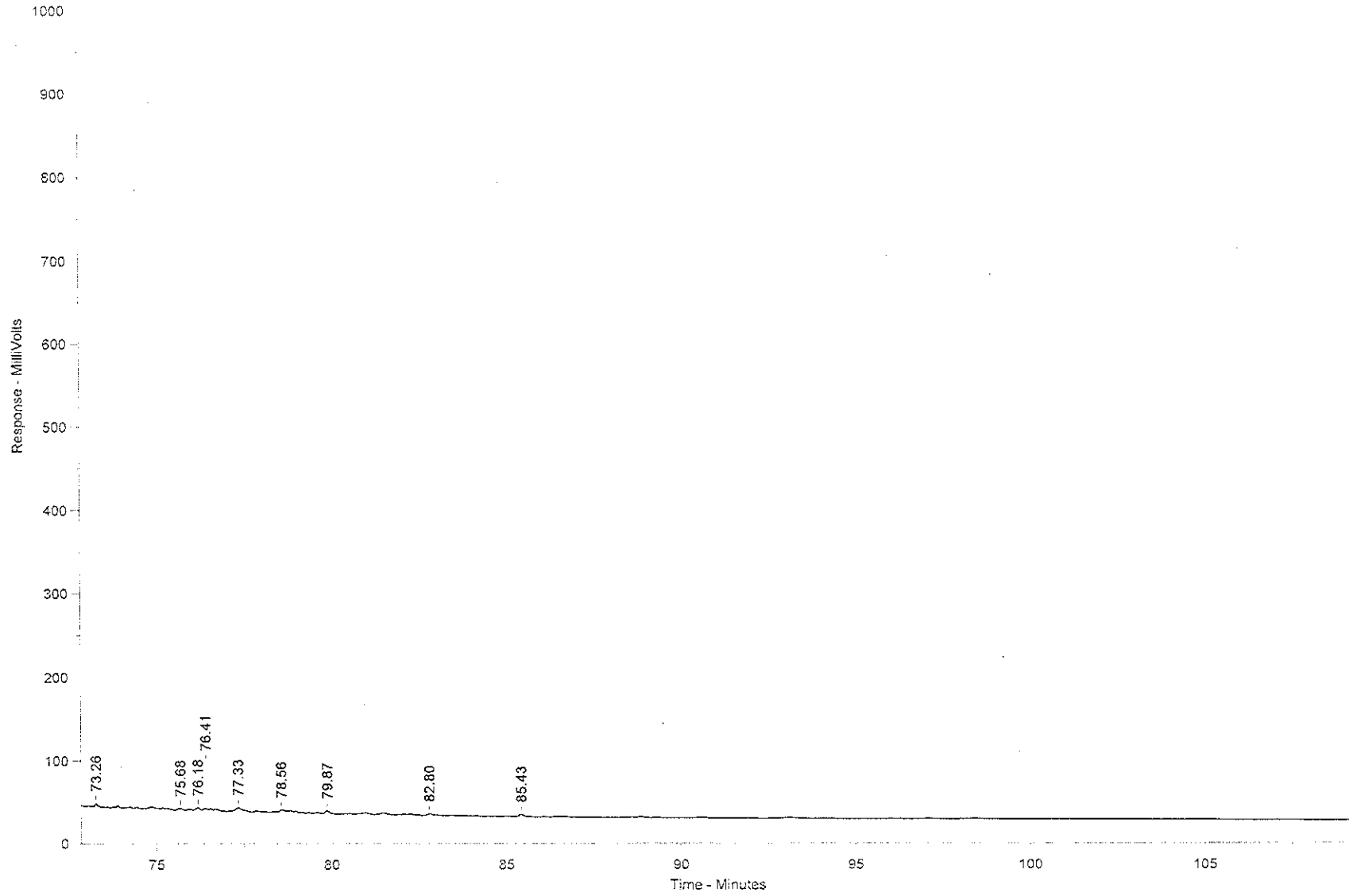
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Chrom Perfect Chromatogram Report

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43576-3 [PZ-10.5] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

Sample Name = 43576-3 [PZ-10.5] [600+400CS2] + IS F-090913-1

Instrument = Instrument 1

Acquisition Port = DP#

Heading 1 =

Heading 2 =

Raw File Name = C:\CPSpirit\2014\May14\050514.0008.RAW

Date Taken (end) = 5/7/2014 6:50:58 PM

Method File Name = C:\CPSpirit\C344.met

Method Version = 44

Calibration File Name = C:\CPSpirit\2014\May14\050514.0008.BND

Calibration Version = 10

Peak Name	Ret. Time	Area %	Area
8	7.03	0.0321	28862.60
11	7.54	0.0099	8855.90
CS2	8.36	0.2044	183592.30
17	9.53	0.0542	48708.67
18	9.69	0.0380	34147.63
19	10.31	0.0327	29377.79
25	12.45	0.0226	20343.87
26	12.59	0.0345	30974.20
27	12.81	0.0832	74729.82
29	14.35	0.0257	23062.14
32	15.29	0.3852	346006.20
	15.47	0.0979	87925.57
	15.76	0.0363	32636.02
	16.18	0.0690	62002.57
	16.37	0.0603	54166.59
34A	16.45	0.1230	110497.50
34B	16.55	0.0455	40872.96
35	16.66	0.0419	37615.96
IS #1	17.21	0.5271	473470.40
	18.75	0.0456	40958.62
	19.02	0.6335	569112.40
38	19.69	0.1308	117509.40
39	19.83	0.1447	129990.90
	20.24	1.1190	1005265.00
	20.75	0.3237	290743.30
40	20.94	0.1261	113317.30
41A	21.24	0.0376	33743.51
	21.71	0.1484	133268.10
42	21.78	0.2622	235556.20
43	22.12	0.0135	12107.00
45	22.35	0.1216	109231.40
	22.56	0.1310	117641.70
46B	22.74	0.3186	286175.30
46A	22.84	0.3018	271106.40
	23.31	0.2082	186996.20
	23.54	0.2260	203060.80
	23.69	0.1769	158939.00
48	23.78	0.2107	189311.20
	23.93	0.0570	51240.64
	24.14	0.1631	146561.00
49	24.56	0.8843	794342.90
50	25.11	0.2170	194958.90
	25.36	0.0262	23538.59
	25.52	0.0908	81585.02
	25.82	0.1031	92581.61
	26.10	0.1058	95068.65
51	26.23	0.2387	214416.40
	26.38	0.0881	79157.57
52	26.54	0.8751	786080.40
	26.76	0.1867	167726.60
53	26.93	1.4923	1340595.00
	27.08	0.2232	200545.50
	27.22	0.1692	152032.50
	27.30	0.2520	226335.30
	27.40	0.2049	184047.70

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	27.67	0.2188	196523.90
54	27.76	0.6548	588209.10
	27.93	0.5503	494373.20
	28.05	0.0436	39160.62
	28.16	0.0284	25547.81
55	28.33	0.5923	532069.60
	28.63	0.0444	39923.11
	28.72	0.2237	200964.40
56	28.82	0.1178	105779.20
	29.20	0.4608	413902.80
58	29.31	0.1087	97688.96
59	29.40	0.2193	196958.80
	29.54	0.2402	215752.50
	29.69	0.1595	143243.70
61	29.84	0.2561	230045.50
	30.11	0.5080	456354.50
	30.20	0.2689	241523.00
	30.36	0.2453	220392.80
	30.50	0.1142	102604.80
	30.58	0.1447	129971.40
62	31.05	0.1413	126922.70
I.S. #2	31.18	0.7898	709523.20
	31.41	0.4342	390061.80
	31.59	0.1457	130855.60
63	31.83	0.0482	43326.70
	31.96	0.0729	65512.63
64	32.10	1.0466	940166.90
	32.32	0.0918	82465.98
	32.41	0.0233	20973.99
	32.49	0.0742	66621.37
	32.73	0.1218	109378.60
	32.83	0.4507	404900.00
	32.94	0.1506	135330.40
65	33.23	0.8343	749448.50
	33.32	0.2001	179764.20
	33.41	0.1317	118313.10
	33.51	0.1708	153456.50
66	33.68	0.8205	737043.90
	33.84	0.0912	81961.59
	33.91	0.1312	117896.10
	34.00	0.0863	77483.55
68	34.25	0.2839	255020.50
69	34.52	0.7990	717779.30
70	34.73	0.3359	301744.20
	34.84	0.3372	302893.30
	35.13	0.2850	255986.50
	35.32	0.1288	115712.60
	35.52	0.8584	771146.40
	35.68	0.3397	305158.50
72	35.90	0.0988	88730.74
73	36.07	0.4500	404270.70
	36.16	0.3449	309864.00
	36.25	0.4562	409807.30
	36.43	0.2872	258017.50
	36.57	0.1464	131508.10
74	36.70	0.1681	151045.00
75	36.86	0.2634	236583.90
76	37.03	0.3527	316868.80
	37.18	0.2496	224220.60
	37.34	0.1348	121130.40
	37.49	0.1636	146959.50
	37.70	0.3190	286555.70
	37.81	0.0599	53784.04
	37.89	0.1817	163236.10
	38.00	0.0828	74418.21
	38.21	0.2886	259251.30
78	38.38	0.9541	857114.00

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	38.56	0.1896	170337.90
	38.71	0.3505	314864.70
	38.80	0.4364	392001.30
	39.03	0.5019	450836.60
	39.21	0.2013	180825.80
79	39.27	0.3066	275451.90
	39.35	0.2191	196783.90
	39.53	0.0891	80029.38
80	39.65	0.7238	650186.90
	39.94	0.2203	197913.40
81	40.08	0.5007	449756.20
	40.18	0.1702	152918.20
82	40.30	0.0803	72114.18
	40.40	0.1905	171126.80
83	40.66	0.3333	299423.00
	40.73	0.2117	190185.50
84	40.83	0.1468	131837.70
	40.98	0.0970	87172.59
85	41.09	0.3118	280078.80
	41.18	0.1599	143644.20
	41.32	0.3442	309200.90
	41.39	0.3298	296243.30
	41.52	0.3772	338823.30
	41.72	0.3960	355724.80
	41.92	0.2150	193155.20
	42.08	0.5200	467132.60
	42.28	0.0827	74325.57
	42.35	0.1953	175427.10
n-C11	42.51	0.1623	145802.20
	42.60	0.0927	83318.34
87	42.82	0.1227	110231.50
	42.90	0.1452	130401.40
	43.17	0.7927	712132.90
	43.32	0.1637	147081.70
	43.44	0.4253	382089.50
	43.57	0.1685	151352.80
	43.69	0.1559	140068.70
	43.95	0.5693	511440.30
	44.01	0.7439	668300.30
	44.14	0.3959	355613.60
	44.29	0.5124	460297.70
89	44.40	0.3019	271186.60
	44.63	0.4079	366415.40
	44.79	0.2062	185249.90
	44.87	0.1189	106789.80
	45.06	0.2789	250565.20
	45.21	0.1647	147925.10
	45.38	0.1131	101626.50
	45.47	0.0908	81534.15
	45.63	0.3414	306717.50
	45.83	0.1133	101789.70
	45.92	0.2120	190441.20
	46.04	0.1226	110167.80
	46.13	0.2731	245348.50
	46.23	0.1227	110252.60
	46.33	0.2711	243544.80
	46.42	0.4894	439658.30
	46.68	0.7144	641780.40
	46.77	0.4925	442424.70
	46.83	0.6327	568362.10
	47.04	0.6996	628492.90
	47.22	0.0625	56113.09
	47.31	0.4011	360358.20
	47.47	0.2854	256374.50
	47.53	0.3628	325924.10
	47.68	0.1914	171956.80
	47.81	0.3878	348336.70

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
i-C13	47.95	1.3697	1230463.00
	48.19	0.1584	142302.30
	48.26	0.3168	284608.50
	48.37	0.1187	106671.60
	48.50	1.4147	1270851.00
	48.71	0.3200	287454.90
	48.94	0.9731	874119.10
	49.08	0.2444	219575.60
	49.15	0.2143	192516.10
	49.25	0.2663	239234.20
	49.34	0.2411	216586.90
	49.40	0.4620	415003.50
	49.52	0.1827	164122.50
	49.62	0.1549	139151.40
	49.79	0.6922	621776.40
	49.87	0.6895	619378.40
	i-C14	50.10	2.5508
50.22		0.2333	209543.30
50.30		0.3644	327379.50
50.44		0.2947	264739.80
50.51		1.3526	1215047.00
50.73		0.4437	398616.80
50.80		0.4703	422440.30
51.00		0.5398	484946.50
51.10		0.1513	135886.50
51.27		1.0042	902069.10
51.46		0.7302	655944.10
51.56		0.1489	133758.10
51.65		0.2169	194833.30
51.72		0.2121	190507.80
51.77		0.4906	440723.20
51.92		0.4991	448357.10
52.03		0.1906	171221.80
52.21		0.7971	716066.80
52.39		0.6755	606791.60
52.51		0.1312	117894.60
52.61		0.2072	186142.90
52.78		0.3367	302456.60
52.84		0.2447	219792.80
52.92	0.1431	128538.70	
i-C15	53.00	0.2018	181243.20
	53.10	2.5453	2286468.00
	53.27	0.3139	282001.20
	53.33	0.2763	248248.30
	53.48	0.4428	397786.80
	53.59	1.1462	1029645.00
	53.74	0.5983	537496.10
	53.93	0.5725	514269.70
	54.02	0.4120	370121.40
	54.14	0.1472	132204.90
	54.29	0.2435	218777.00
	54.44	0.7418	666366.00
	54.61	0.3926	352670.30
i-C16	54.71	0.1322	118801.00
	54.78	0.2635	236676.50
	54.82	0.4527	406640.20
	55.00	0.1532	137603.90
	55.11	1.8456	1657964.00
	55.23	0.1129	101406.70
	55.42	0.1175	105565.10
	55.51	0.3894	349774.70
	55.64	0.2408	216272.80
55.77	0.3486	313126.80	
55.82	0.2496	224246.90	
55.91	0.5191	466278.50	
56.10	0.1720	154516.90	
56.16	0.1448	130077.30	

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	56.26	0.2101	188713.50
	56.37	0.3329	299065.20
	56.49	0.4205	377736.50
	56.66	0.1392	125084.70
	56.81	0.2914	261765.40
	56.90	0.3705	332832.30
	56.99	0.5069	455375.70
	57.12	0.1390	124873.60
	57.21	0.6737	605214.00
	57.50	0.3050	273970.20
	57.64	0.3555	319335.90
	57.81	0.2664	239275.40
	57.90	0.2181	195914.90
	58.02	0.3555	319360.70
	58.14	0.0957	85993.48
	58.20	0.1724	154849.00
	58.30	0.2123	190677.30
	58.40	0.2121	190503.40
	58.59	0.1473	132295.10
i-C18	58.69	1.4829	1332166.00
	58.90	0.1187	106598.20
	59.02	0.1168	104949.10
	59.16	0.1076	96669.60
	59.24	0.0448	40235.51
	59.36	0.2047	183903.50
	59.43	0.1107	99438.45
	59.50	0.2412	216689.00
Pristane	59.65	1.6577	1489121.00
	59.76	0.3053	274256.30
	59.85	0.1199	107678.10
	59.99	0.2468	221722.90
	60.15	0.0513	46106.55
	60.24	0.1775	159430.80
	60.37	0.2518	226206.30
	60.45	0.0680	61064.10
	60.78	0.0567	50907.62
	61.02	0.1713	153878.00
	61.17	0.0570	51234.82
Phytane	61.26	0.9365	841294.10
	61.38	0.0526	47236.50
	61.52	0.0540	48514.14
	61.61	0.1049	94275.55
	62.00	0.0633	56834.75
	62.05	0.1111	99787.28
	62.32	0.0901	80956.77
	62.44	0.2233	200572.60
	62.52	0.0959	86128.32
	62.75	0.0694	62354.38
	62.86	0.0627	56311.00
	63.12	0.0185	16660.55
	63.20	0.0290	26075.90
	63.40	0.0255	22897.68
	63.67	0.1040	93409.63
	63.85	0.0392	35195.43
	63.98	0.0311	27913.88
	64.29	0.0213	19177.30
	64.43	0.0529	47488.92
	64.53	0.0786	70598.97
	64.72	0.0674	60566.21
IS #3	64.84	0.4111	369265.90
	65.16	0.1719	154421.80
	65.44	0.0593	53273.04
	65.58	0.0358	32149.45
	65.89	0.0353	31743.44
	66.14	0.0453	40700.89
	66.25	0.0400	35901.84
	66.46	0.0502	45086.84

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	66.66	0.0449	40311.91
	66.82	0.0451	40517.11
	67.02	0.0178	16025.67
	67.30	0.0239	21455.03
	67.41	0.0459	41207.59
	67.79	0.0216	19379.13
	68.18	0.0215	19274.45
	68.39	0.0145	13009.73
	69.08	0.0154	13832.01
	70.07	0.0188	16911.74
	72.13	0.0118	10561.86
	73.26	0.0296	26556.28
	75.68	0.0226	20334.61
	76.18	0.0249	22334.80
	76.41	0.0165	14837.16
	77.33	0.0753	67613.97
	78.56	0.0200	17969.23
	79.87	0.0346	31078.12
	82.80	0.0304	27306.45
	85.43	0.0287	25750.19

Total Area = 8.983223E+07

Total Height = 2.260456E+07

Total Amount = 1

5/5/2014

ZymaX ID 43576-4
Sample ID PZ-6

Evaporation

n-Pentane / n-Heptane 0.00
2-Methylpentane / 2-Methylheptane 0.00

Waterwashing

Benzene / Cyclohexane 0.00
Toluene / Methylcyclohexane 0.00
Aromatics / Total Paraffins (n+iso+cyc) 1.28
Aromatics / Naphthenes 25.12

Biodegradation

(C4 - C8 Para + Isopara) / C4 - C8 Olefins 0.00
3-Methylhexane / n-Heptane 0.00
Methylcyclohexane / n-Heptane 0.00
Isoparaffins + Naphthenes / Paraffins 3.99

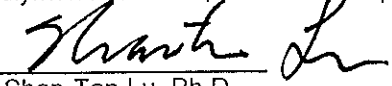
Octane rating

2,2,4,-Trimethylpentane / Methylcyclohexane 0.00

Relative percentages - Bulk hydrocarbon composition as PIANO

% Paraffinic 8.64
% Isoparaffinic 32.27
% Aromatic 55.27
% Naphthenic 2.20
% Olefinic 1.61

Submitted by,
Zymax Forensics, a DPRA Company


Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

5/5/2014

ZymaX ID		43576-4
Sample ID		PZ-6
		Relative Area %
1	Propane	0.00
2	Isobutane	0.00
3	Isobutene	0.00
4	Butane/Methanol	0.00
5	trans-2-Butene	0.00
6	cis-2-Butene	0.00
7	3-Methyl-1-butene	0.00
8	Isopentane	0.00
9	1-Pentene	0.00
10	2-Methyl-1-butene	0.00
11	Pentane	0.00
12	trans-2-Pentene	0.00
13	cis-2-Pentene/t-Butanol	0.00
14	2-Methyl-2-butene	0.00
15	2,2-Dimethylbutane	0.00
16	Cyclopentane	0.00
17	2,3-Dimethylbutane/MTBE	0.00
18	2-Methylpentane	0.00
19	3-Methylpentane	0.00
20	Hexane	0.00
21	trans-2-Hexene	0.00
22	3-Methylcyclopentene	0.00
23	3-Methyl-2-pentene	0.00
24	cis-2-Hexene	0.00
25	3-Methyl-trans-2-pentene	0.00
26	Methylcyclopentane	0.00
27	2,4-Dimethylpentane	0.00
28	Benzene	0.00
29	5-Methyl-1-hexene	0.00
30	Cyclohexane	0.00
31	2-Methylhexane/TAME	0.00
32	2,3-Dimethylpentane	0.50
33	3-Methylhexane	0.00
34A	1-trans-3-Dimethylcyclopentane	0.00
34B	1-cis-3-Dimethylcyclopentane	0.32
35	2,2,4-Trimethylpentane	1.34
I.S. #1	à,à,à-Trifluorotoluene	0.00

5/5/2014

ZymaX ID		43576-4
Sample ID		PZ-6
		Relative Area %
36	n-Heptane	0.00
37	Methylcyclohexane	0.00
38	2,5-Dimethylhexane	0.00
39	2,4-Dimethylhexane	0.52
40	2,3,4-Trimethylpentane	1.88
41	Toluene/2,3,3-Trimethylpentane	1.50
42	2,3-Dimethylhexane	1.05
43	2-Methylheptane	0.00
44	4-Methylheptane	0.00
45	3,4-Dimethylhexane	0.34
46A	3-Ethyl-3-methylpentane	2.78
46B	1,4-Dimethylcyclohexane	0.00
47	3-Methylheptane	0.52
48	2,2,5-Trimethylhexane	1.26
49	n-Octane	4.01
50	2,2-Dimethylheptane	0.80
51	2,4-Dimethylheptane	1.32
52	Ethylcyclohexane	1.88
53	2,6-Dimethylheptane	8.97
54	Ethylbenzene	3.04
55	m+p Xylenes	1.24
56	4-Methyloctane	0.47
57	2-Methyloctane	0.00
58	3-Ethylheptane	0.00
59	3-Methyloctane	2.00
60	o-Xylene	0.00
61	1-Nonene	1.61
62	n-Nonane	3.37
I.S.#2	p-Bromofluorobenzene	0.00
63	Isopropylbenzene	0.72
64	3,3,5-Trimethylheptane	2.89
65	2,4,5-Trimethylheptane	3.02
66	n-Propylbenzene	5.48
67	1-Methyl-3-ethylbenzene	0.00
68	1-Methyl-4-ethylbenzene	1.79
69	1,3,5-Trimethylbenzene	7.07
70	3,3,4-Trimethylheptane	1.23

5/5/2014

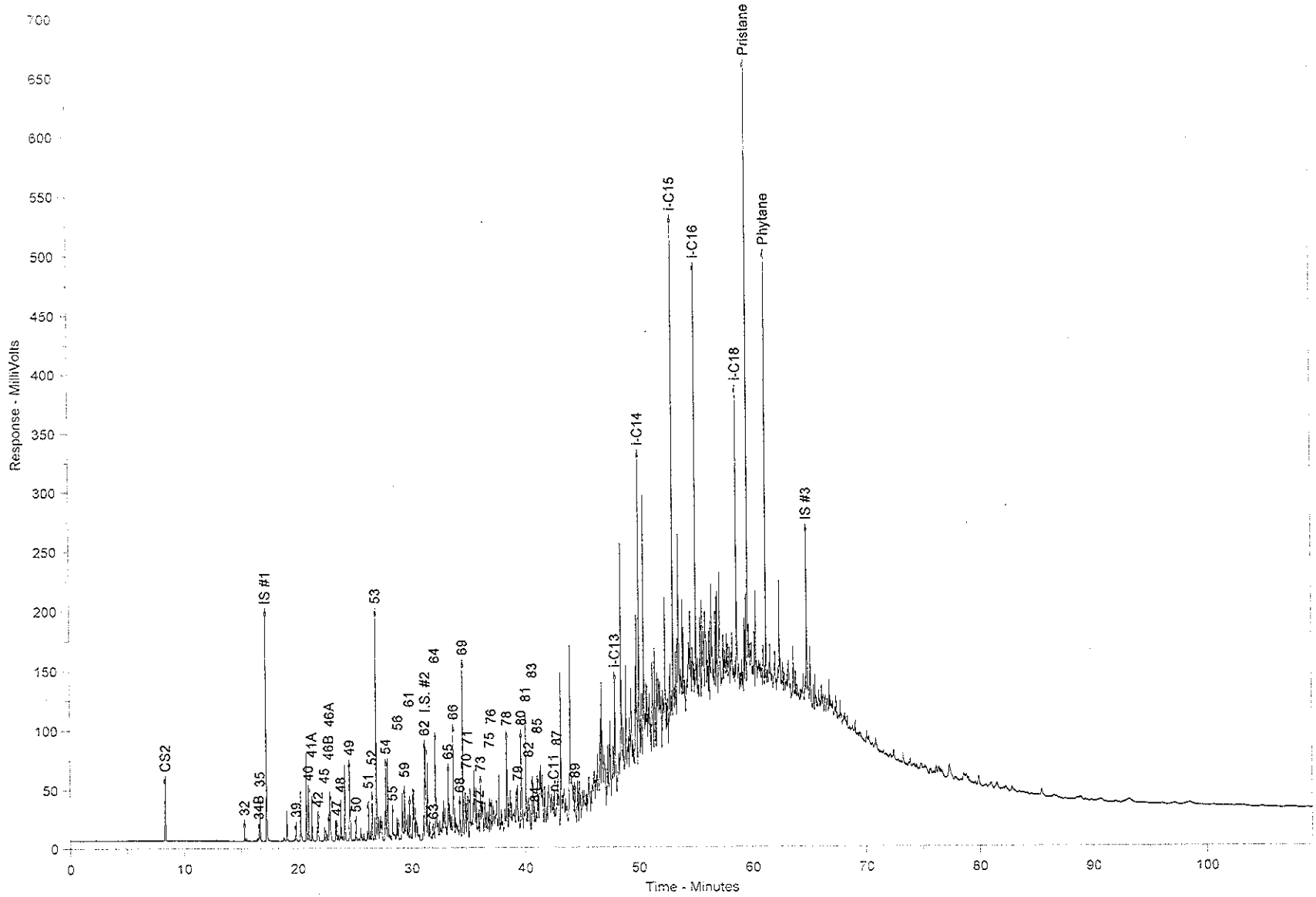
ZymaX ID
Sample ID43576-4
PZ-6

		Relative Area %
71	1-Methyl-2-ethylbenzene	1.63
72	3-Methylnonane	1.38
73	1,2,4-Trimethylbenzene	2.95
74	Isobutylbenzene	0.00
75	sec-Butylbenzene	1.72
76	n-Decane	1.26
77	1,2,3-Trimethylbenzene	0.00
78	Indan	6.36
79	1,3-Diethylbenzene	1.65
80	1,4-Diethylbenzene	5.98
81	n-Butylbenzene	4.85
82	1,3-Dimethyl-5-ethylbenzene	1.03
83	1,4-Dimethyl-2-ethylbenzene	2.84
84	1,3-Dimethyl-4-ethylbenzene	0.79
85	1,2-Dimethyl-4-ethylbenzene	1.81
86	Undecene	0.00
87	1,2,4,5-Tetramethylbenzene	0.70
88	1,2,3,5-Tetramethylbenzene	0.00
89	1,2,3,4-Tetramethylbenzene	2.12
90	Naphthalene	0.00
91	2-Methyl-naphthalene	0.00
92	1-Methyl-naphthalene	0.00

Chrom Perfect Chromatogram Report

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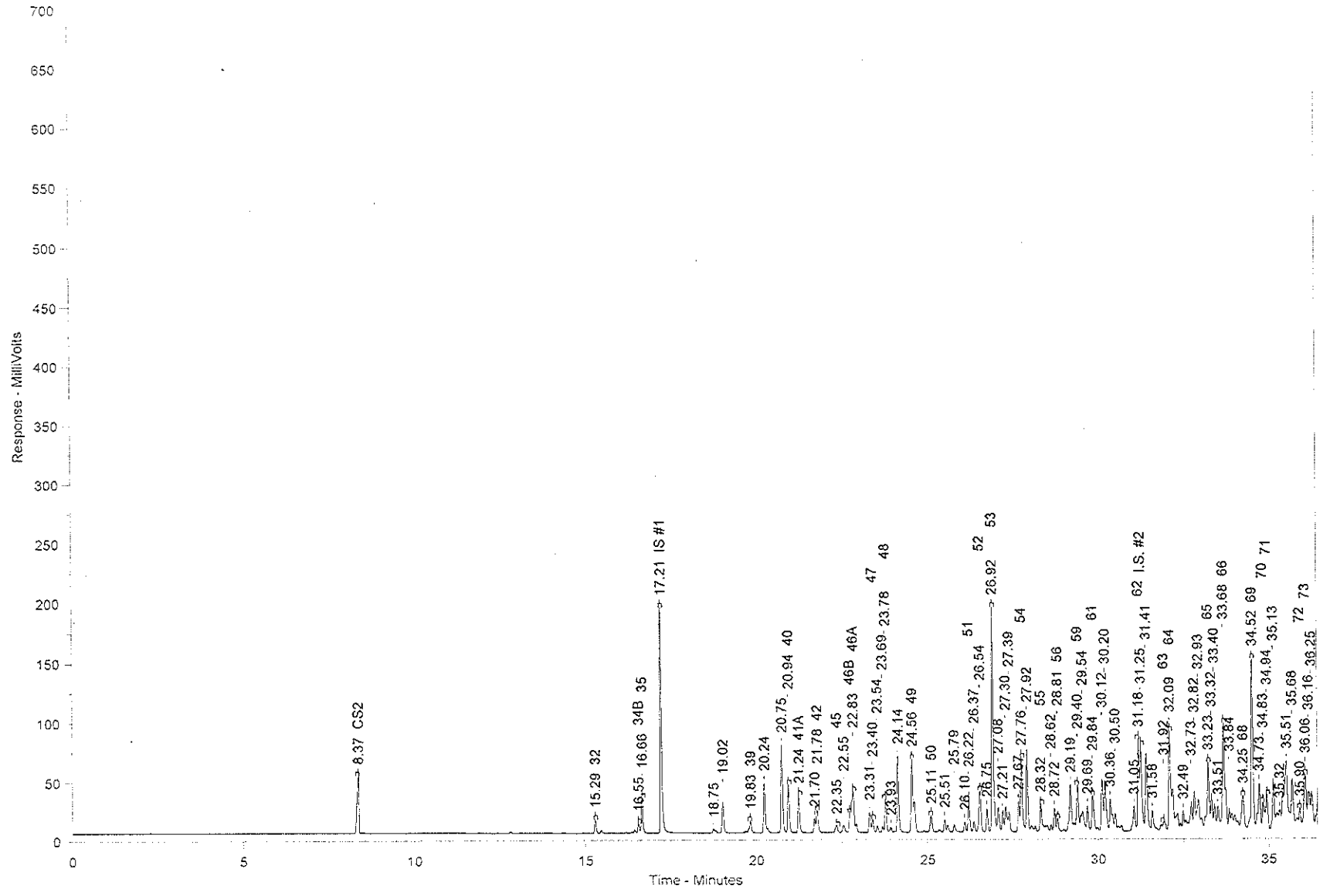
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Chrom Perfect Chromatogram Report

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750

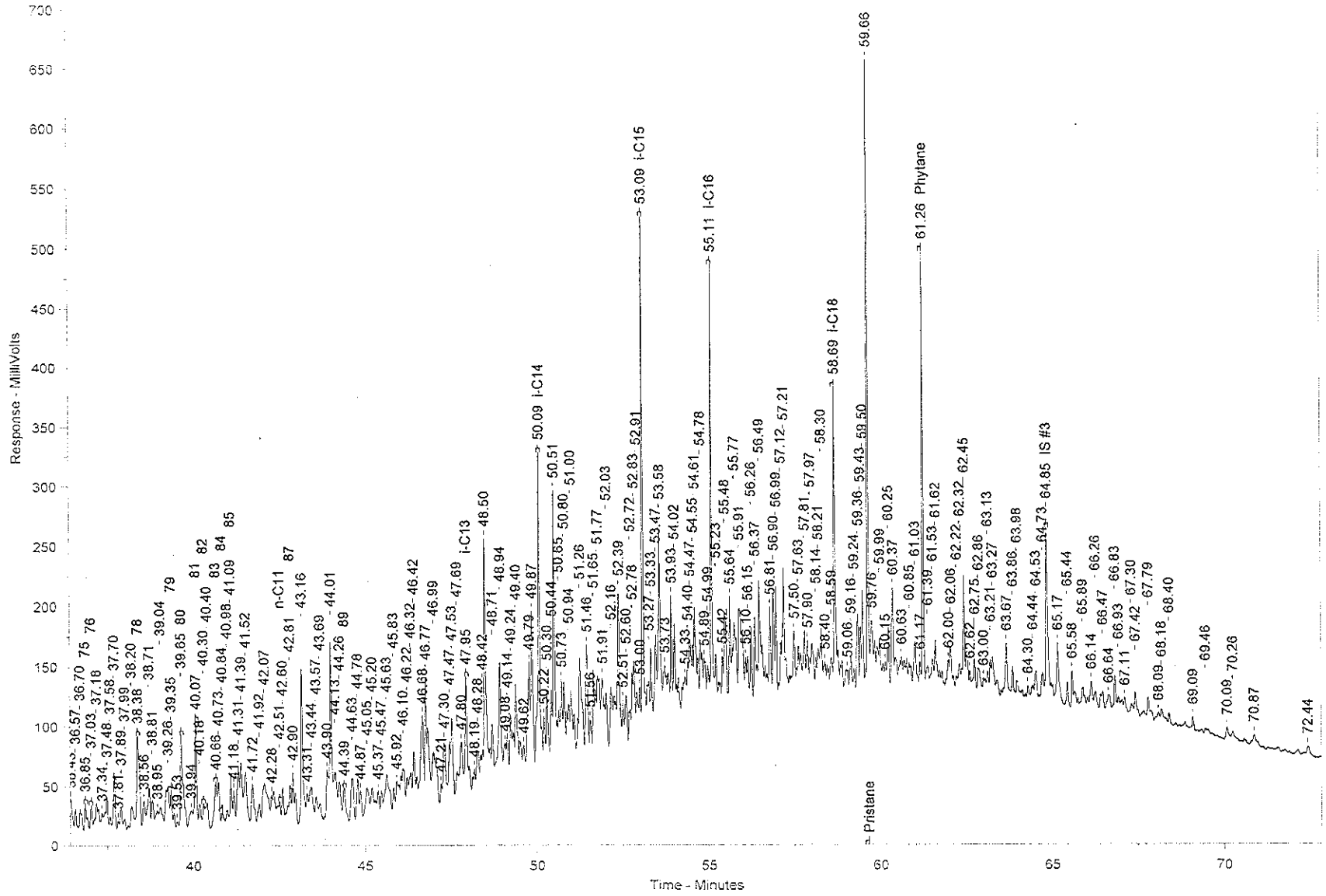
43576-4 [PZ-6] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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753

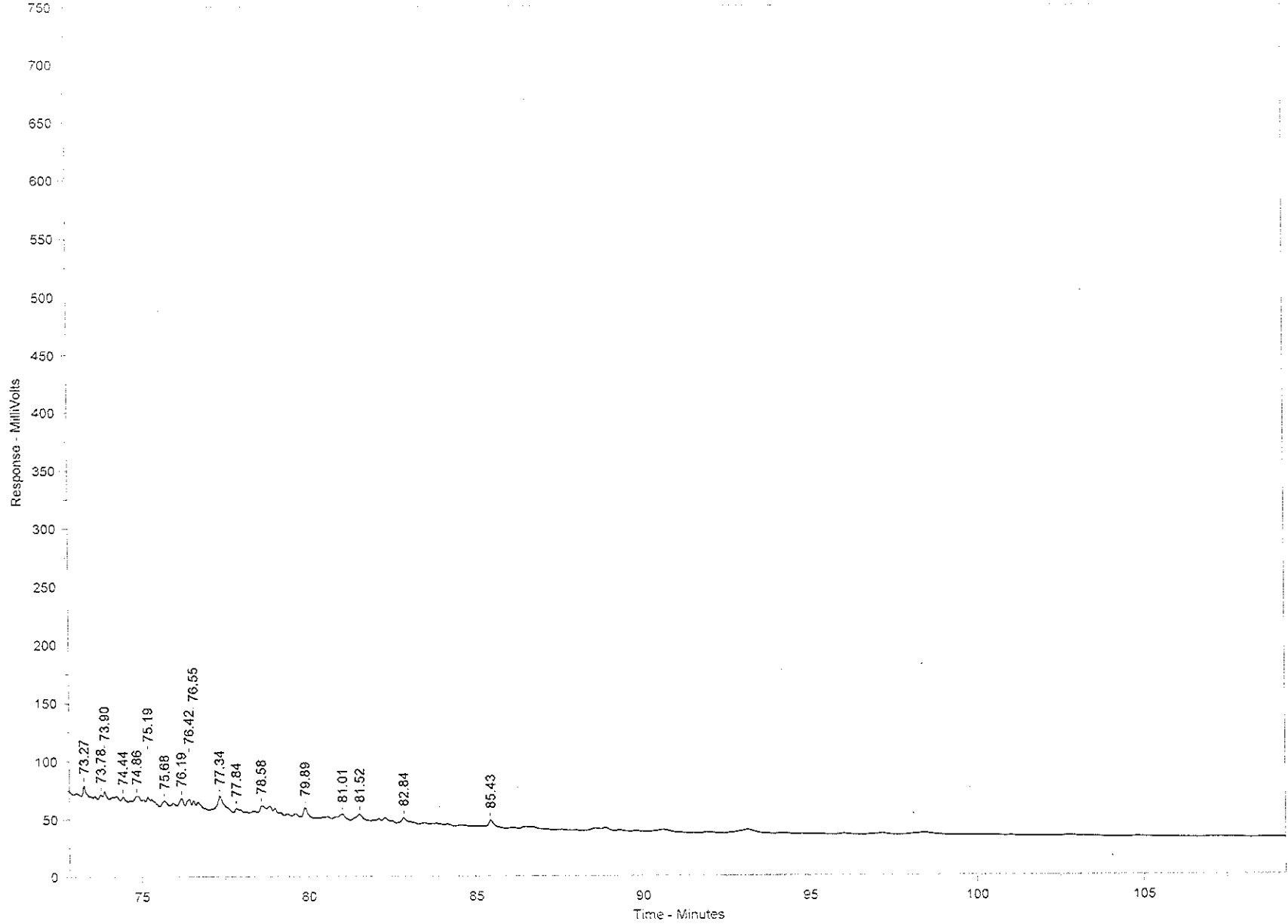
43576-4 [PZ-6] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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43576-4 [PZ-6] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

Sample Name = 43576-4 [PZ-6] [600+400CS2] + IS F-090913-1

Instrument = Instrument 1
 Heading 1 =
 Heading 2 =

Acquisition Port = DP#

Raw File Name = C:\CPSpirit\2014\May14\050514.0009.RAW
 Method File Name = C:\CPSpirit\C344.met
 Calibration File Name = C:\CPSpirit\2014\May14\050514.0009.BND

Date Taken (end) = 5/7/2014 8:56:33 PM
 Method Version = 44
 Calibration Version = 10

Peak Name	Ret. Time	Area %	Area
CS2	8.37	0.3160	184846.50
32	15.29	0.0634	37089.50
34B	16.55	0.0409	23932.01
35	16.66	0.1707	99873.48
IS #1	17.21	1.0676	624563.10
	18.75	0.0292	17088.29
	19.02	0.1524	89165.46
39	19.83	0.0661	38698.54
	20.24	0.2590	151536.30
	20.75	0.4239	248010.30
40	20.94	0.2392	139969.50
41A	21.24	0.1905	111452.40
	21.70	0.0615	36002.39
42	21.78	0.1338	78267.36
45	22.35	0.0435	25474.51
	22.55	0.0436	25511.70
46A	22.83	0.3527	206323.90
	23.31	0.0991	57992.95
47	23.40	0.0658	38479.30
	23.54	0.0319	18667.80
	23.69	0.0263	15403.16
48	23.78	0.1600	93594.91
	23.93	0.0266	15568.19
	24.14	0.3765	220292.10
49	24.56	0.5097	298197.20
50	25.11	0.1010	59065.29
	25.51	0.0475	27791.83
	25.79	0.0434	25397.22
	26.10	0.0486	28431.23
51	26.22	0.1672	97835.81
	26.37	0.0515	30137.09
52	26.54	0.2386	139619.00
	26.75	0.1146	67044.01
53	26.92	1.1396	666722.90
	27.08	0.1399	81830.90
	27.21	0.0993	58111.64
	27.30	0.1532	89623.09
	27.39	0.1039	60761.07
	27.67	0.1361	79614.07
54	27.76	0.3860	225822.70
	27.92	0.3686	215630.40
55	28.32	0.1570	91838.48
	28.62	0.0279	16294.67
	28.72	0.1050	61423.96
56	28.81	0.0598	34995.40
	29.19	0.2857	167151.00
59	29.40	0.2535	148302.50
	29.54	0.1838	107536.50
	29.69	0.1120	65506.00
61	29.84	0.2048	119815.60
	30.12	0.2808	164287.20
	30.20	0.2695	157669.90
	30.36	0.1934	113128.20
	30.50	0.0621	36318.79
	31.05	0.1530	89494.73

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
62	31.18	0.4279	250313.90
I.S. #2	31.25	0.4761	278541.40
	31.41	0.4725	276439.30
	31.58	0.1215	71100.09
63	31.92	0.0910	53237.13
64	32.09	0.3674	214915.30
	32.49	0.0502	29384.51
	32.73	0.0995	58183.73
	32.82	0.1326	77596.26
	32.93	0.1273	74500.30
65	33.23	0.3834	224316.50
	33.32	0.1495	87486.34
	33.40	0.1075	62866.52
	33.51	0.1012	59211.25
66	33.68	0.6966	407535.60
	33.84	0.0434	25402.99
68	34.25	0.2278	133274.50
69	34.52	0.8981	525449.70
	34.73	0.3168	185354.10
70	34.83	0.1563	91451.27
71	34.94	0.2069	121060.80
	35.13	0.2710	158563.40
	35.32	0.2216	129642.80
	35.51	0.7889	461510.00
	35.68	0.3209	187747.10
72	35.90	0.1757	102771.90
73	36.06	0.3743	218962.30
	36.16	0.2533	148165.40
	36.25	0.2200	128704.60
	36.43	0.2929	171333.40
	36.57	0.1447	84673.85
	36.70	0.1877	109788.60
75	36.85	0.2184	127751.60
76	37.03	0.1600	93598.49
	37.18	0.1918	112212.90
	37.34	0.1222	71467.84
	37.48	0.3006	175871.00
	37.58	0.0793	46385.92
	37.70	0.3316	194028.20
	37.81	0.0539	31536.93
	37.89	0.1425	83383.82
	37.99	0.0835	48861.41
	38.20	0.2477	144887.20
78	38.38	0.8084	472948.70
	38.56	0.2021	118247.30
	38.71	0.3335	195122.10
	38.81	0.2040	119349.60
	38.95	0.1624	95029.27
	39.04	0.2333	136512.40
	39.26	0.4554	266426.90
79	39.35	0.2096	122639.40
	39.53	0.0431	25238.91
80	39.65	0.7598	444510.80
	39.94	0.1840	107625.40
81	40.07	0.6161	360425.90
	40.18	0.1711	100107.90
82	40.30	0.1314	76874.68
	40.40	0.2065	120811.50
83	40.66	0.3608	211080.70
	40.73	0.2428	142071.30
84	40.84	0.0998	58403.17
	40.98	0.1129	66029.09
85	41.09	0.2305	134827.80
	41.18	0.1710	100044.80
	41.31	0.3839	224611.20
	41.39	0.3705	216782.10
	41.52	0.4254	248853.00

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	41.72	0.2762	161560.60
	41.92	0.0981	57365.11
	42.07	0.4109	240380.80
	42.28	0.0279	16313.55
n-C11	42.51	0.0321	18769.70
	42.60	0.1189	69537.59
87	42.81	0.0893	52263.11
	42.90	0.1333	77977.80
	43.16	0.9094	532008.20
	43.31	0.1839	107559.90
	43.44	0.3812	223040.00
	43.57	0.1939	113426.60
	43.69	0.1367	79969.66
	43.90	0.3946	230850.70
	44.01	0.9793	572950.60
	44.13	0.4548	266068.50
	44.26	0.2944	172251.10
89	44.39	0.2688	157241.10
	44.63	0.3303	193239.20
	44.78	0.2374	138867.40
	44.87	0.1403	82080.24
	45.05	0.3099	181318.40
	45.20	0.2227	130312.50
	45.37	0.1305	76353.52
	45.47	0.1252	73255.09
	45.63	0.5121	299583.90
	45.83	0.1306	76389.33
	45.92	0.2742	160435.90
	46.10	0.3159	184826.00
	46.22	0.1757	102807.30
	46.32	0.2822	165085.20
	46.42	0.3584	209705.70
	46.68	0.8445	494064.20
	46.77	1.0798	631754.40
	46.99	0.6858	401235.20
	47.21	0.0803	46957.37
	47.30	0.4412	258091.30
	47.47	0.3380	197721.50
	47.53	0.4459	260886.30
	47.69	0.1727	101009.80
	47.80	0.4525	264702.90
i-C13	47.95	0.6994	409199.00
	48.19	0.1469	85921.91
	48.28	0.3004	175733.60
	48.42	0.3093	180974.30
	48.50	1.5985	935197.30
	48.71	0.3426	200434.30
	48.94	0.9944	581791.00
	49.08	0.2649	154954.40
	49.14	0.2435	142477.00
	49.24	0.3773	220724.00
	49.40	0.5939	347452.00
	49.62	0.1881	110038.80
	49.79	0.8237	481891.40
	49.87	0.8877	519312.60
i-C14	50.09	1.7813	1042153.00
	50.22	0.2494	145921.60
	50.30	0.4372	255767.90
	50.44	0.3777	220946.10
	50.51	1.3939	815479.10
	50.65	0.2616	153065.60
	50.73	0.4163	243578.20
	50.80	0.4301	251622.20
	50.94	0.4350	254475.30
	51.00	0.4244	248273.60
	51.26	0.9760	570991.50
	51.46	0.6435	376453.10

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	51.56	0.1782	104275.30
	51.65	0.3160	184852.50
	51.77	0.6288	367887.10
	51.91	0.6191	362186.60
	52.03	0.2519	147366.30
	52.16	0.4047	236774.40
	52.39	0.9107	532804.80
	52.51	0.1853	108392.60
	52.60	0.2647	154857.80
	52.72	0.1730	101186.20
	52.78	0.2395	140119.70
	52.83	0.3403	199093.00
	52.91	0.2681	156862.20
	53.00	0.2015	117883.50
i-C15	53.09	1.9918	1165280.00
	53.27	0.3804	222564.60
	53.33	0.3398	198771.50
	53.47	0.5286	309253.70
	53.58	1.1976	700668.70
	53.73	0.5228	305879.30
	53.93	0.4670	273192.70
	54.02	0.5454	319066.50
	54.33	0.3509	205318.30
	54.40	0.1759	102910.60
	54.47	0.4864	284570.00
	54.55	0.2115	123763.40
	54.61	0.6852	400891.90
	54.78	0.4196	245455.00
	54.89	0.2178	127399.10
	54.99	0.2062	120613.60
i-C16	55.11	1.4489	847646.10
	55.23	0.1528	89377.65
	55.42	0.1452	84976.59
	55.48	0.4982	291487.70
	55.64	0.4096	239619.90
	55.77	0.7355	430302.00
	55.91	0.9667	565540.90
	56.10	0.1727	101048.70
	56.15	0.1563	91468.91
	56.26	0.2985	174613.70
	56.37	0.4304	251810.60
	56.49	0.8105	474188.80
	56.81	0.3854	225450.60
	56.90	0.4269	249776.50
	56.99	0.3656	213891.30
	57.12	0.1293	75637.72
	57.21	0.6937	405843.10
	57.50	0.1998	116865.90
	57.63	0.0576	33715.85
	57.81	0.1607	94002.80
	57.90	0.1321	77261.04
	57.97	0.0250	14634.59
	58.14	0.0778	45509.84
	58.21	0.1677	98133.46
	58.30	0.2655	156303.00
	58.40	0.1616	94570.96
	58.59	0.1239	72471.18
i-C18	58.69	1.2204	713975.50
	59.06	0.1372	80288.79
	59.16	0.1586	92807.74
	59.24	0.0778	45493.84
	59.36	0.3877	226825.70
	59.43	0.2261	132292.90
	59.50	0.4091	239345.80
Pristane	59.66	2.2310	1305223.00
	59.76	0.7029	411237.10
	59.99	0.2505	146531.50

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	60.15	0.1121	65594.68
	60.25	0.3194	186857.60
	60.37	0.5139	300673.10
	60.63	0.3182	186136.80
	60.85	0.2037	119198.20
	61.03	0.3747	219230.60
	61.17	0.1280	74879.80
Phytane	61.26	1.5705	918795.90
	61.39	0.1765	103266.90
	61.53	0.2323	135884.80
	61.62	0.3788	221629.40
	62.00	0.1762	103094.40
	62.06	0.2117	123866.10
	62.22	0.0619	36229.89
	62.32	0.1392	81432.05
	62.45	0.5432	317805.60
	62.62	0.0744	43507.04
	62.75	0.1402	82006.84
	62.86	0.1382	80862.43
	63.00	0.0649	37998.03
	63.13	0.0691	40416.45
	63.21	0.1151	67318.05
	63.27	0.1531	89558.17
	63.67	0.3896	227926.50
	63.86	0.1650	96529.38
	63.98	0.1439	84181.75
	64.30	0.0840	49137.25
	64.44	0.1099	64315.35
	64.53	0.2297	134397.80
	64.73	0.2029	118697.30
IS #3	64.85	1.1980	700879.90
	65.17	0.4851	283791.80
	65.44	0.1191	69658.52
	65.58	0.2601	152170.20
	65.89	0.1826	106828.10
	66.14	0.1766	103294.80
	66.26	0.1314	76886.96
	66.47	0.1399	81875.02
	66.64	0.1194	69865.92
	66.83	0.1316	77003.34
	66.93	0.0311	18176.60
	67.11	0.0433	25348.10
	67.30	0.0679	39718.86
	67.42	0.1355	79273.17
	67.79	0.0698	40827.23
	68.09	0.0323	18925.50
	68.18	0.1007	58929.66
	68.40	0.0523	30583.81
	69.09	0.0536	31377.24
	69.46	0.0522	30547.53
	70.09	0.1103	64503.97
	70.26	0.0882	51589.79
	70.87	0.1529	89427.78
	72.44	0.0709	41469.52
	73.27	0.0852	49861.84
	73.78	0.0424	24824.51
	73.90	0.0644	37674.20
	74.44	0.0376	22000.53
	74.86	0.1010	59092.66
	75.19	0.1413	82684.62
	75.68	0.0716	41875.53
	76.19	0.0885	51758.37
	76.42	0.0699	40876.08
	76.55	0.0324	18954.44
	77.34	0.2756	161237.60
	77.84	0.0206	12052.46
	78.58	0.0556	32550.94

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	79.89	0.1555	90948.20
	81.01	0.1025	59968.95
	81.52	0.1317	77021.20
	82.84	0.1172	68545.52
	85.43	0.0960	56142.43

Total Area = 5.850406E+07

Total Height = 1.431471E+07

Total Amount = 0

5/5/2014

ZymaX ID 43576-5
Sample ID PZ-4.5

Evaporation

n-Pentane / n-Heptane 0.00
2-Methylpentane / 2-Methylheptane 1.56

Waterwashing

Benzene / Cyclohexane 0.00
Toluene / Methylcyclohexane 0.41
Aromatics / Total Paraffins (n+iso+cyc) 0.65
Aromatics / Naphthenes 2.82

Biodegradation

(C4 - C8 Para + Isopara) / C4 - C8 Olefins 158.03
3-Methylhexane / n-Heptane 0.00
Methylcyclohexane / n-Heptane 0.00
Isoparaffins + Naphthenes / Paraffins 12.18

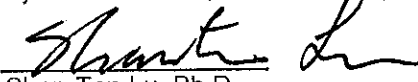
Octane rating

2,2,4,-Trimethylpentane / Methylcyclohexane 0.71

Relative percentages - Bulk hydrocarbon composition as PIANO

% Paraffinic 4.55
% Isoparaffinic 41.60
% Aromatic 38.87
% Naphthenic 13.80
% Olefinic 1.17

Submitted by,
Zymax Forensics, a DPRA Company


Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

5/5/2014

ZymaX ID	43576-5	
Sample ID	PZ-4.5	
	Relative	
	Area %	
1	Propane	0.00
2	Isobutane	0.00
3	Isobutene	0.00
4	Butane/Methanol	0.00
5	trans-2-Butene	0.00
6	cis-2-Butene	0.00
7	3-Methyl-1-butene	0.00
8	Isopentane	1.04
9	1-Pentene	0.00
10	2-Methyl-1-butene	0.00
11	Pentane	0.00
12	trans-2-Pentene	0.00
13	cis-2-Pentene/t-Butanol	0.00
14	2-Methyl-2-butene	0.00
15	2,2-Dimethylbutane	0.00
16	Cyclopentane	0.00
17	2,3-Dimethylbutane/MTBE	0.68
18	2-Methylpentane	0.97
19	3-Methylpentane	1.68
20	Hexane	0.00
21	trans-2-Hexene	0.00
22	3-Methylcyclopentene	0.00
23	3-Methyl-2-pentene	0.00
24	cis-2-Hexene	0.07
25	3-Methyl-trans-2-pentene	0.10
26	Methylcyclopentane	0.14
27	2,4-Dimethylpentane	1.33
28	Benzene	0.00
29	5-Methyl-1-hexene	0.10
30	Cyclohexane	0.00
31	2-Methylhexane/TAME	0.12
32	2,3-Dimethylpentane	3.94
33	3-Methylhexane	0.80
34A	1-trans-3-Dimethylcyclopentane	1.97
34B	1-cis-3-Dimethylcyclopentane	2.77
35	2,2,4-Trimethylpentane	3.15
I.S. #1	à,à,à-Trifluorotoluene	0.00

5/5/2014

ZymaX ID		43576-5
Sample ID		PZ-4.5
		Relative Area %
36	n-Heptane	0.00
37	Methylcyclohexane	4.45
38	2,5-Dimethylhexane	0.84
39	2,4-Dimethylhexane	1.14
40	2,3,4-Trimethylpentane	2.38
41	Toluene/2,3,3-Trimethylpentane	1.83
42	2,3-Dimethylhexane	0.99
43	2-Methylheptane	0.62
44	4-Methylheptane	0.00
45	3,4-Dimethylhexane	0.41
46A	3-Ethyl-3-methylpentane	0.00
46B	1,4-Dimethylcyclohexane	0.00
47	3-Methylheptane	0.52
48	2,2,5-Trimethylhexane	1.84
49	n-Octane	1.72
50	2,2-Dimethylheptane	0.65
51	2,4-Dimethylheptane	0.94
52	Ethylcyclohexane	4.48
53	2,6-Dimethylheptane	6.85
54	Ethylbenzene	1.91
55	m+p Xylenes	1.71
56	4-Methyloctane	0.24
57	2-Methyloctane	0.00
58	3-Ethylheptane	1.07
59	3-Methyloctane	1.02
60	o-Xylene	0.00
61	1-Nonene	0.90
62	n-Nonane	1.59
I.S.#2	p-Bromofluorobenzene	0.00
63	Isopropylbenzene	0.28
64	3,3,5-Trimethylheptane	3.10
65	2,4,5-Trimethylheptane	3.16
66	n-Propylbenzene	3.53
67	1-Methyl-3-ethylbenzene	0.00
68	1-Methyl-4-ethylbenzene	0.97
69	1,3,5-Trimethylbenzene	3.97
70	3,3,4-Trimethylheptane	1.81

5/5/2014

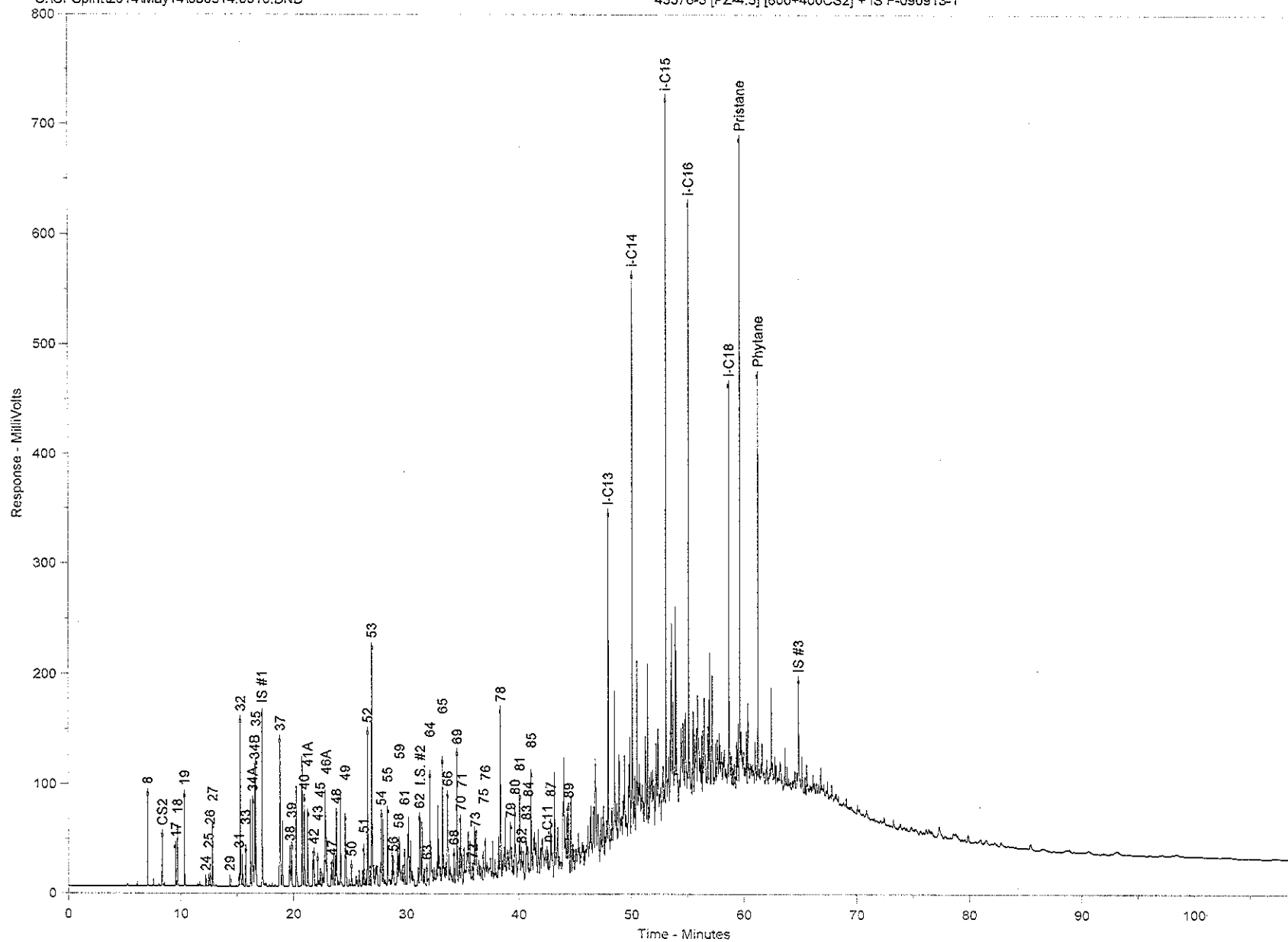
ZymaX ID 43576-5
Sample ID PZ-4.5

		Relative Area %
71	1-Methyl-2-ethylbenzene	0.64
72	3-Methylnonane	0.31
73	1,2,4-Trimethylbenzene	1.32
74	Isobutylbenzene	0.00
75	sec-Butylbenzene	0.92
76	n-Decane	1.23
77	1,2,3-Trimethylbenzene	0.00
78	Indan	5.14
79	1,3-Diethylbenzene	2.18
80	1,4-Diethylbenzene	2.84
81	n-Butylbenzene	2.62
82	1,3-Dimethyl-5-ethylbenzene	1.04
83	1,4-Dimethyl-2-ethylbenzene	1.39
84	1,3-Dimethyl-4-ethylbenzene	0.76
85	1,2-Dimethyl-4-ethylbenzene	2.63
86	Undecene	0.00
87	1,2,4,5-Tetramethylbenzene	0.93
88	1,2,3,5-Tetramethylbenzene	0.00
89	1,2,3,4-Tetramethylbenzene	2.25
90	Naphthalene	0.00
91	2-Methyl-naphthalene	0.00
92	1-Methyl-naphthalene	0.00

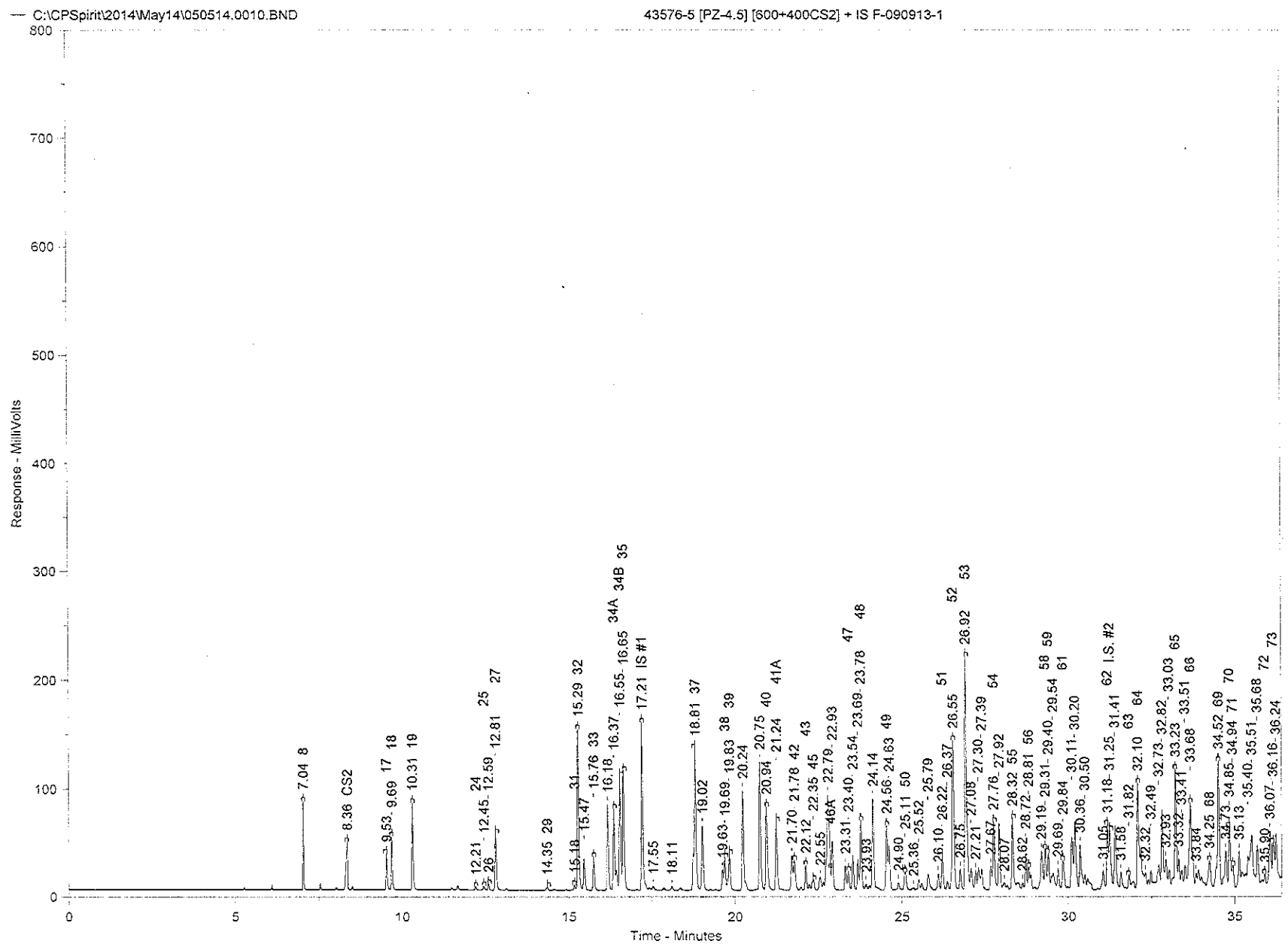
Chrom Perfect Chromatogram Report

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43576-5 [PZ-4.5] [600+400CS2] + IS F-090913-1



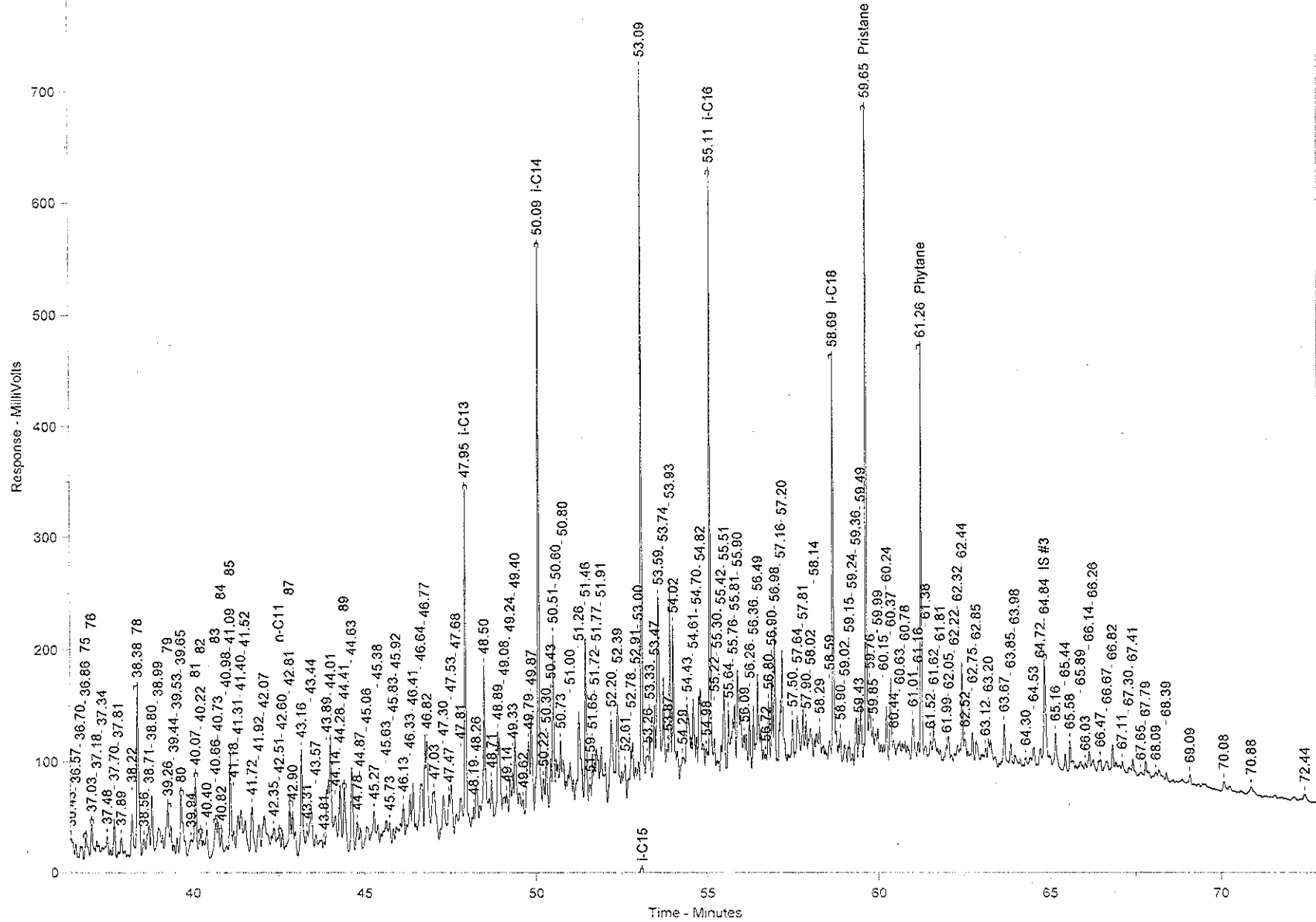
Chrom Perfect Chromatogram Report



Chrom Perfect Chromatogram Report

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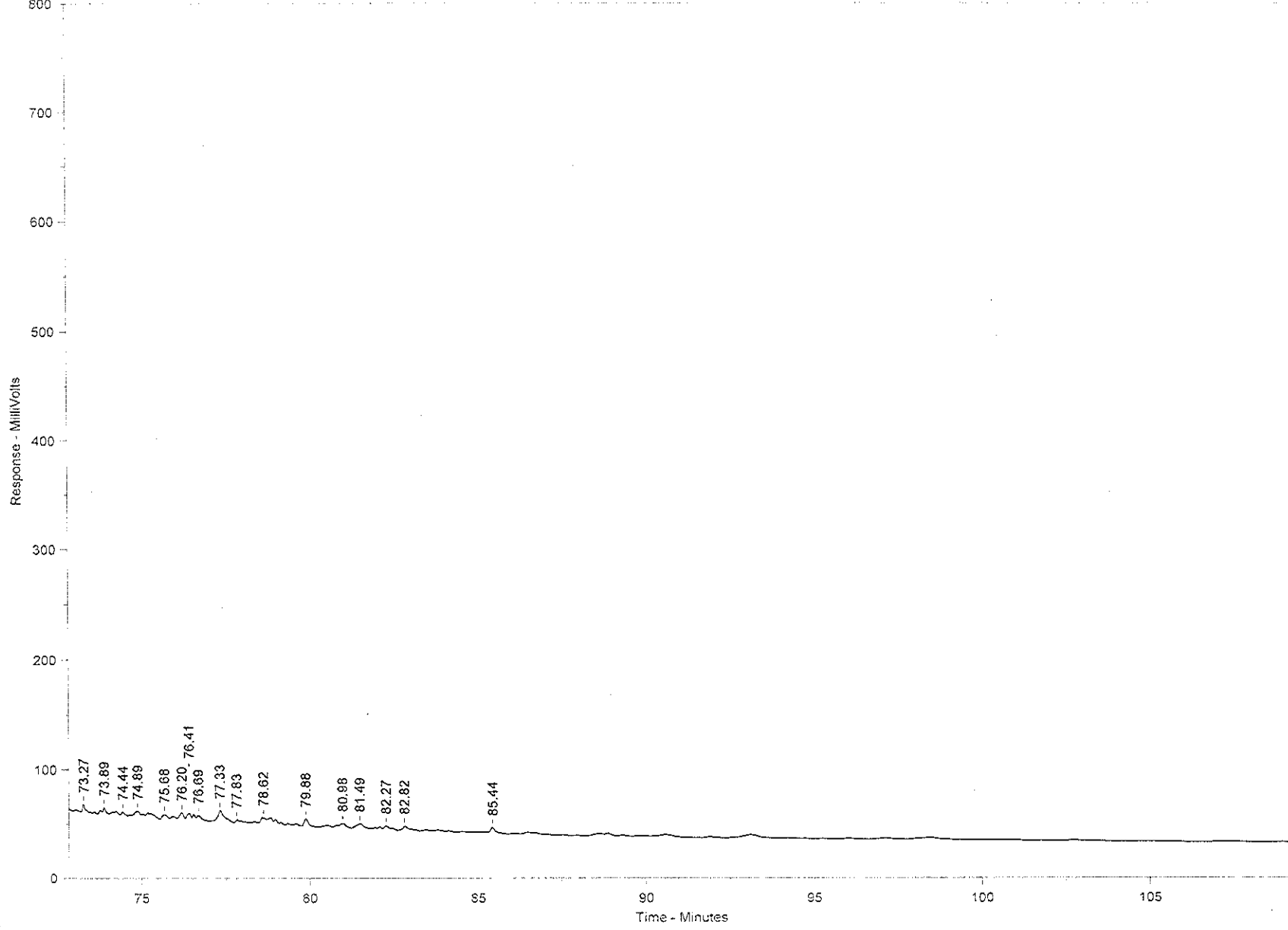
43576-5 [PZ-4.5] [600+400CS2] + IS F-090913-1



Chrom Perfect Chromatogram Report

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43576-5 [PZ-4.5] [600+400CS2] + [S F-090913-1



Chrom Perfect Chromatogram Report

Sample Name = 43576-5 [PZ-4.5] [600+400CS2] + IS F-090913-1

Instrument = Instrument 1

Acquisition Port = DP#

Heading 1 =

Heading 2 =

Raw File Name = C:\CPSpirit\2014\May14\050514.0010.RAW

Date Taken (end) = 5/7/2014 11:01:26 PM

Method File Name = C:\CPSpirit\C344.met

Method Version = 44

Calibration File Name = C:\CPSpirit\2014\May14\050514.0010.BND

Calibration Version = 10

Peak Name	Ret. Time	Area %	Area
8	7.04	0.1999	123933.60
CS2	8.36	0.2494	154613.50
17	9.53	0.1317	81643.09
18	9.69	0.1877	116363.90
19	10.31	0.3244	201079.70
24	12.21	0.0143	8864.52
25	12.45	0.0186	11511.65
26	12.59	0.0269	16644.80
27	12.81	0.2560	158699.10
29	14.35	0.0200	12418.49
31	15.18	0.0229	14203.35
32	15.29	0.7595	470821.10
	15.47	0.1582	98075.45
33	15.76	0.1547	95893.60
	16.18	0.4033	250027.30
34A	16.37	0.3801	235595.80
34B	16.55	0.5339	330924.50
35	16.65	0.6069	376175.70
IS #1	17.21	0.8056	499367.60
	17.55	0.0279	17308.89
	18.11	0.0195	12090.77
37	18.81	0.8581	531905.20
	19.02	0.3354	207901.50
	19.63	0.0890	55163.55
38	19.69	0.1624	100669.80
39	19.83	0.2194	135982.30
	20.24	0.5183	321293.40
	20.75	0.6298	390372.10
40	20.94	0.4591	284573.20
41A	21.24	0.3526	218551.70
	21.70	0.1720	106603.90
42	21.78	0.1918	118911.50
43	22.12	0.1205	74704.91
45	22.35	0.0797	49429.06
	22.55	0.0853	52861.80
	22.79	0.8237	510571.30
	22.93	0.2473	153302.70
	23.31	0.1224	75850.16
47	23.40	0.0996	61754.43
	23.54	0.1736	107635.40
	23.69	0.1433	88851.47
48	23.78	0.3552	220167.00
	23.93	0.0337	20909.59
	24.14	0.4857	301080.20
49	24.56	0.3325	206112.40
	24.63	0.2251	139513.70
	24.90	0.0439	27198.54
50	25.11	0.1260	78112.16
	25.36	0.0170	10549.41
	25.52	0.0575	35628.32
	25.79	0.1143	70854.98
	26.10	0.0859	53263.39
51	26.22	0.1823	113027.90
	26.37	0.0440	27296.24
52	26.55	0.8648	536053.20

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
53	26.75	0.1099	68098.55
	26.92	1.3224	819737.40
	27.08	0.1339	82998.88
	27.21	0.0935	57951.76
	27.30	0.1364	84551.95
	27.39	0.1200	74386.89
54	27.67	0.1134	70305.90
	27.76	0.3692	228859.10
	27.92	0.3161	195970.80
55	28.07	0.0287	17781.18
	28.32	0.3299	204502.40
	28.62	0.0213	13188.30
56	28.72	0.1343	83239.15
	28.81	0.0460	28499.93
58	29.19	0.2568	159171.60
	29.31	0.2065	127977.00
59	29.40	0.1963	121700.50
	29.54	0.1566	97087.93
61	29.69	0.0994	61610.07
	29.84	0.1735	107519.50
	30.11	0.3092	191667.00
	30.20	0.3788	234805.00
	30.36	0.2310	143163.70
	30.50	0.0443	27471.22
62	31.05	0.1170	72544.09
	31.18	0.3074	190575.60
	31.25	0.3456	214204.00
	31.41	0.3846	238416.90
63	31.58	0.1023	63439.70
	31.82	0.0541	33536.84
64	32.10	0.5980	370696.00
	32.32	0.0735	45590.18
	32.49	0.0976	60495.98
	32.73	0.1559	96612.70
	32.82	0.3904	242016.40
	32.93	0.1622	100573.40
	33.03	0.0862	53437.39
	33.23	0.6093	377718.10
	33.32	0.1275	79020.59
	33.41	0.0753	46703.37
65	33.51	0.1075	66619.25
	33.68	0.6804	421739.40
66	33.84	0.0273	16899.16
	34.25	0.1874	116194.90
68	34.52	0.7667	475275.80
69	34.73	0.2603	161328.20
	34.85	0.3498	216838.10
70	34.94	0.1231	76306.94
	35.13	0.1355	83969.34
	35.40	0.0962	59633.61
	35.51	0.3516	217921.10
	35.68	0.1960	121492.10
	35.90	0.0600	37194.81
72	36.07	0.3209	198943.10
	36.16	0.2553	158252.40
73	36.24	0.3330	206401.00
	36.43	0.1834	113689.60
	36.57	0.0802	49726.62
	36.70	0.1121	69464.02
	36.86	0.1778	110186.00
75	37.03	0.2380	147560.90
	37.18	0.1555	96406.09
	37.34	0.0836	51846.30
	37.48	0.1101	68217.93
	37.70	0.1949	120799.10
	37.81	0.0221	13678.99
	37.89	0.0901	55834.51

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area	
78	38.22	0.2672	165645.10	
	38.38	0.9921	614964.30	
	38.56	0.1191	73828.22	
	38.71	0.2525	156541.90	
	38.80	0.3345	207347.10	
	38.99	0.3402	210897.70	
79	39.26	0.4213	261131.80	
	39.44	0.0669	41439.89	
	39.53	0.0996	61754.31	
80	39.65	0.5476	339429.80	
	39.94	0.1676	103901.10	
81	40.07	0.5052	313158.50	
82	40.22	0.2014	124852.10	
	40.40	0.1892	117279.40	
83	40.66	0.2684	166387.00	
	40.73	0.1900	117777.10	
84	40.82	0.1476	91474.43	
	40.98	0.0769	47657.17	
85	41.09	0.5073	314440.30	
	41.18	0.1323	82007.45	
	41.31	0.2812	174308.30	
	41.40	0.3044	188712.00	
	41.52	0.2911	180452.80	
	41.72	0.3296	204337.30	
	41.92	0.2047	126866.50	
	42.07	0.4528	280703.70	
	42.35	0.2306	142960.80	
	n-C11	42.51	0.0884	54780.25
		42.60	0.0768	47607.11
	87	42.81	0.1801	111615.80
		42.90	0.1245	77146.41
43.16		0.6307	390952.00	
43.31		0.1117	69266.76	
43.44		0.3475	215422.30	
43.57		0.0544	33723.02	
43.81		0.0223	13799.89	
43.89		0.2421	150081.00	
44.01		0.5928	367489.10	
44.14		0.2970	184088.80	
44.28		0.4274	264955.10	
89		44.41	0.4333	268594.10
		44.63	0.5027	311587.20
		44.78	0.1681	104192.30
		44.87	0.1154	71519.62
		45.06	0.2438	151149.80
		45.27	0.3443	213449.00
	45.38	0.1292	80100.55	
	45.63	0.3669	227448.50	
	45.73	0.1234	76502.49	
	45.83	0.0879	54463.41	
	45.92	0.1717	106423.00	
i-C13	46.13	0.2654	164538.10	
	46.33	0.4188	259632.30	
	46.41	0.4301	266588.00	
	46.64	0.6252	387528.90	
	46.77	0.4565	282982.60	
	46.82	0.5844	362242.90	
	47.03	0.6253	387584.10	
	47.30	0.4087	253361.00	
	47.47	0.2382	147625.40	
	47.53	0.3125	193690.80	
	47.68	0.1666	103243.60	
	47.81	0.3464	214754.00	
	i-C13	47.95	1.6579	1027714.00
		48.19	0.1001	62054.76
		48.26	0.3288	203821.20
	48.50	1.2330	764318.10	

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	48.71	0.2708	167850.00
	48.89	0.9713	602102.70
	49.08	0.2152	133428.30
	49.14	0.1794	111182.40
	49.24	0.2452	151977.90
	49.33	0.2533	157032.40
	49.40	0.5448	337696.30
	49.62	0.1321	81912.77
	49.79	0.6334	392637.70
	49.87	0.6126	379739.80
i-C14	50.09	2.5484	1579724.00
	50.22	0.2058	127560.50
	50.30	0.3375	209216.60
	50.43	0.2746	170243.70
	50.51	0.8191	507763.40
	50.60	0.3898	241631.40
	50.73	0.4343	269189.00
	50.80	0.3314	205405.20
	51.00	0.6207	384775.50
	51.26	0.9535	591033.00
	51.46	0.7796	483227.00
	51.59	0.1379	85483.58
	51.65	0.2044	126686.20
	51.72	0.1993	123560.40
	51.77	0.4461	276510.60
	51.91	0.4413	273530.60
	52.20	0.7990	495266.80
	52.39	0.6631	411040.20
	52.61	0.2382	147627.90
	52.78	0.3219	199508.10
	52.91	0.1384	85762.03
	53.00	0.2012	124703.10
i-C15	53.09	2.6317	1631335.00
	53.26	0.3206	198747.60
	53.33	0.2803	173741.00
	53.47	0.4328	268304.80
	53.59	1.4612	905788.40
	53.74	0.6646	411952.00
	53.87	0.2736	169623.80
	53.93	0.7850	486612.10
	54.02	0.7938	492076.30
	54.29	0.2867	177698.70
	54.43	0.8723	540742.10
	54.61	0.4111	254810.80
	54.70	0.1654	102527.50
	54.82	0.8565	530923.30
	54.98	0.2170	134487.40
i-C16	55.11	2.0966	1299611.00
	55.22	0.1583	98133.73
	55.30	0.0842	52182.11
	55.42	0.1015	62887.00
	55.51	0.4432	274730.70
	55.64	0.2193	135949.40
	55.76	0.2857	177073.20
	55.81	0.2087	129351.50
	55.90	0.4746	294203.00
	56.09	0.0585	36251.46
	56.26	0.1944	120482.80
	56.36	0.3324	206017.50
	56.49	0.6102	378236.20
	56.72	0.0490	30359.22
	56.80	0.2854	176929.80
	56.90	0.3834	237674.90
	56.98	0.5277	327120.00
	57.16	0.3220	199582.60
	57.20	0.4856	300987.40
	57.50	0.1945	120555.70

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	57.64	0.3228	200094.20
	57.81	0.2333	144607.10
	57.90	0.1766	109475.40
	58.02	0.1887	116960.00
	58.14	0.0349	21607.76
	58.29	0.0848	52554.63
	58.59	0.1187	73603.84
i-C18	58.69	1.6767	1039333.00
	58.90	0.1105	68501.52
	59.02	0.1242	76975.97
	59.15	0.1275	79016.40
	59.24	0.0469	29076.40
	59.36	0.2424	150254.60
	59.43	0.1254	77746.11
Pristane	59.49	0.2439	151160.00
	59.65	2.2601	1400981.00
	59.76	0.2673	165696.10
	59.85	0.0642	39810.49
	59.99	0.0478	29635.24
	60.15	0.0303	18763.27
	60.24	0.2176	134879.50
	60.37	0.3651	226343.50
	60.44	0.1094	67803.37
	60.63	0.1273	78892.45
	60.78	0.0390	24182.76
	61.01	0.2894	179386.70
	61.16	0.0875	54214.43
Phytane	61.26	1.4674	909588.50
	61.38	0.1083	67154.80
	61.52	0.1297	80419.23
	61.62	0.2520	156214.10
	61.81	0.0509	31529.45
	61.99	0.0617	38253.35
	62.05	0.1007	62417.58
	62.22	0.0358	22176.76
	62.32	0.0897	55602.63
	62.44	0.3859	239240.00
	62.52	0.1367	84712.72
	62.75	0.1231	76291.09
	62.85	0.1201	74424.20
	63.12	0.0317	19672.30
	63.20	0.0449	27817.42
	63.67	0.2499	154924.20
	63.85	0.1136	70406.17
	63.98	0.0891	55238.43
	64.30	0.0609	37777.48
	64.53	0.1370	84941.55
	64.72	0.1365	84602.12
IS #3	64.84	0.8190	507659.10
	65.16	0.2815	174495.90
	65.44	0.0787	48789.51
	65.58	0.0925	57323.58
	65.89	0.0520	32229.11
	66.03	0.0276	17111.90
	66.14	0.1088	67423.73
	66.26	0.0815	50524.51
	66.47	0.0996	61733.30
	66.67	0.0855	53017.40
	66.82	0.1032	63953.48
	67.11	0.0417	25854.34
	67.30	0.0450	27882.33
	67.41	0.0928	57499.32
	67.65	0.0501	31051.01
	67.79	0.1320	81848.24
	68.09	0.0196	12136.96
	68.39	0.0323	20040.24
	69.09	0.0439	27214.48

Chrom Perfect Chromatogram Report

Peak Name	Ret. Time	Area %	Area
	70.08	0.0611	37904.20
	70.88	0.0640	39659.97
	72.44	0.0506	31388.91
	73.27	0.0622	38548.04
	73.89	0.0987	61201.29
	74.44	0.0388	24025.75
	74.89	0.0738	45775.14
	75.68	0.0726	45022.79
	76.20	0.0996	61747.89
	76.41	0.0914	56649.12
	76.69	0.0796	49353.83
	77.33	0.2422	150130.70
	77.83	0.0417	25826.76
	78.62	0.0410	25416.90
	79.88	0.0931	57737.21
	80.98	0.0806	49968.36
	81.49	0.1071	66390.90
	82.27	0.0773	47903.79
	82.82	0.0861	53378.59
	85.44	0.0852	52791.57

Total Area = 6.198774E+07

Total Height = 1.640133E+07

Total Amount = 0

GC/MS Full Scan Analysis
(ASTM D5739)

GC/MS FULL SCAN

ION (M/Z)	Mass Chromatograms	COMPOUND CLASS
TIC		All compounds
85		n-Alkanes
113		Iso-Alkanes and Isoprenoids
83		Alkylcyclohexanes
134		C ₄ -benzenes
123		Bicyclanes
191		Terpanes
217		Steranes
253		Monoaromatic steranes
231		Triaromatic steranes
Bar diagram		Aromatic Hydrocarbon Distribution

note: Chromatograms and data follow this cover page.

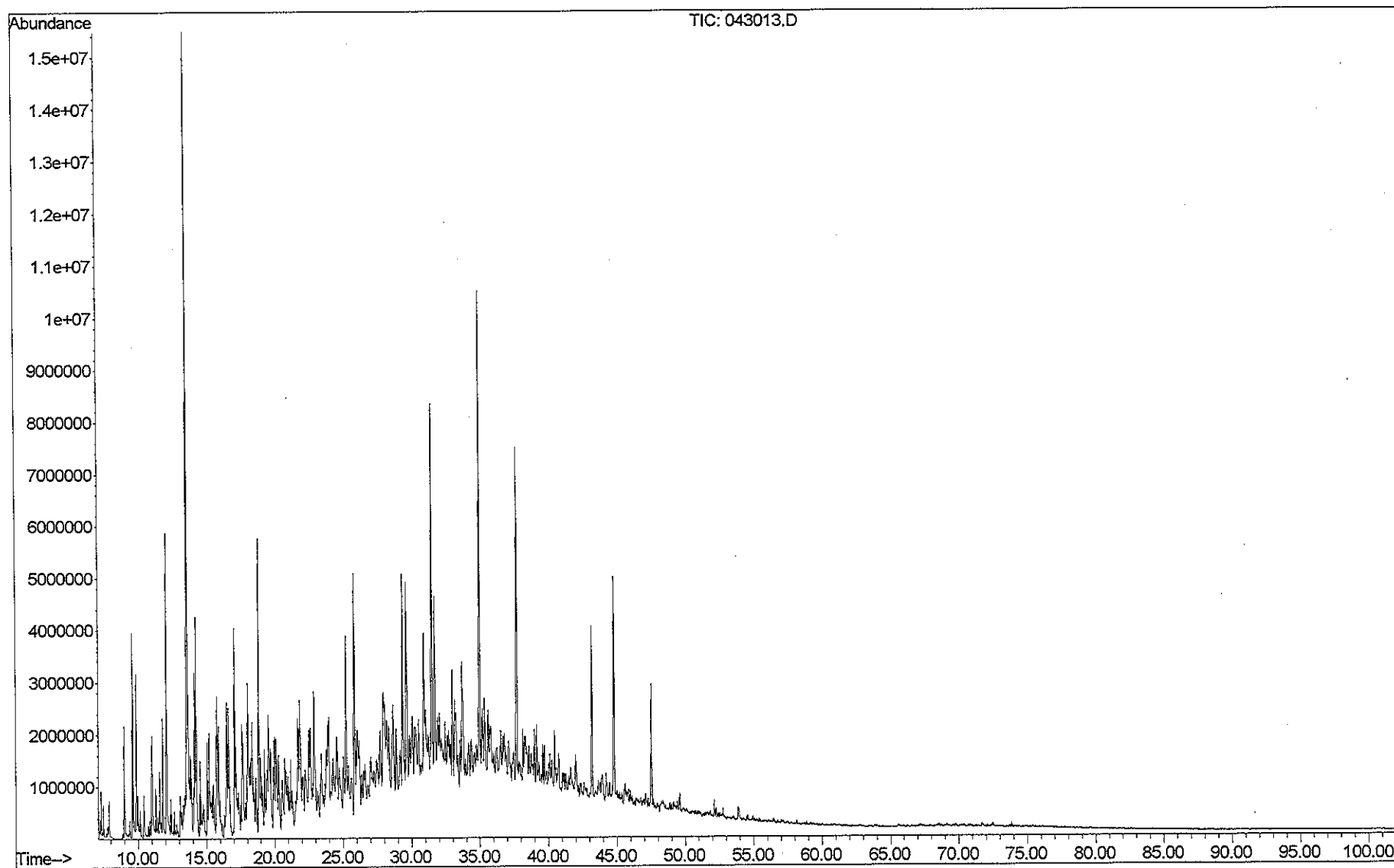
Submitted by,
Zymax Forensics, a DPRA Company



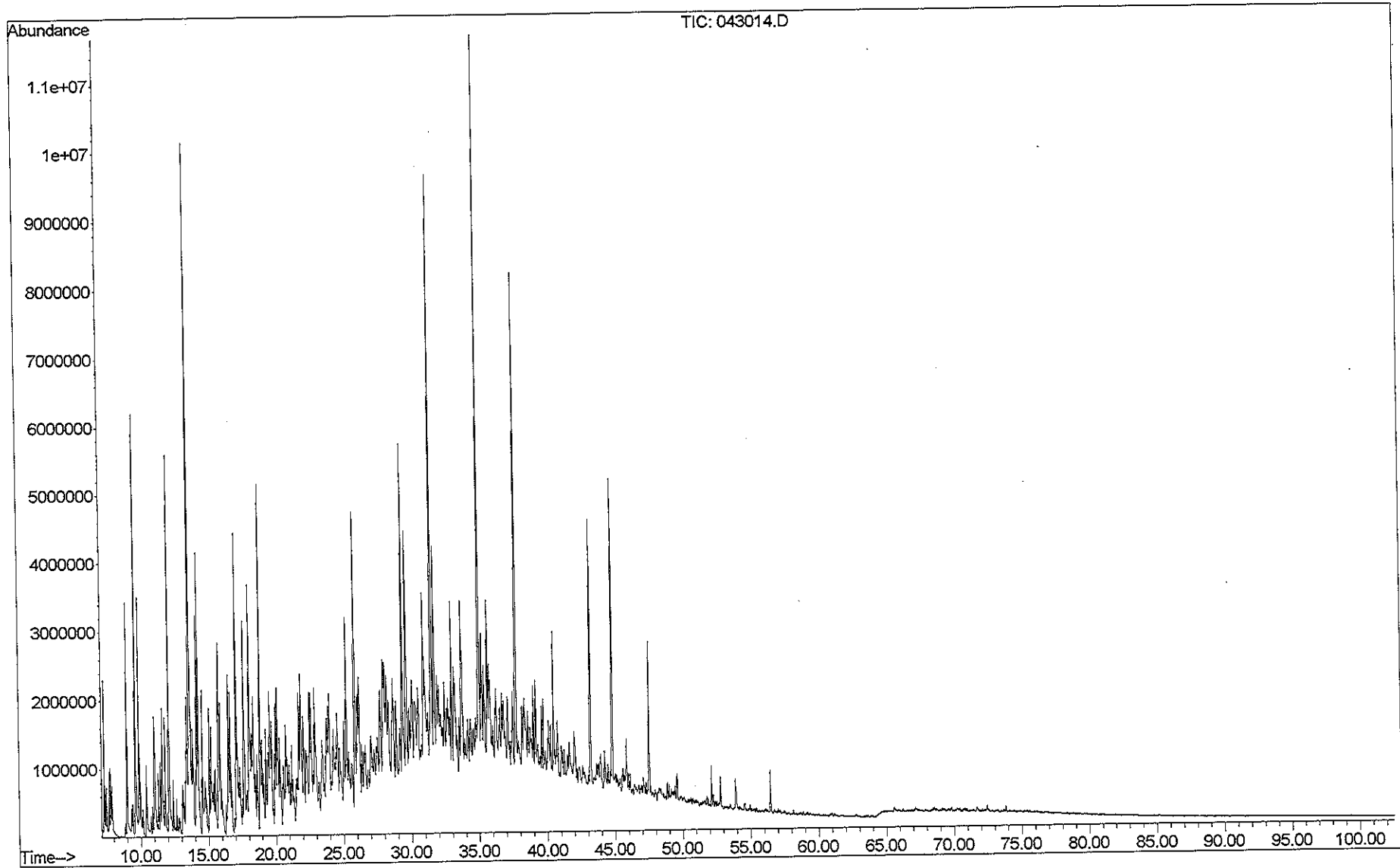
Shan-Tan Lu, Ph.D.
Director of Forensic Geochemistry

STL

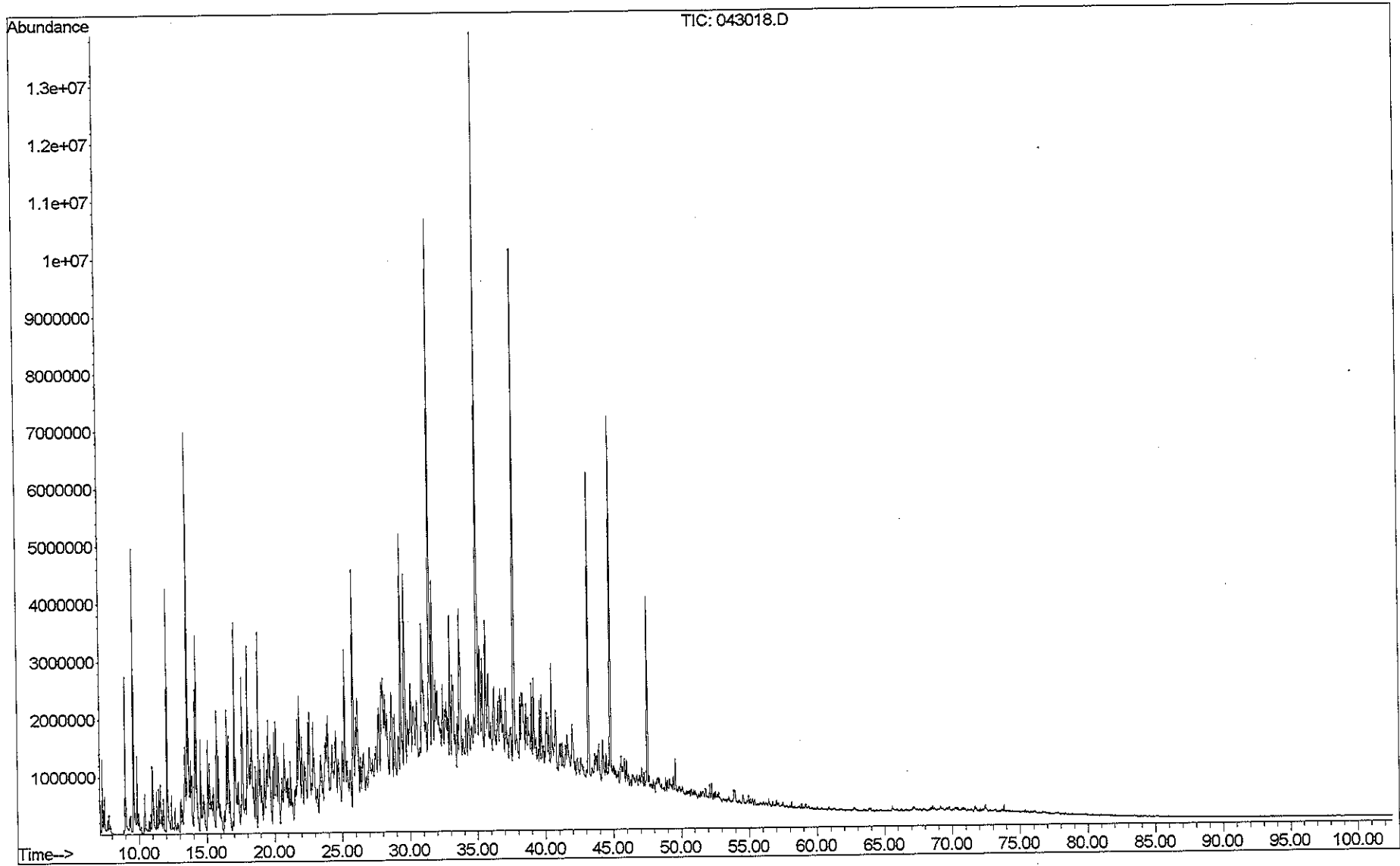
Sample Name: PZ-13 (43576-1) product
 Misc Info : Former Unocal Seattle Marketing Ter



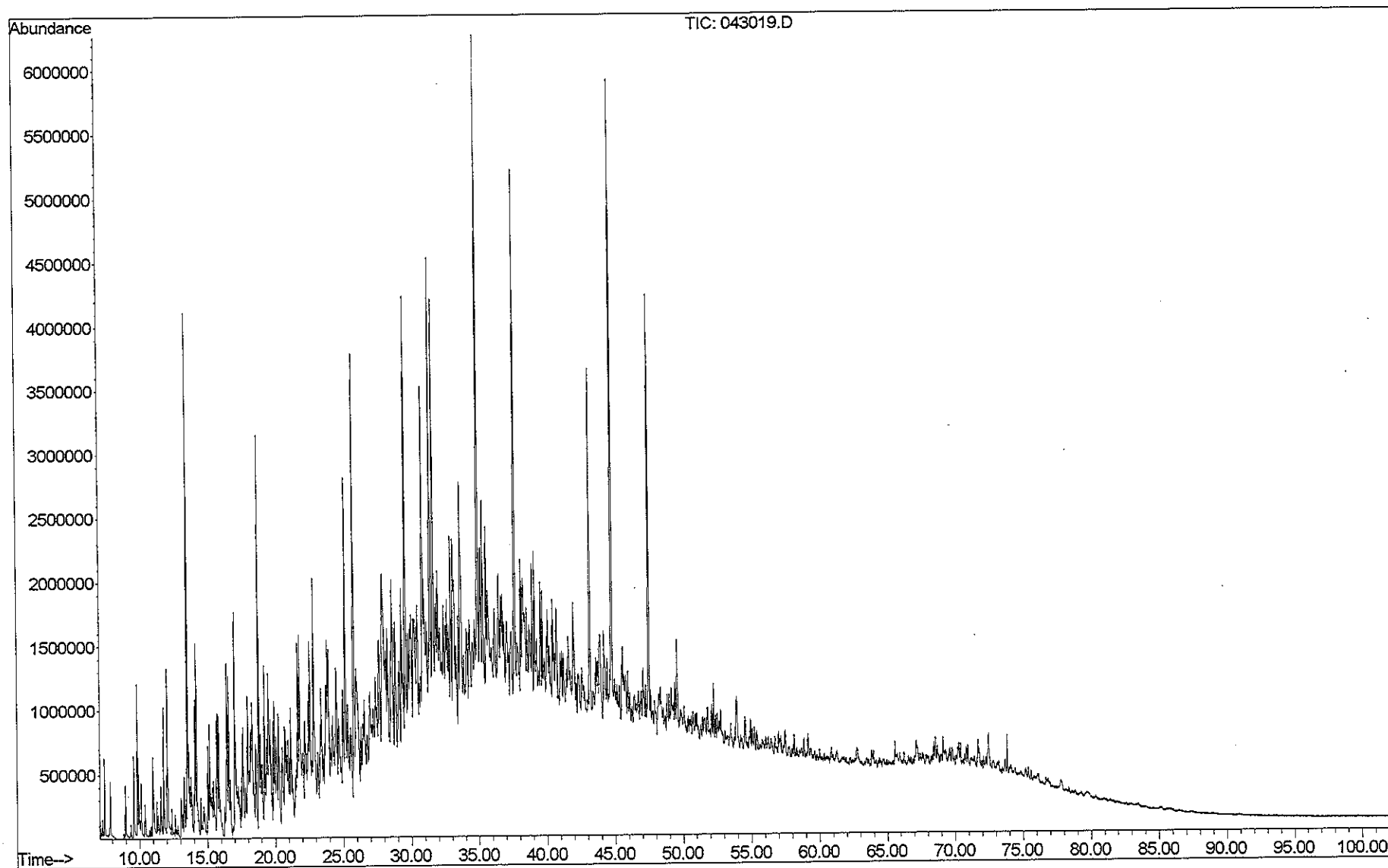
Sample Name: PZ-11.5 (43576-2) product
Misc Info : Former Unocal Seattle Marketing Ter



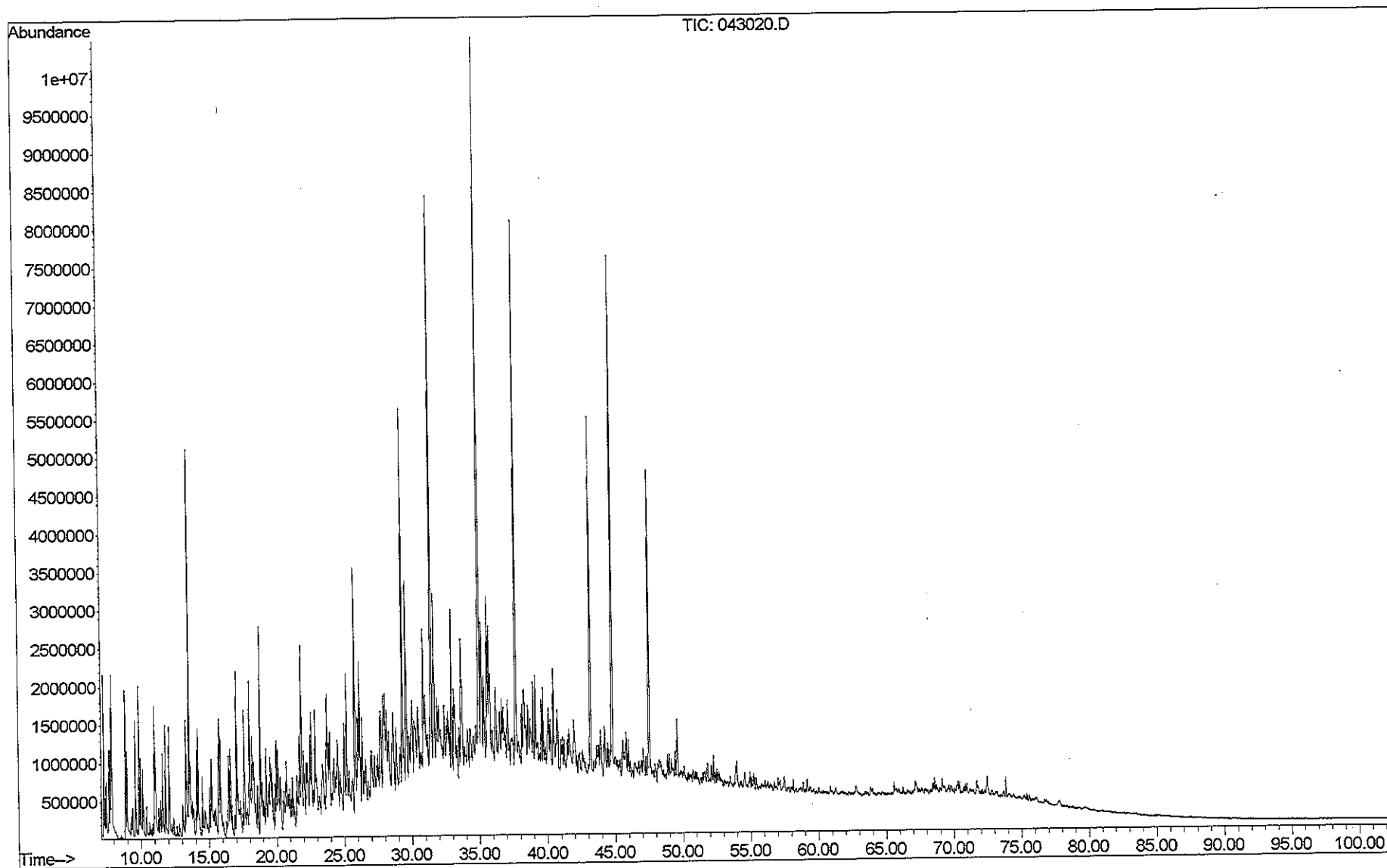
Sample Name: PZ-10.5 (43576-3) product
Misc Info : Former Unocal Seattle Marketing Ter



Sample Name: PZ-6 (43576-4) product
Misc Info : Former Unocal Seattle Marketing Ter

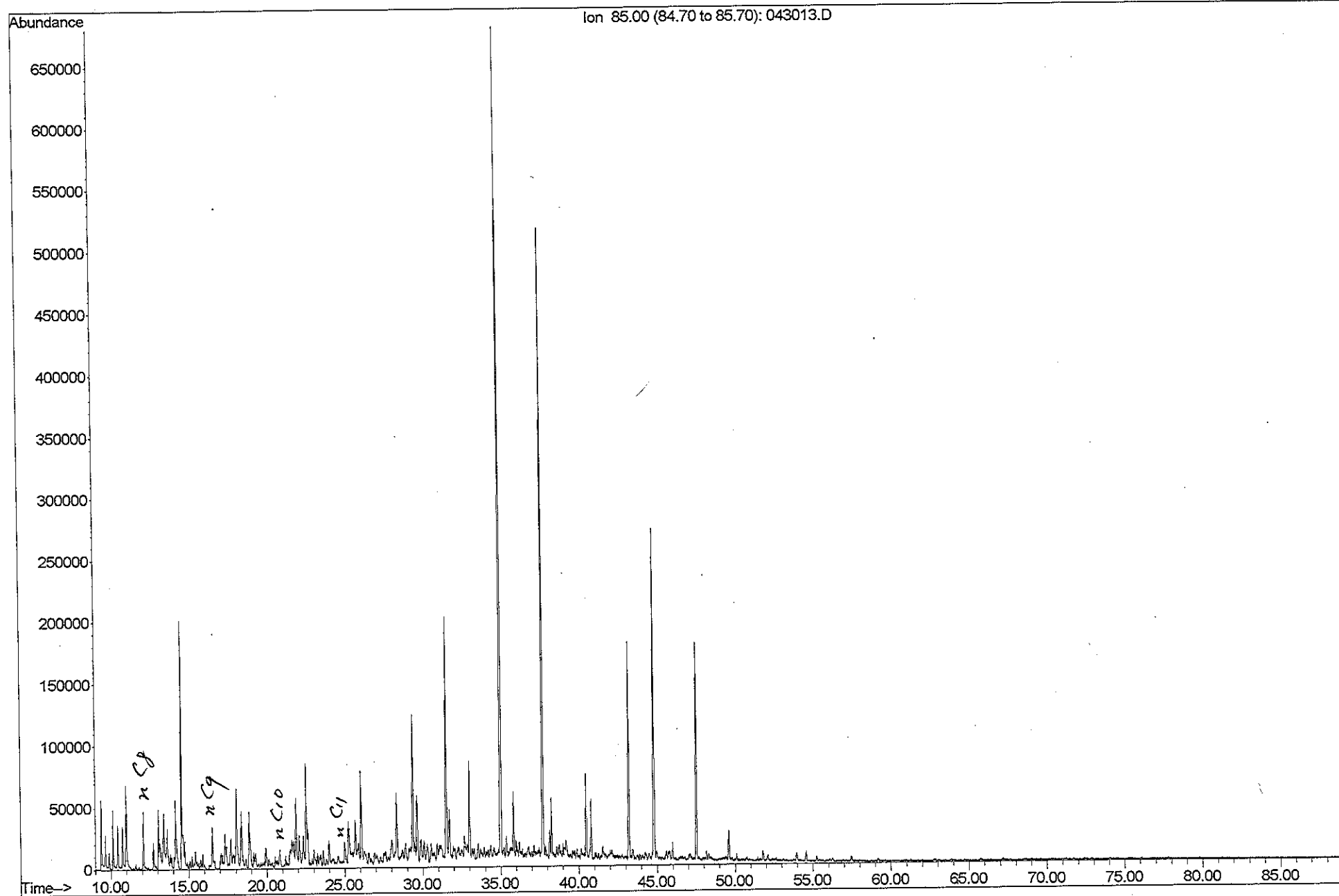


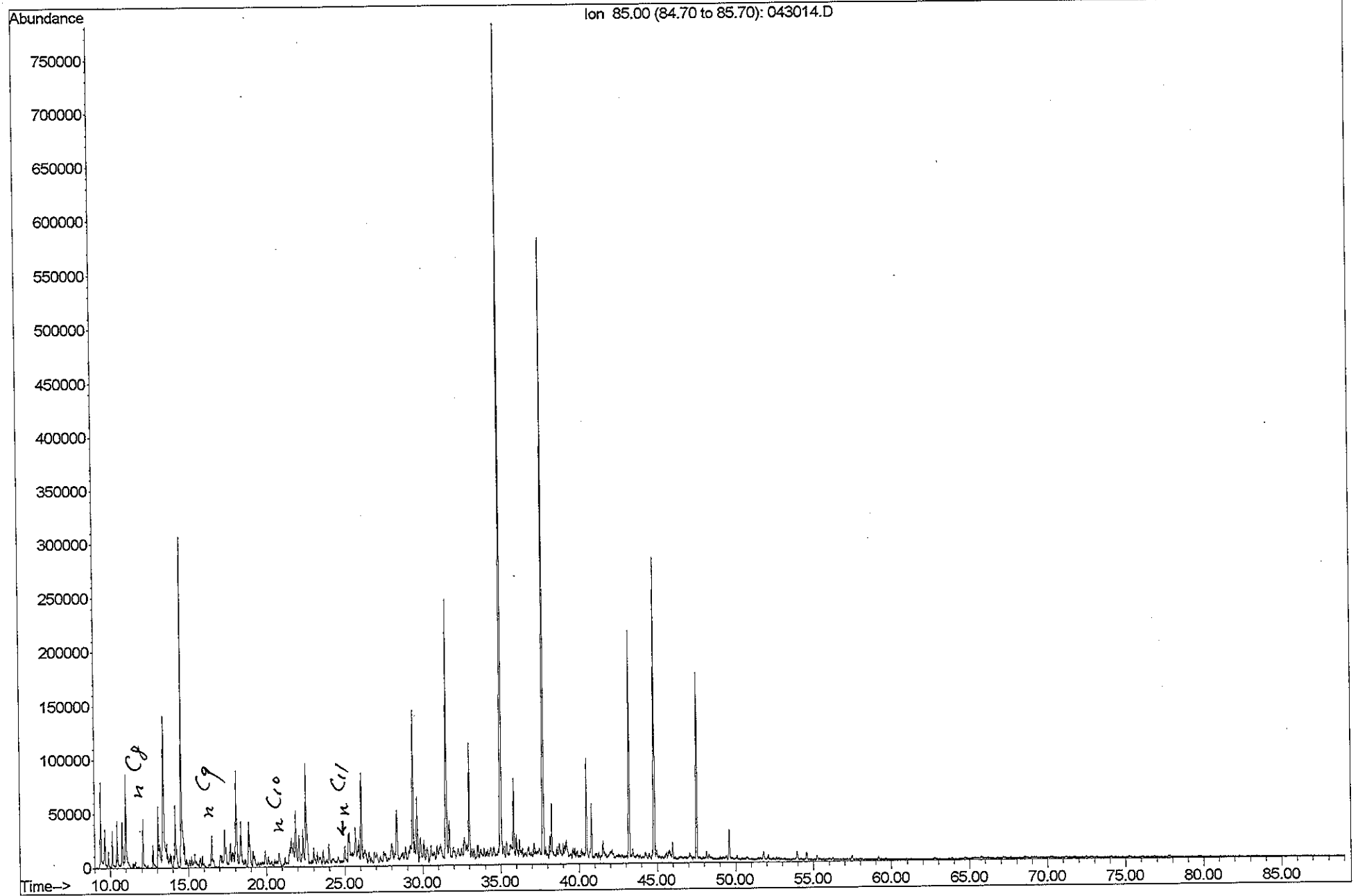
Sample Name: PZ-4.5 (43576-5) product
Misc Info : Former Unocal Seattle Marketing Ter



PZ-13 (43576-1) product
Former Unocal Seattle Marketing Ter

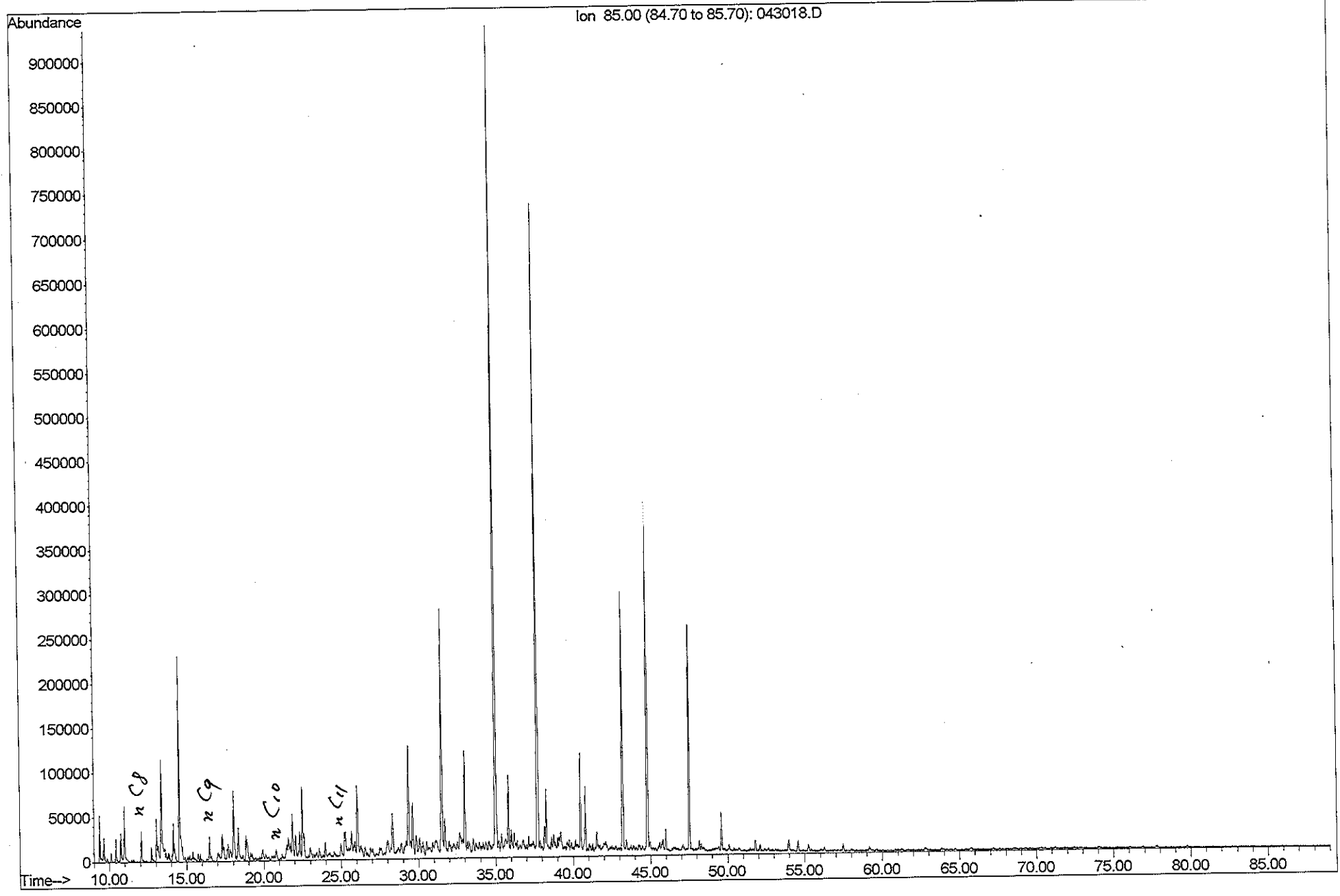
Zymax
FORENSICS





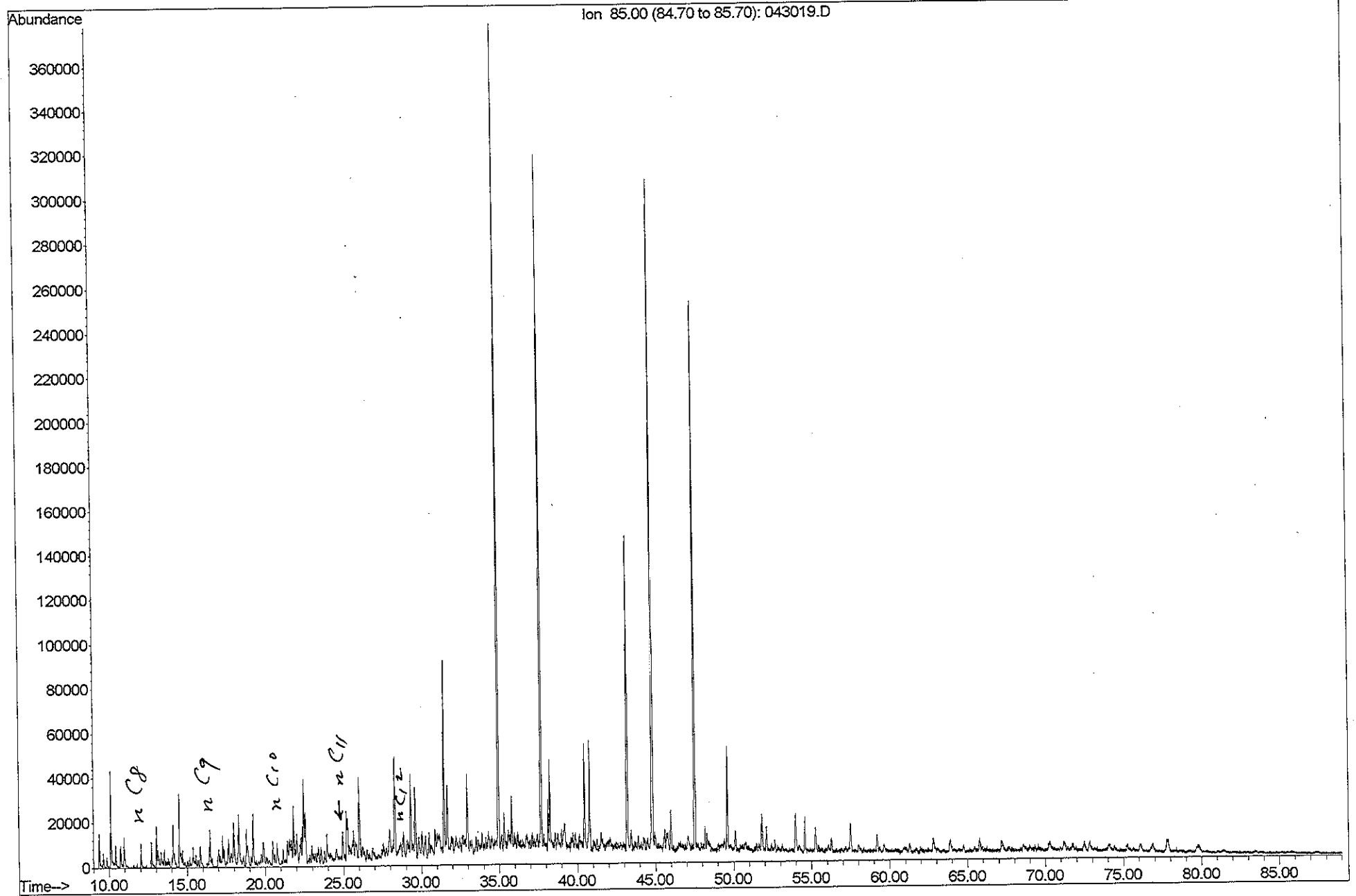
PZ-10.5 (43576-3) product
Former Unocal Seattle Marketing Ter

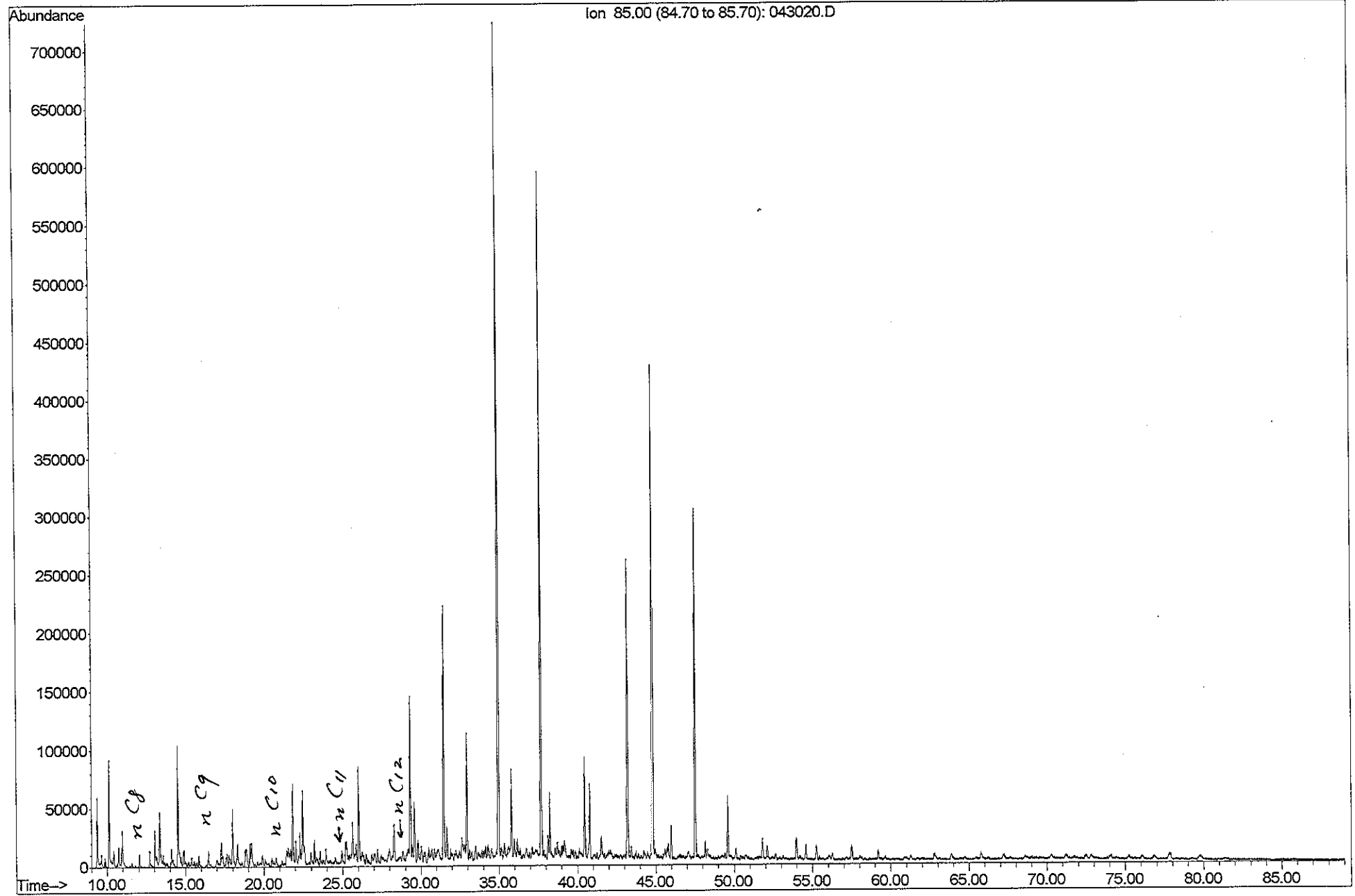
ZymaX
FORENSICS

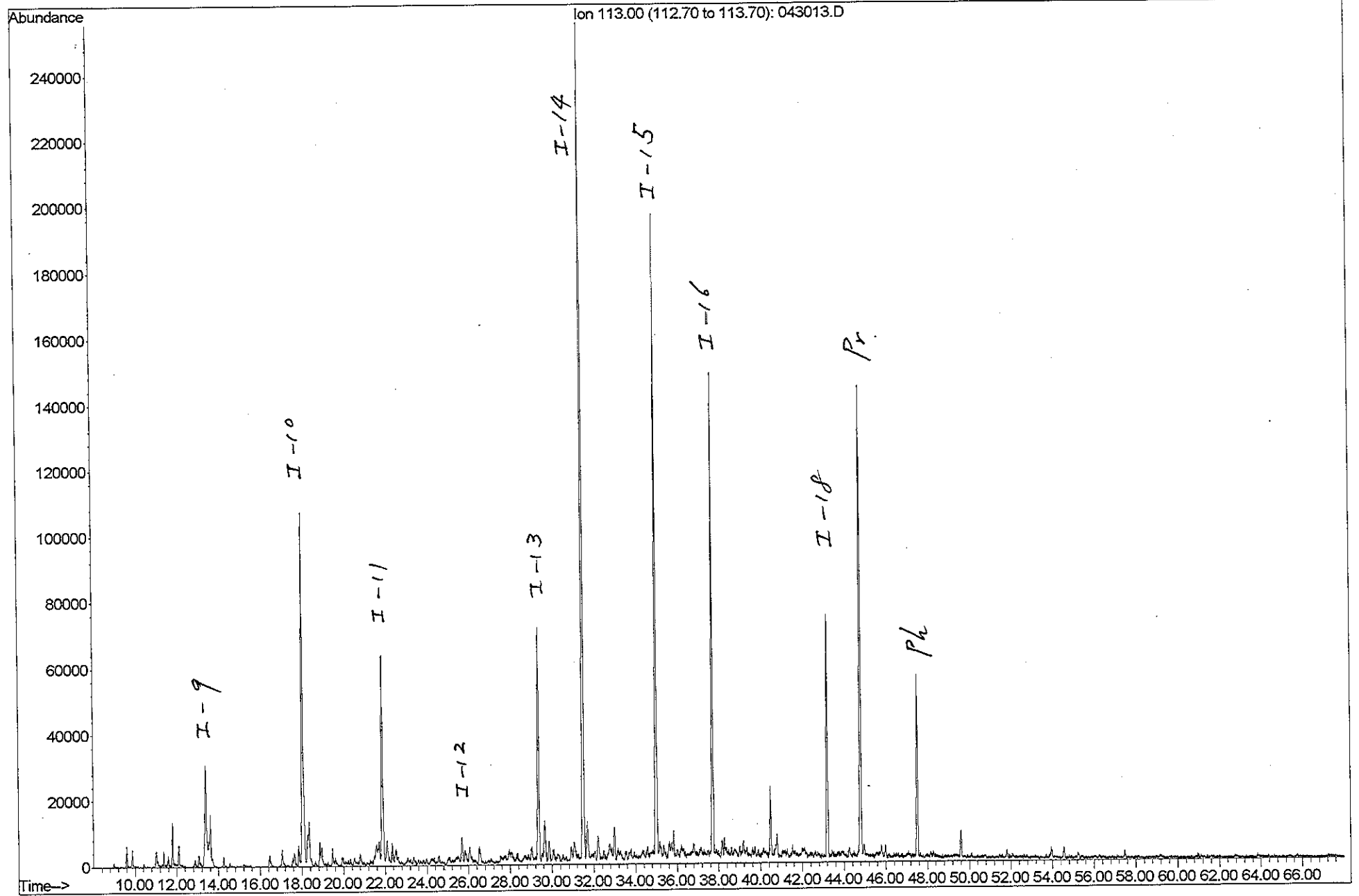


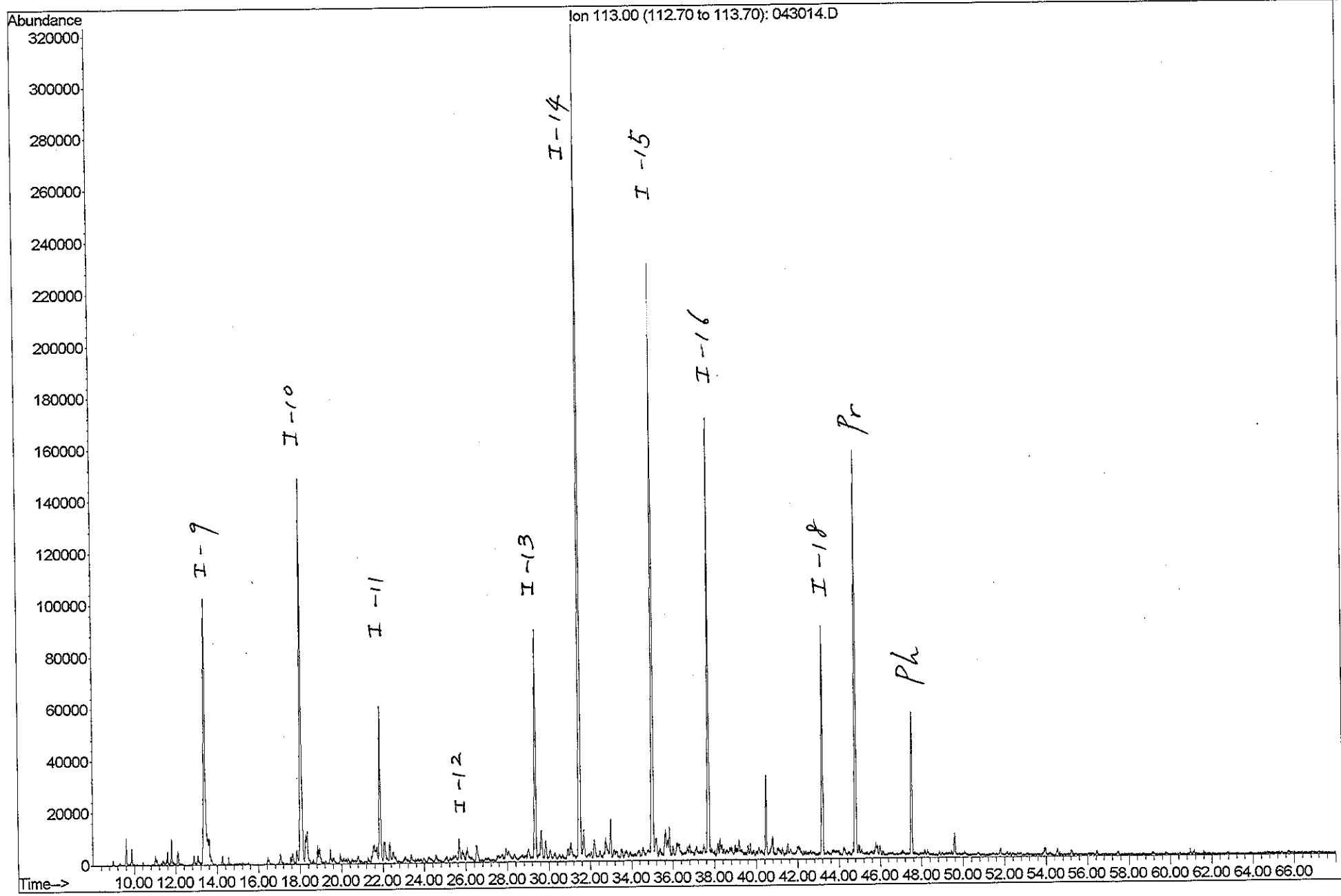
PZ-6 (43576-4) product
Former Unocal Seattle Marketing Ter

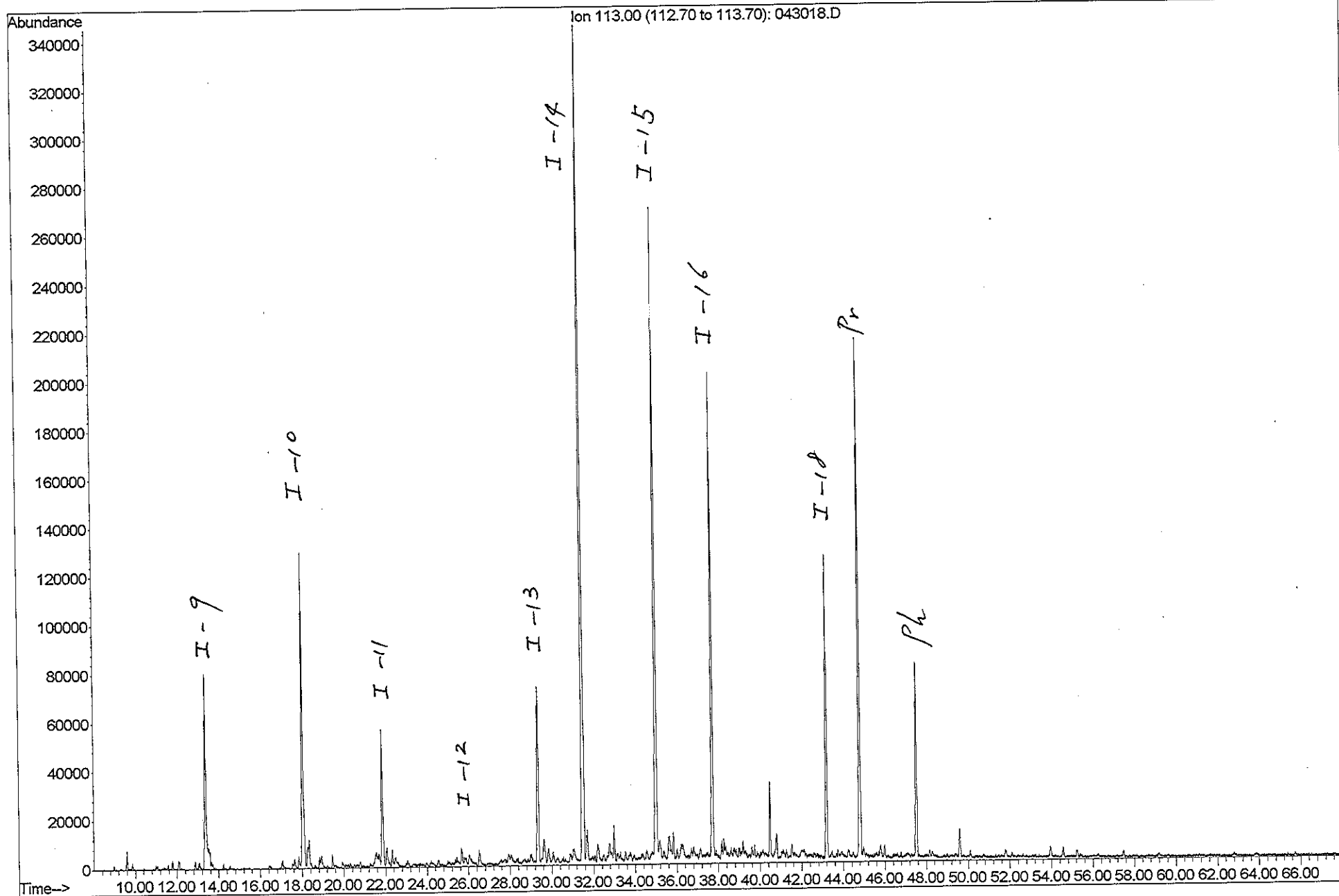
Zymax
FORENSICS

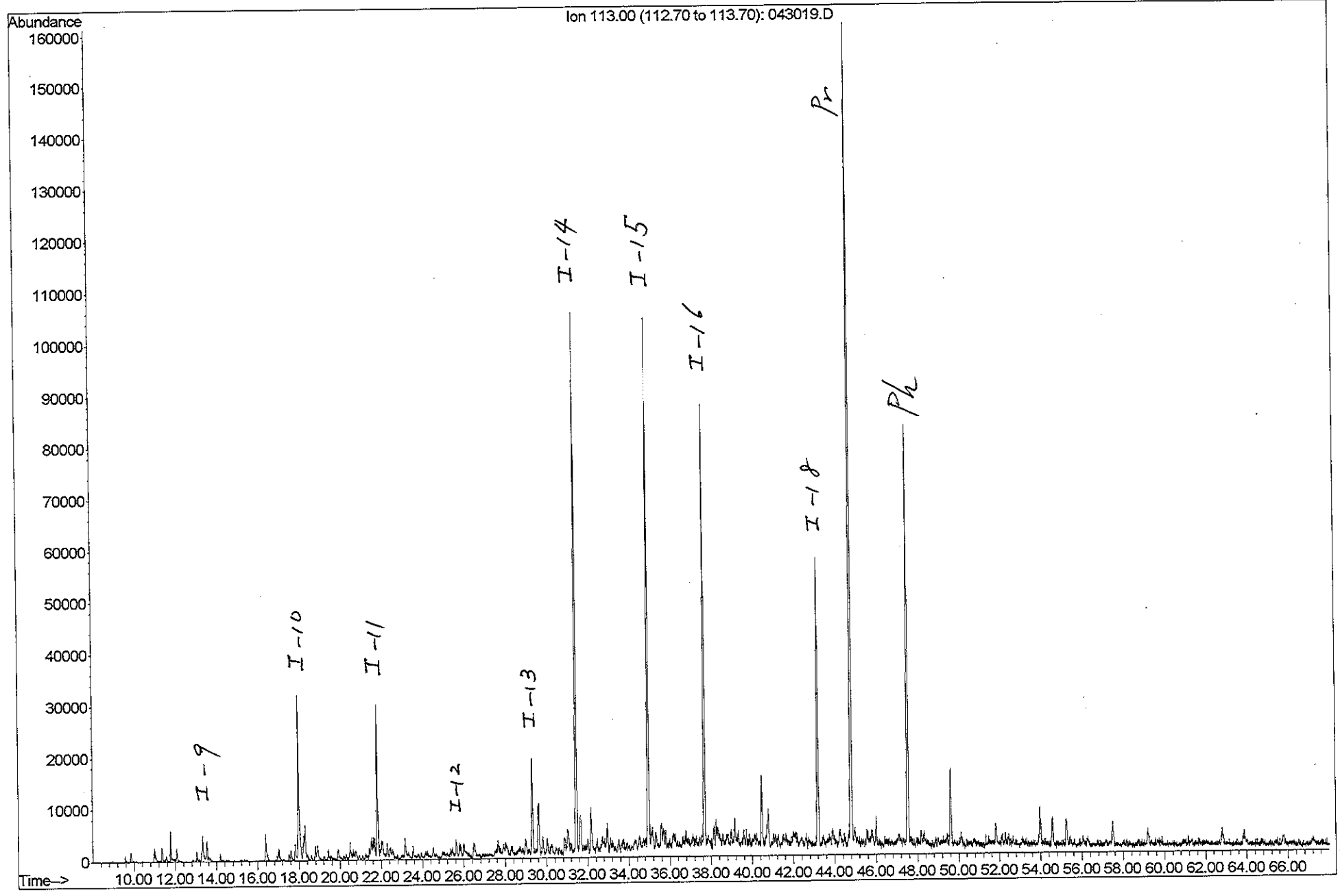


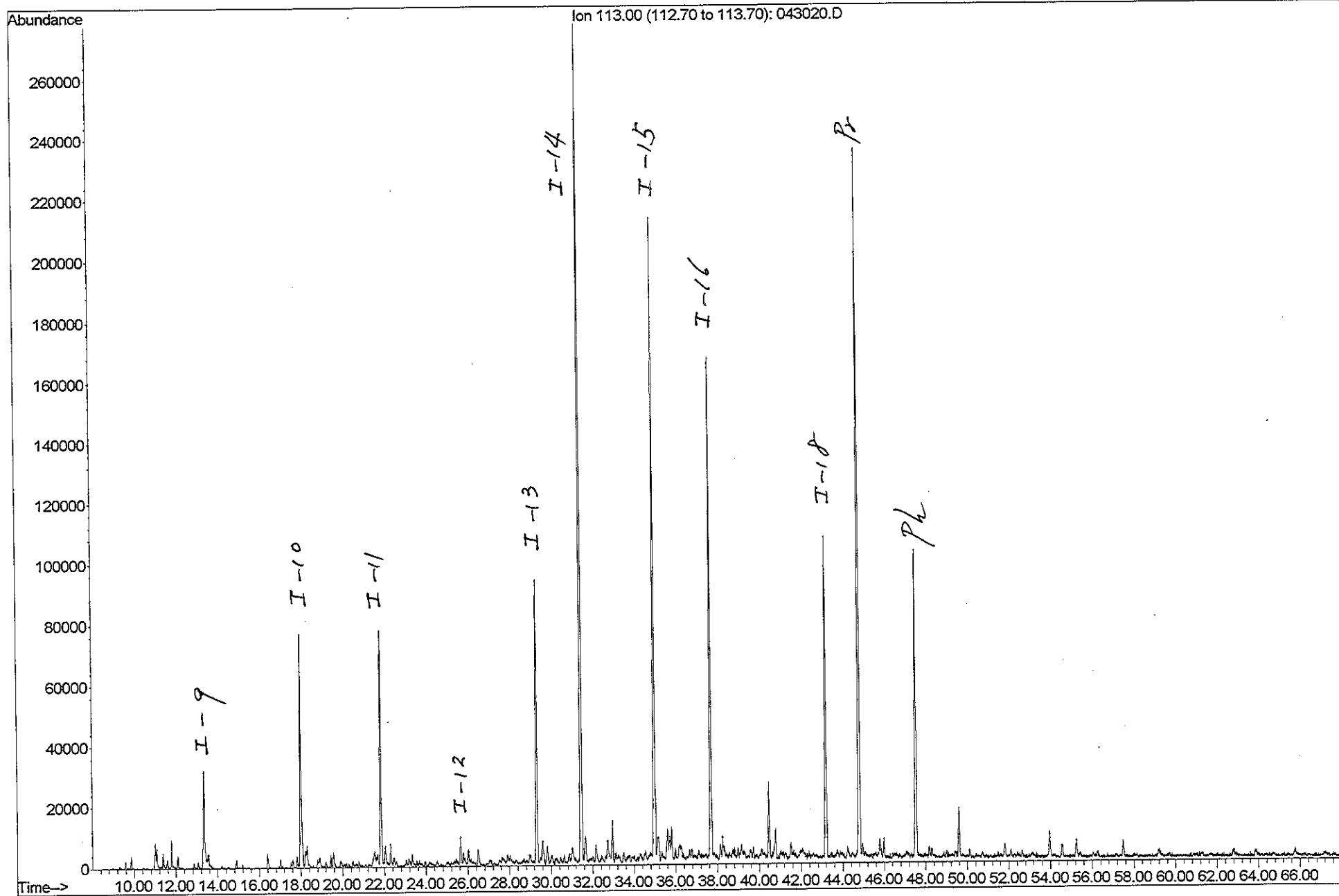


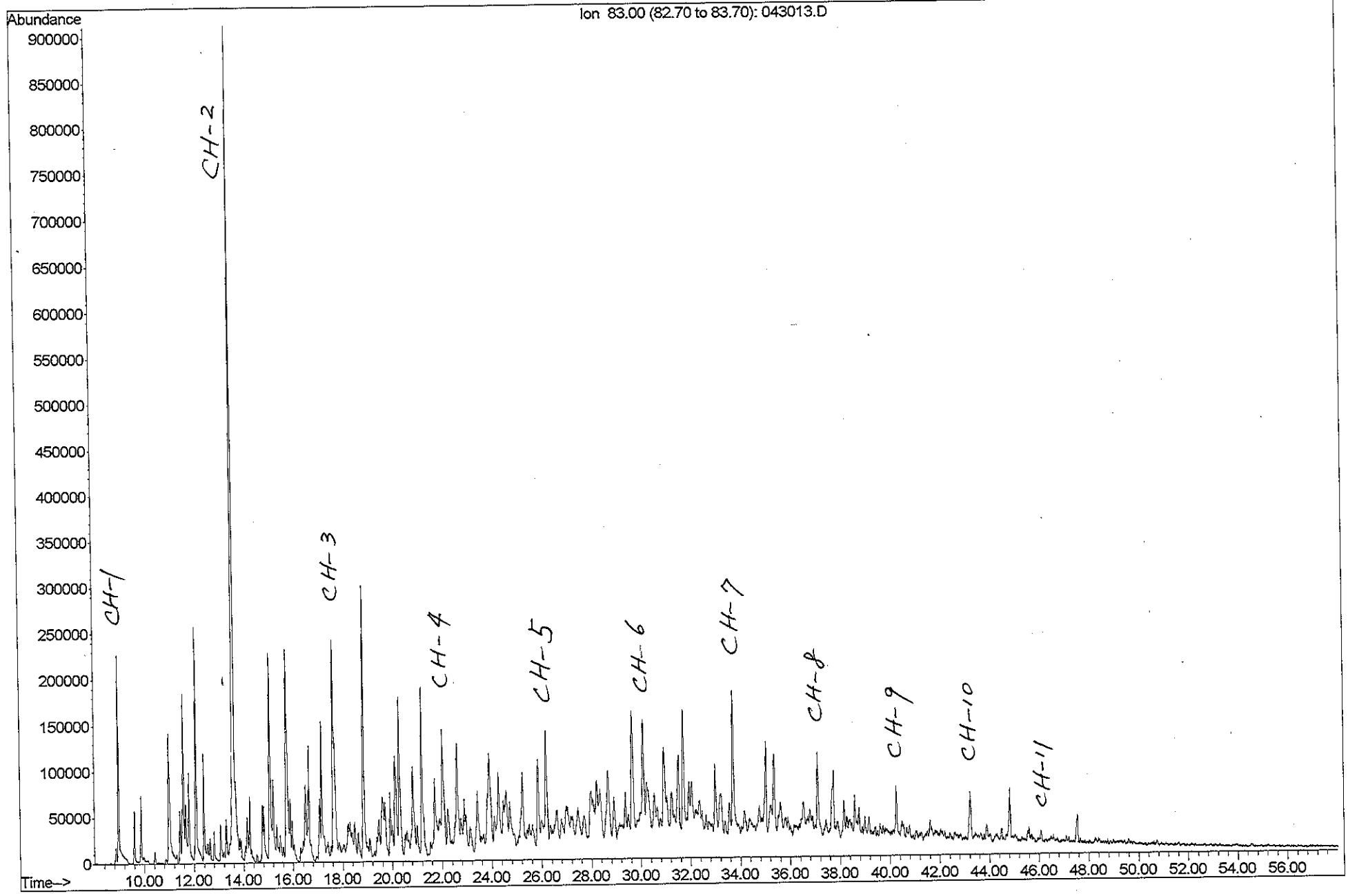


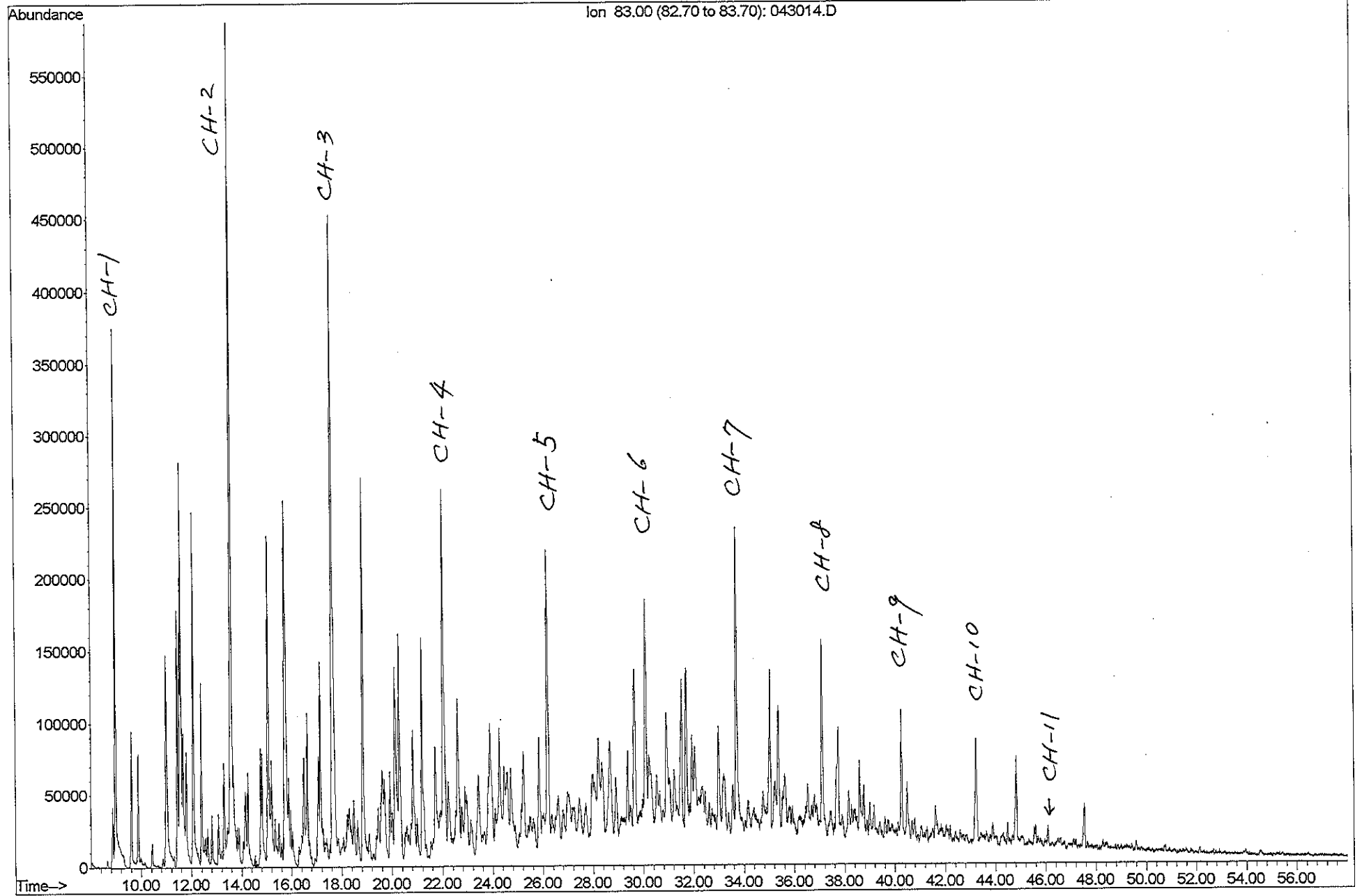


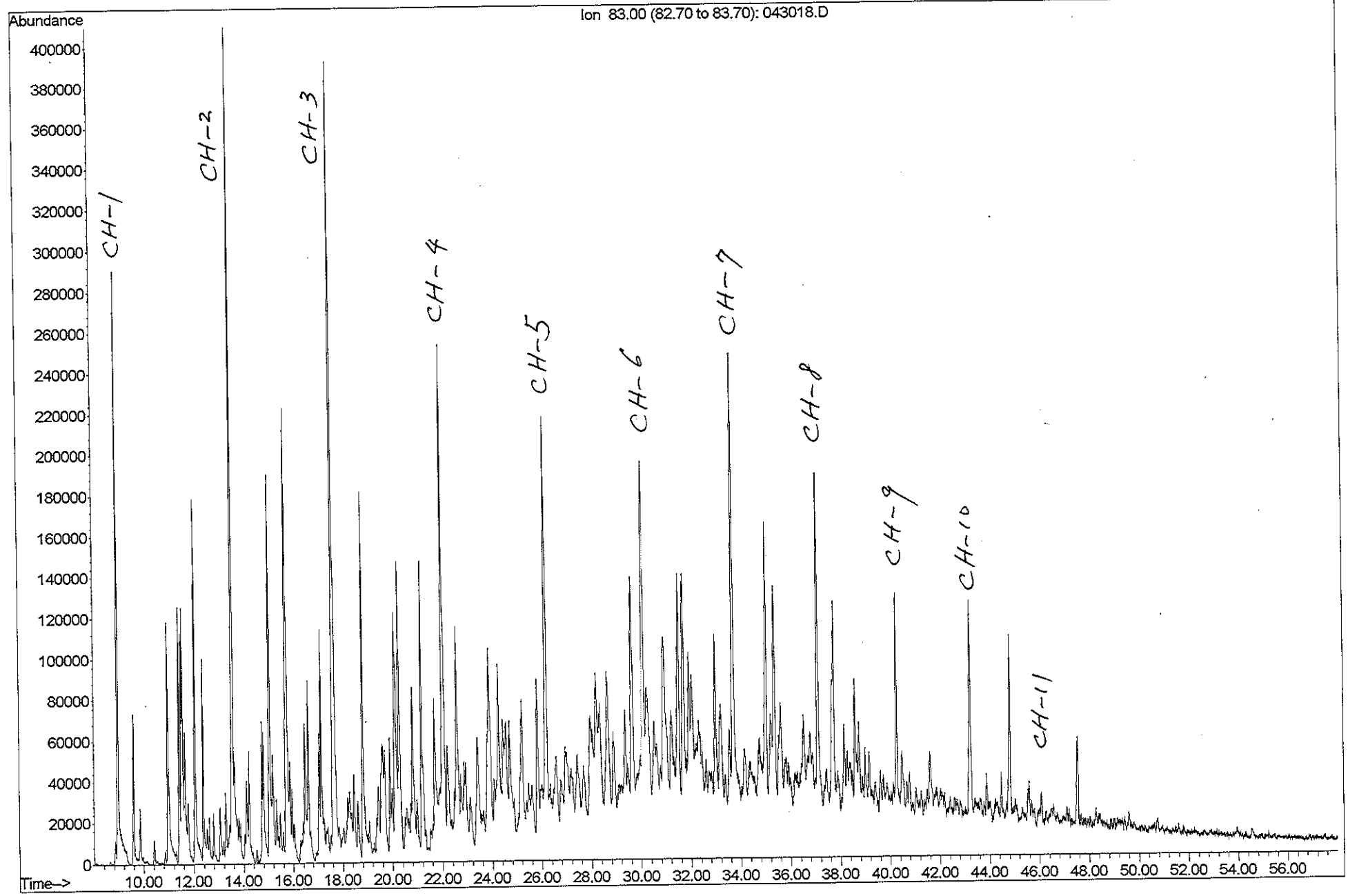


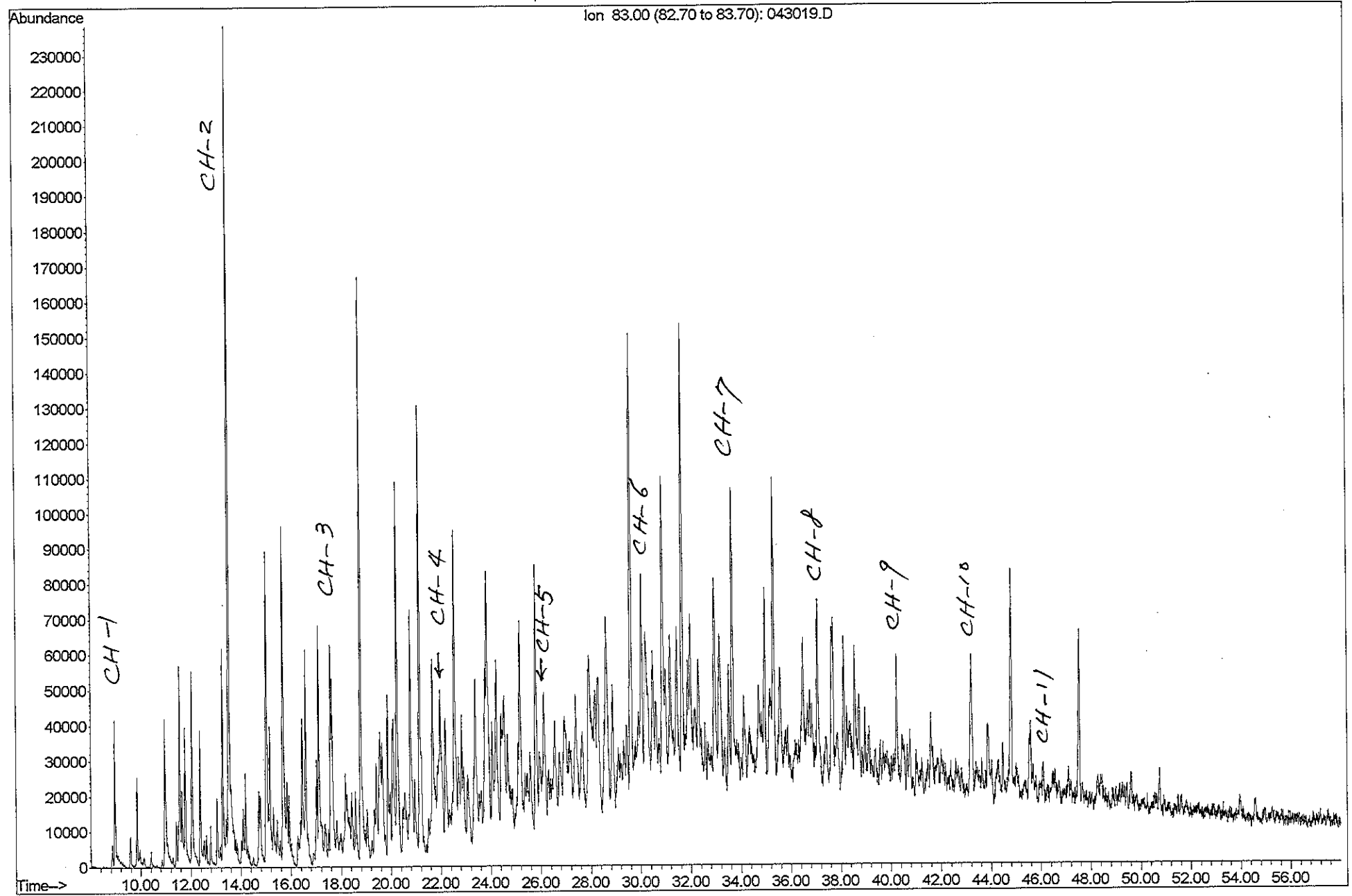


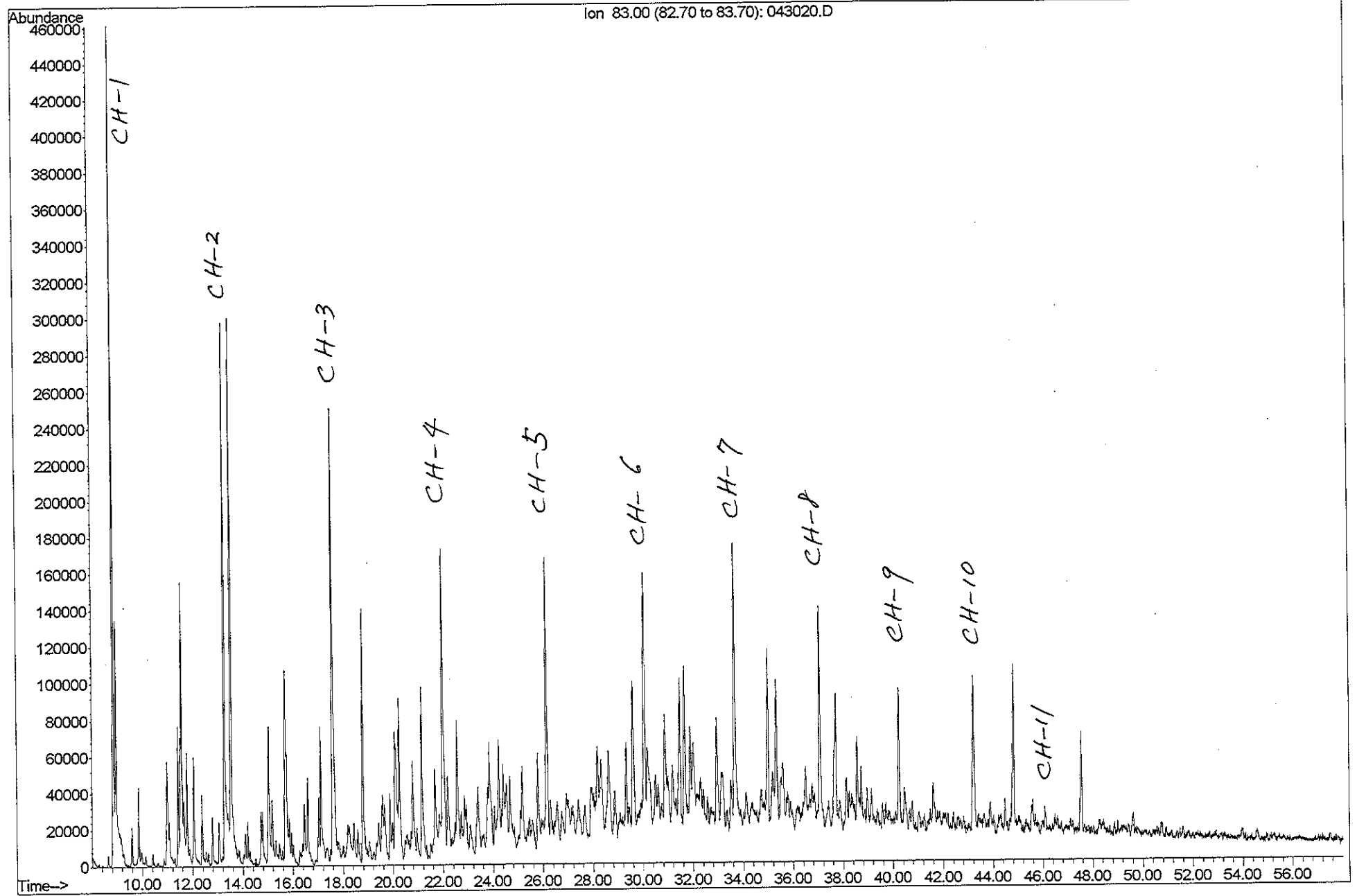


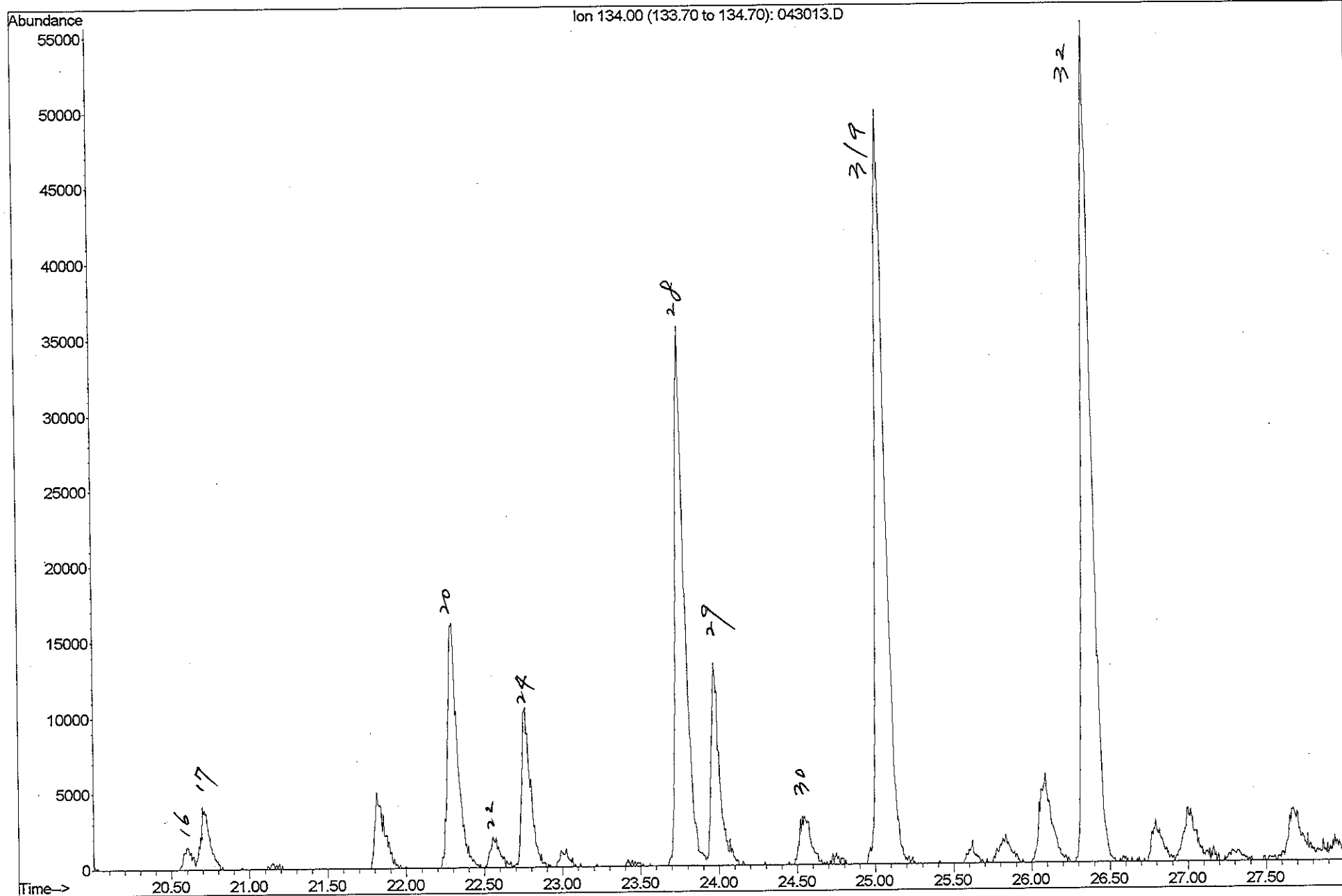


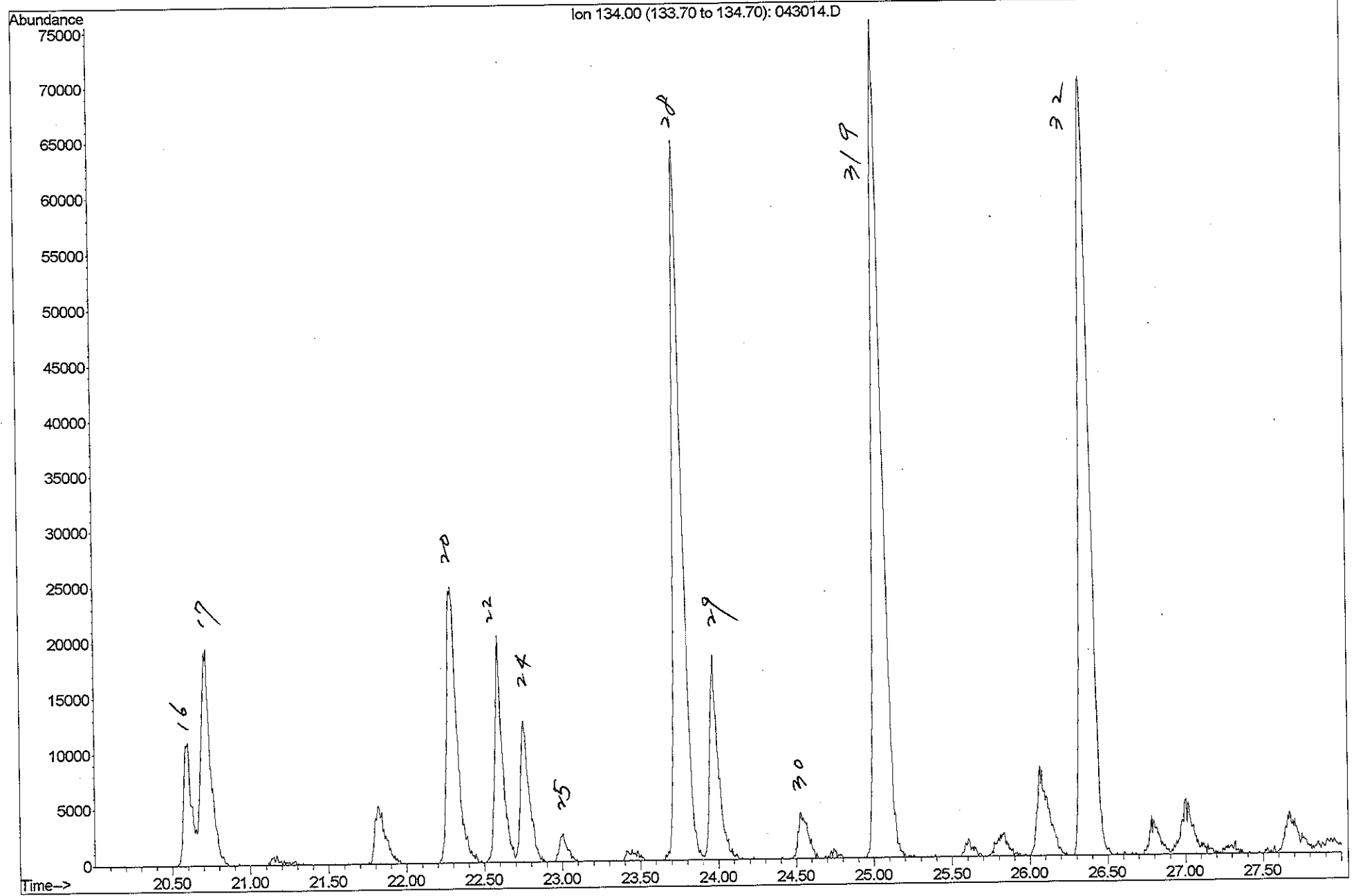


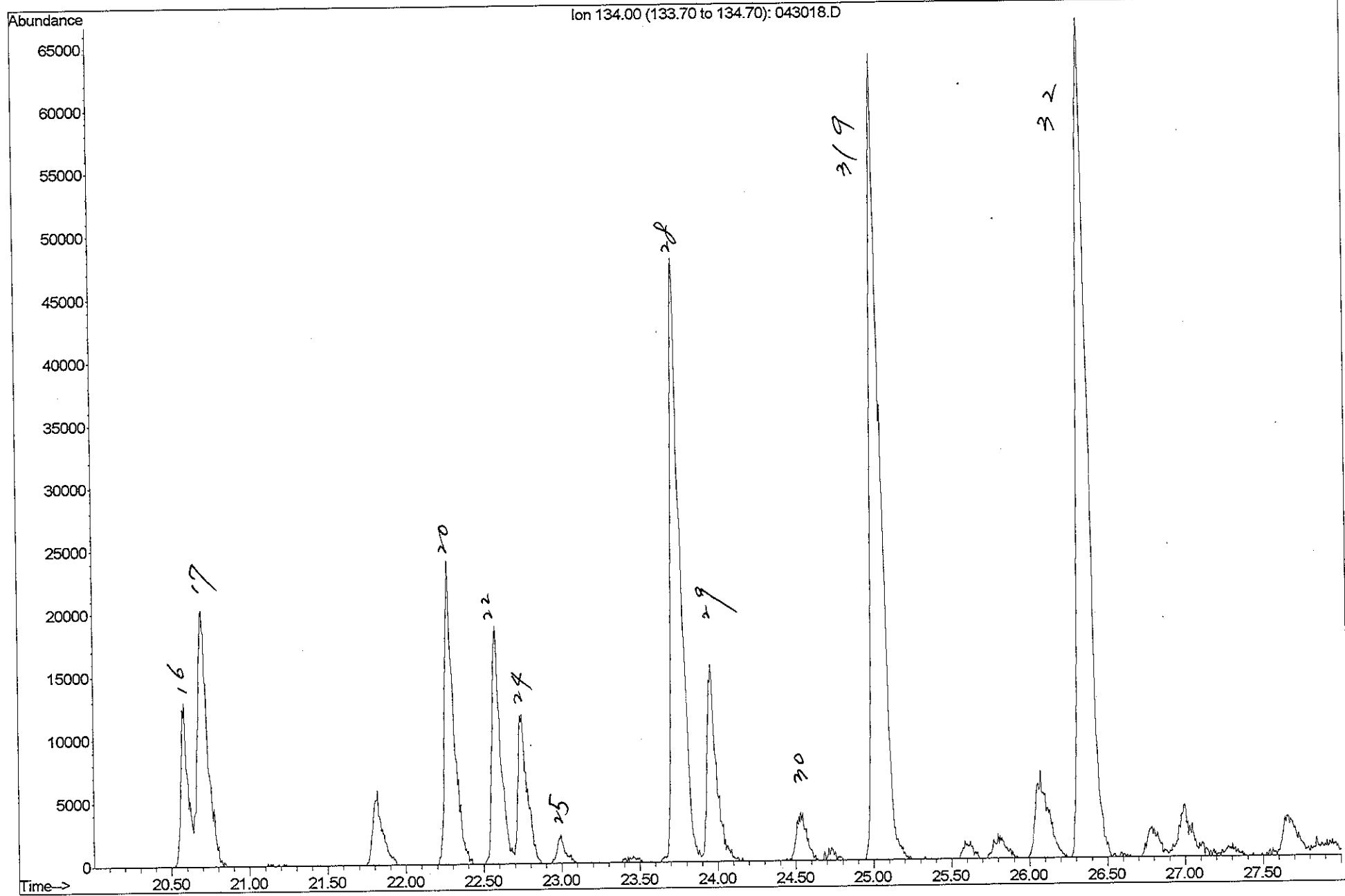


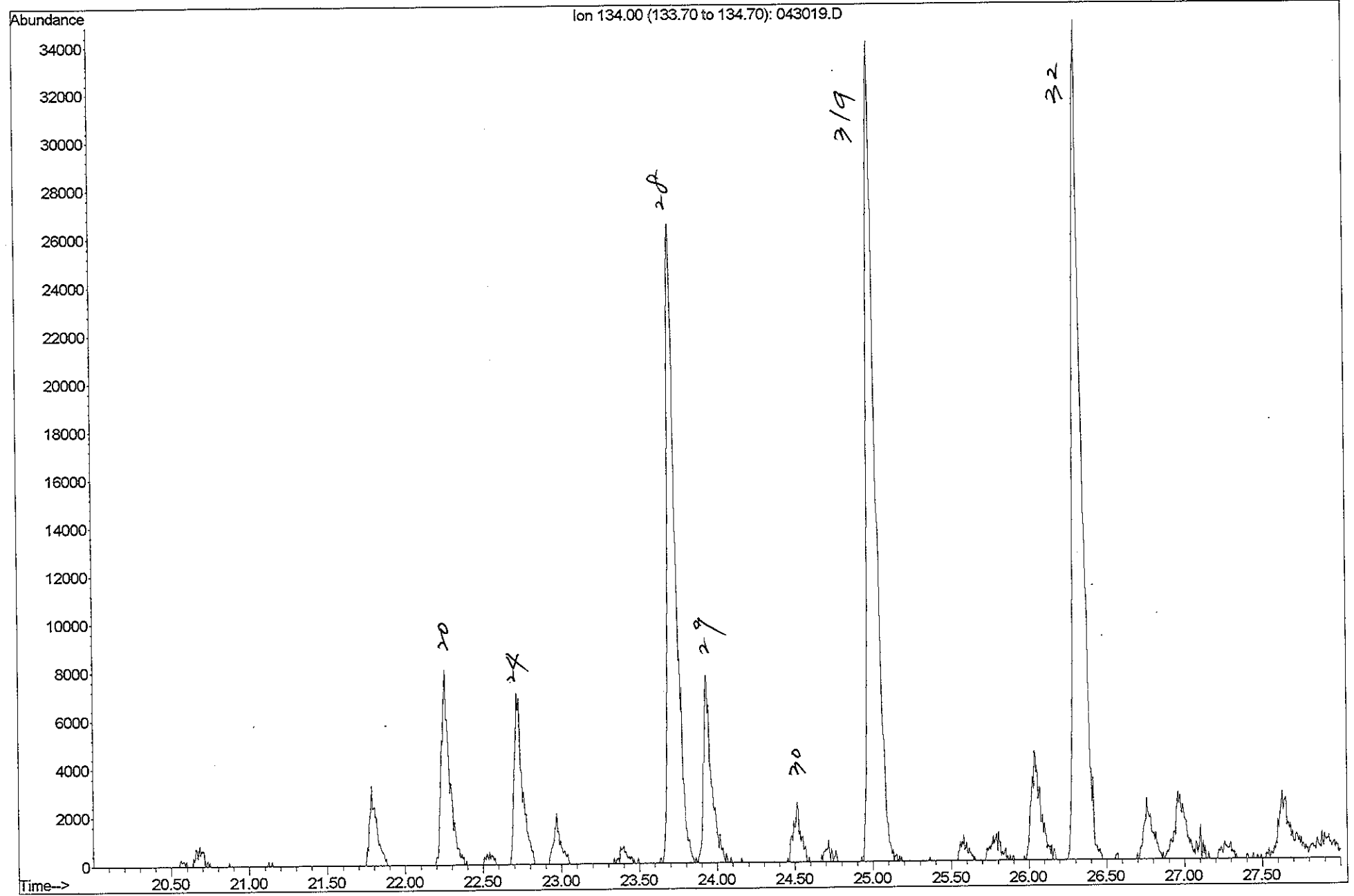


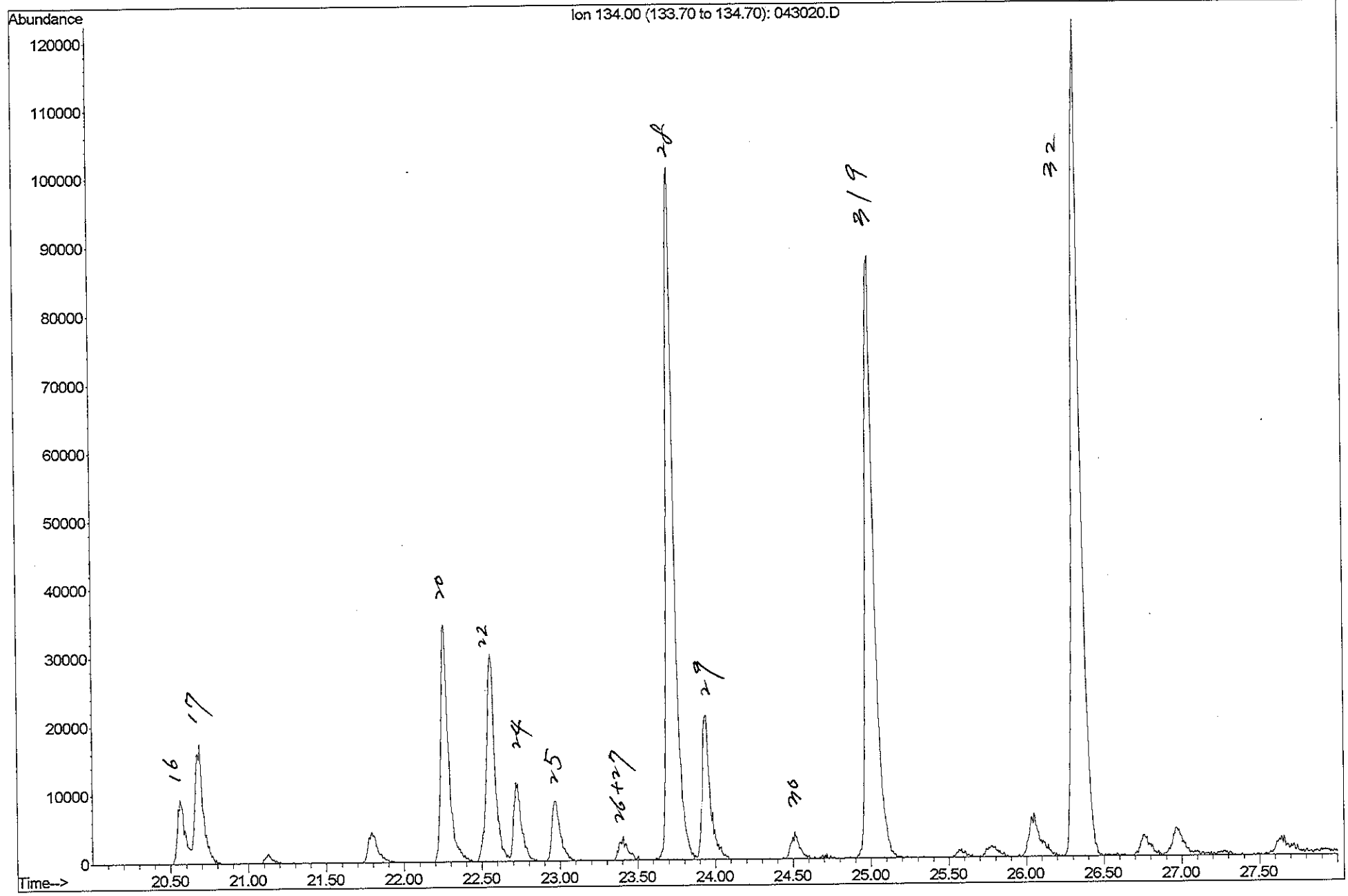


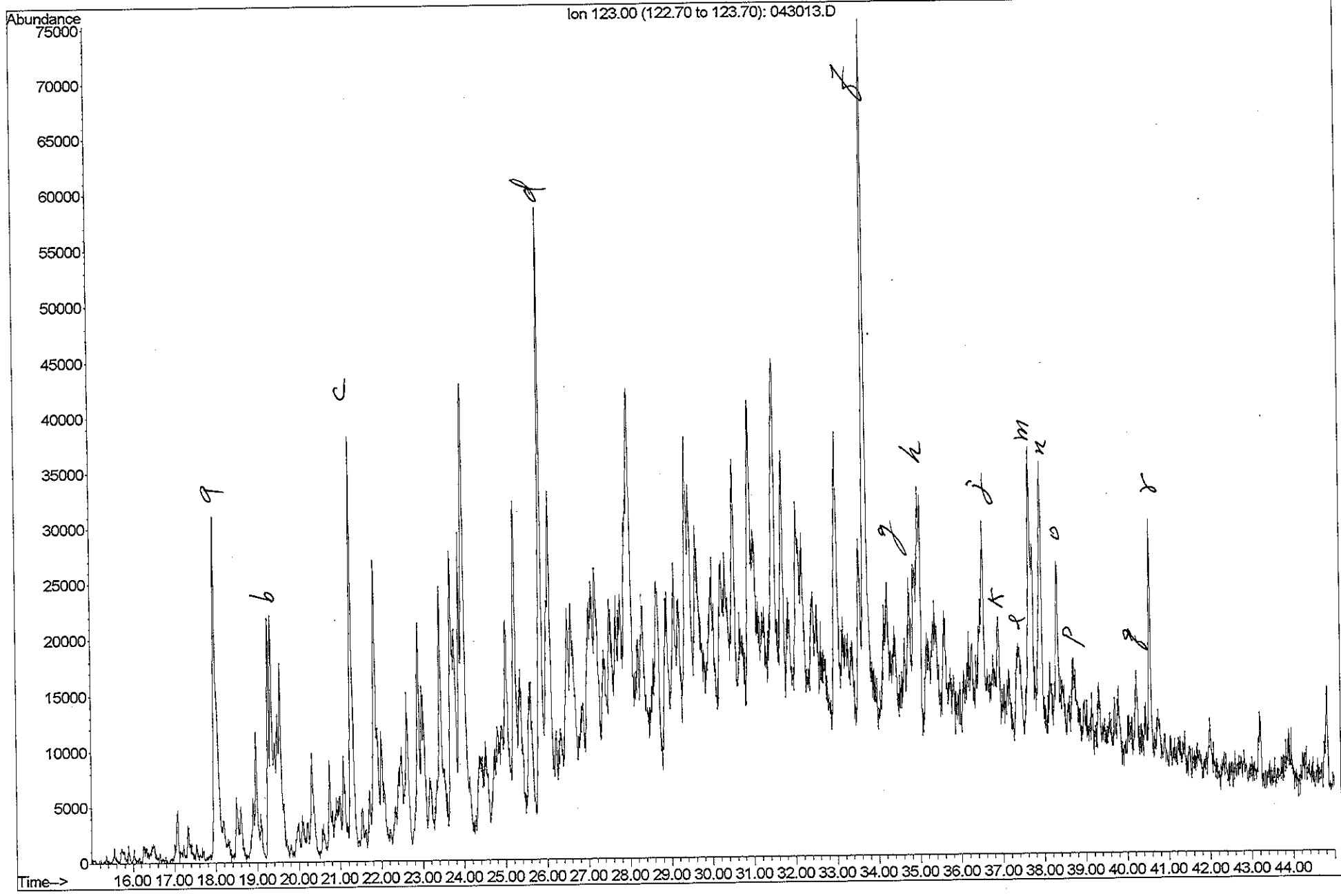


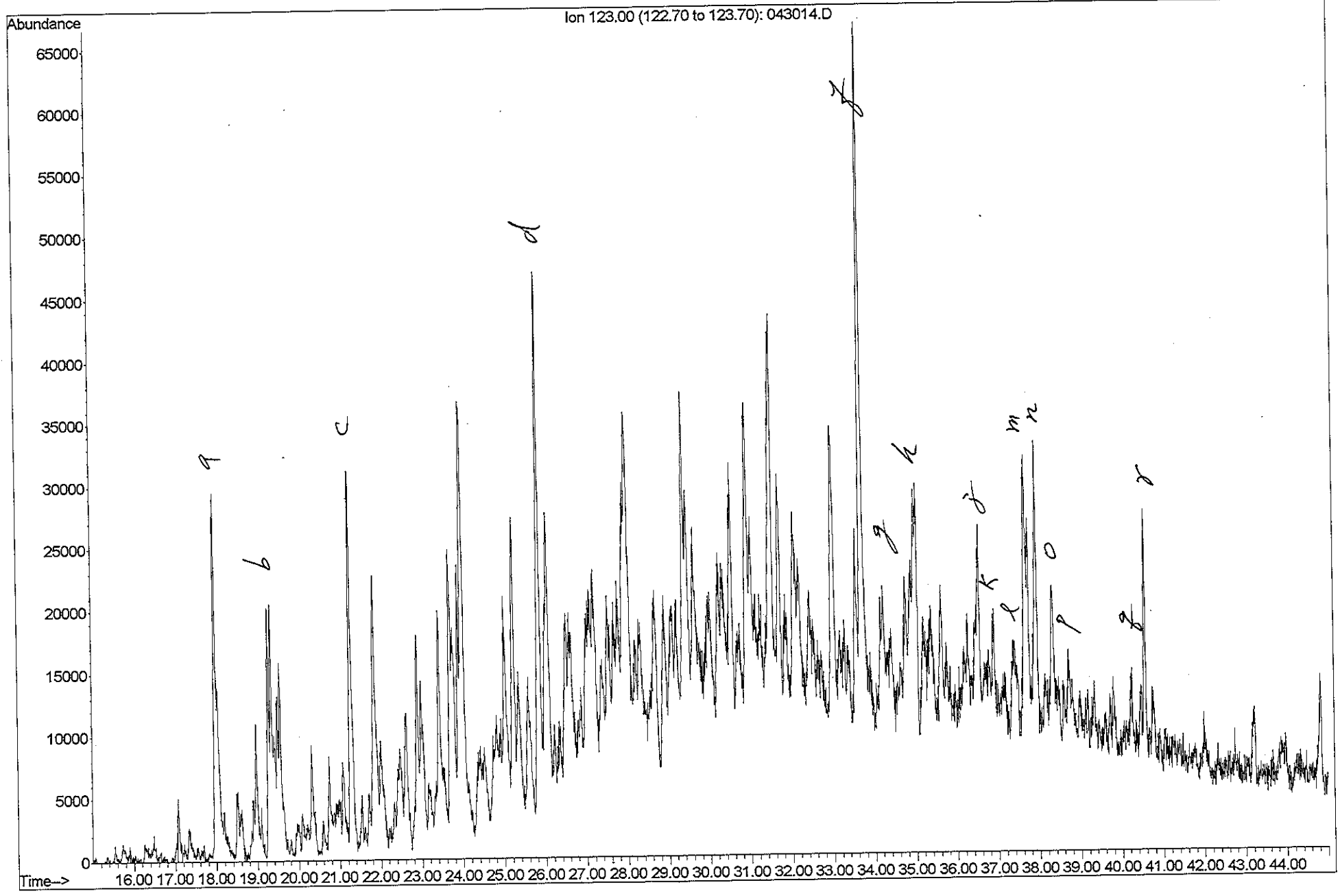


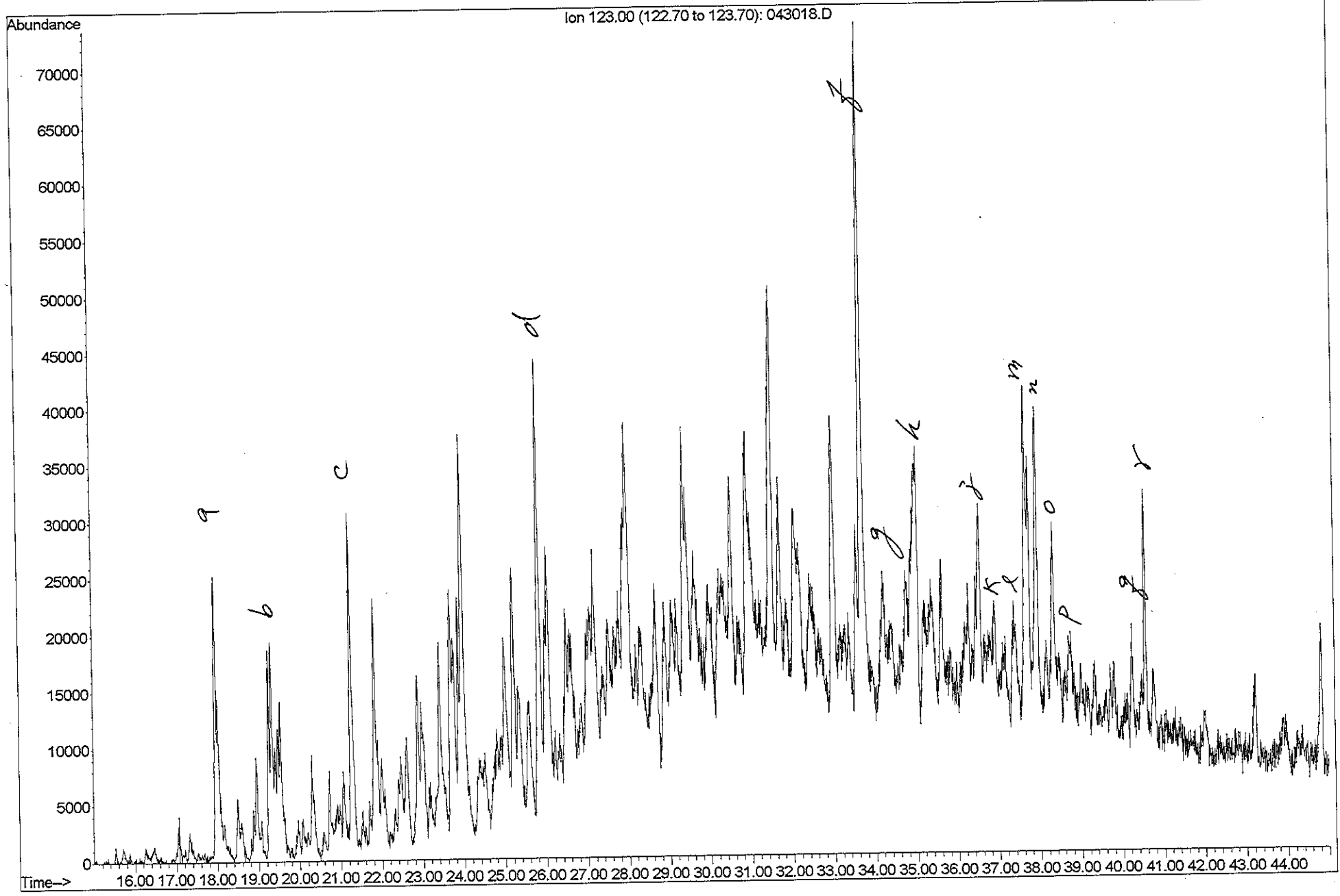


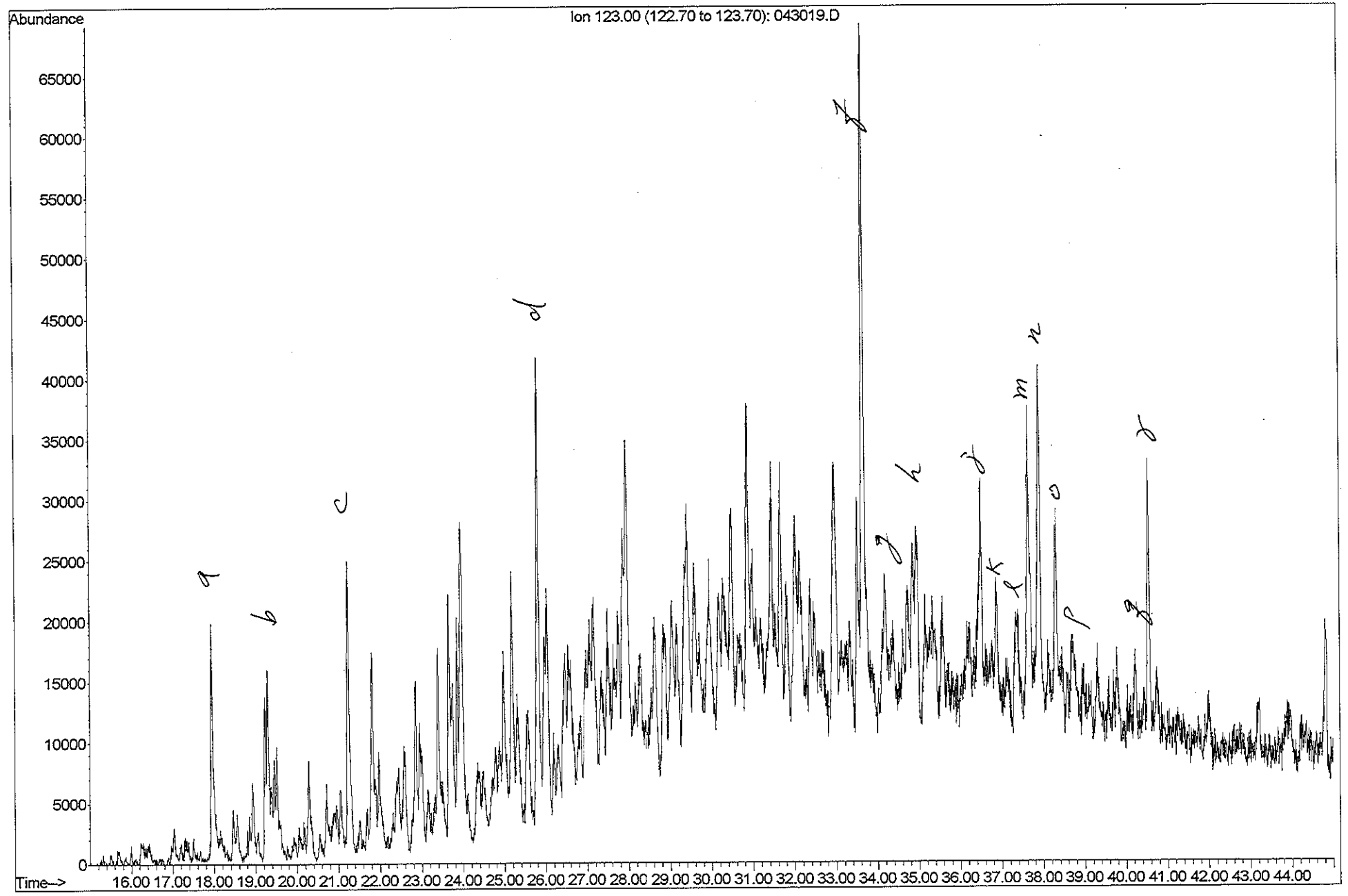


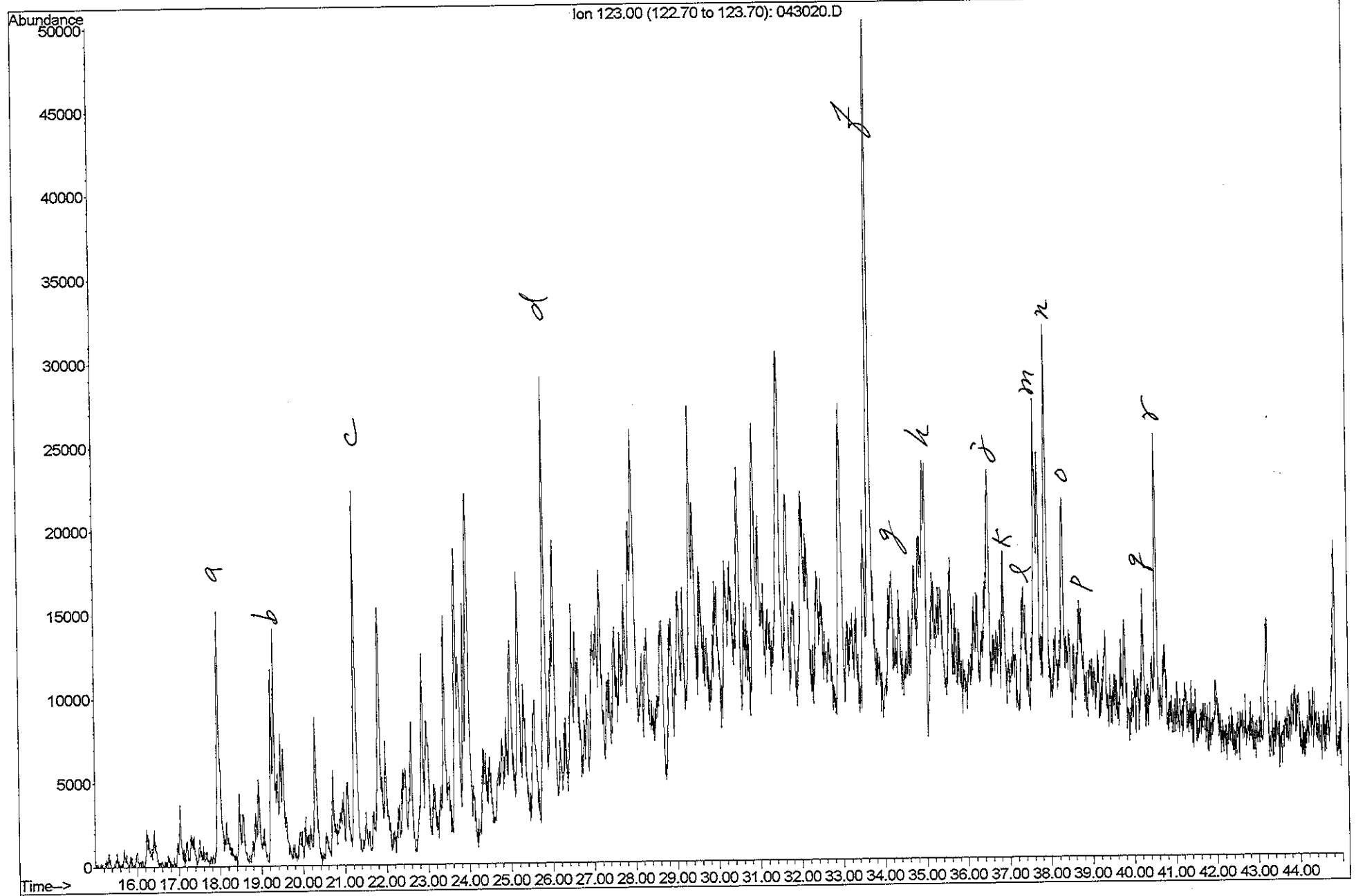


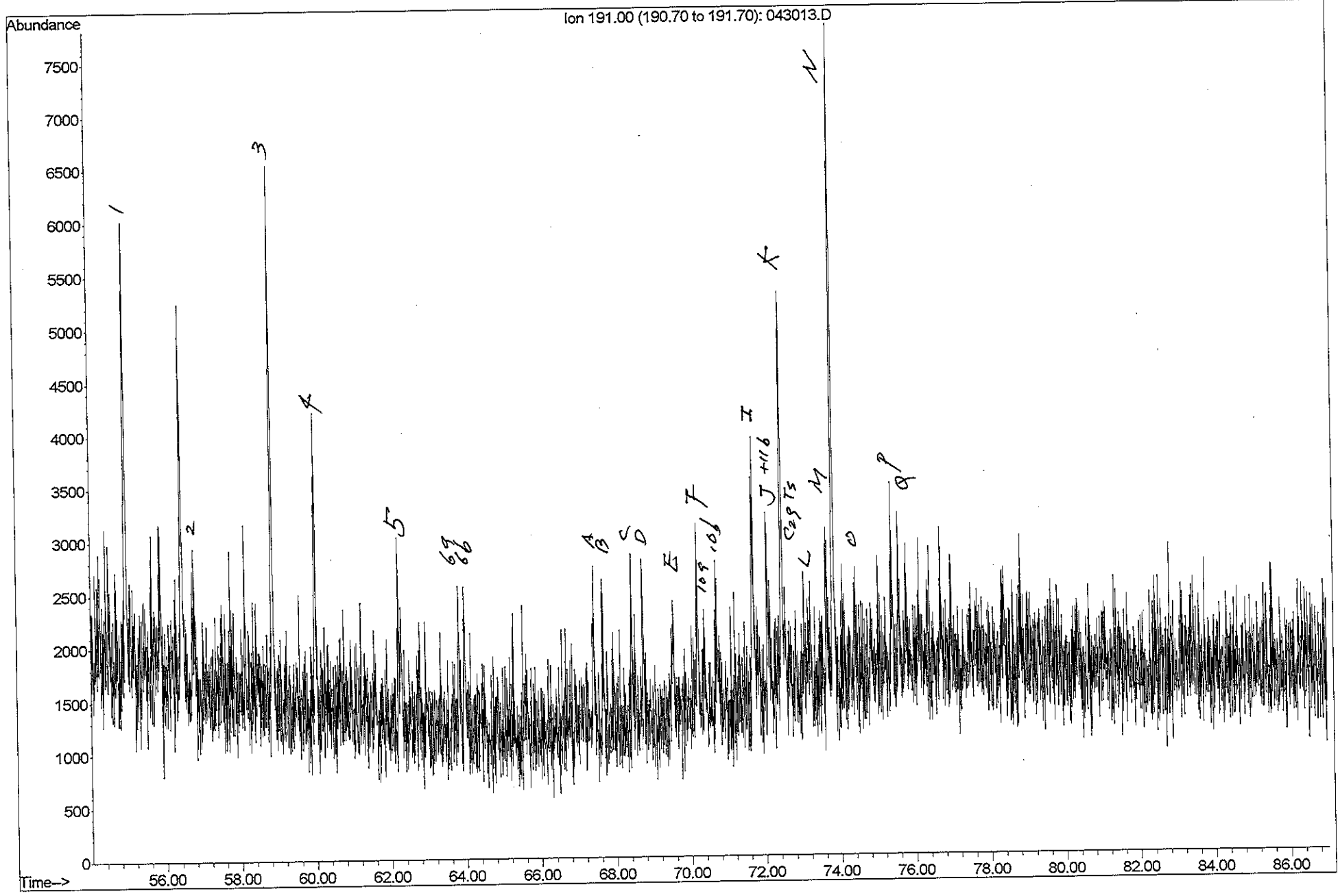


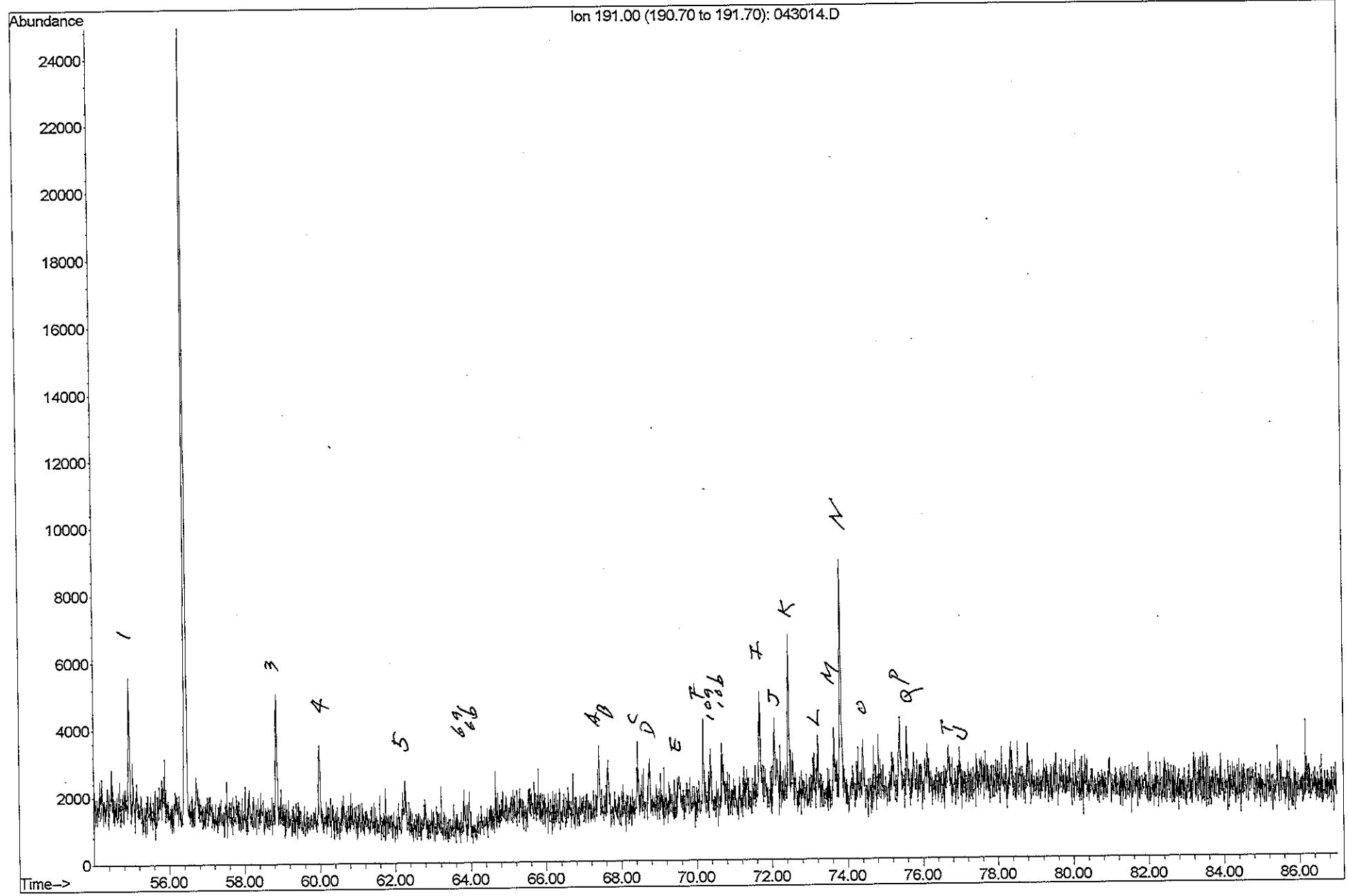


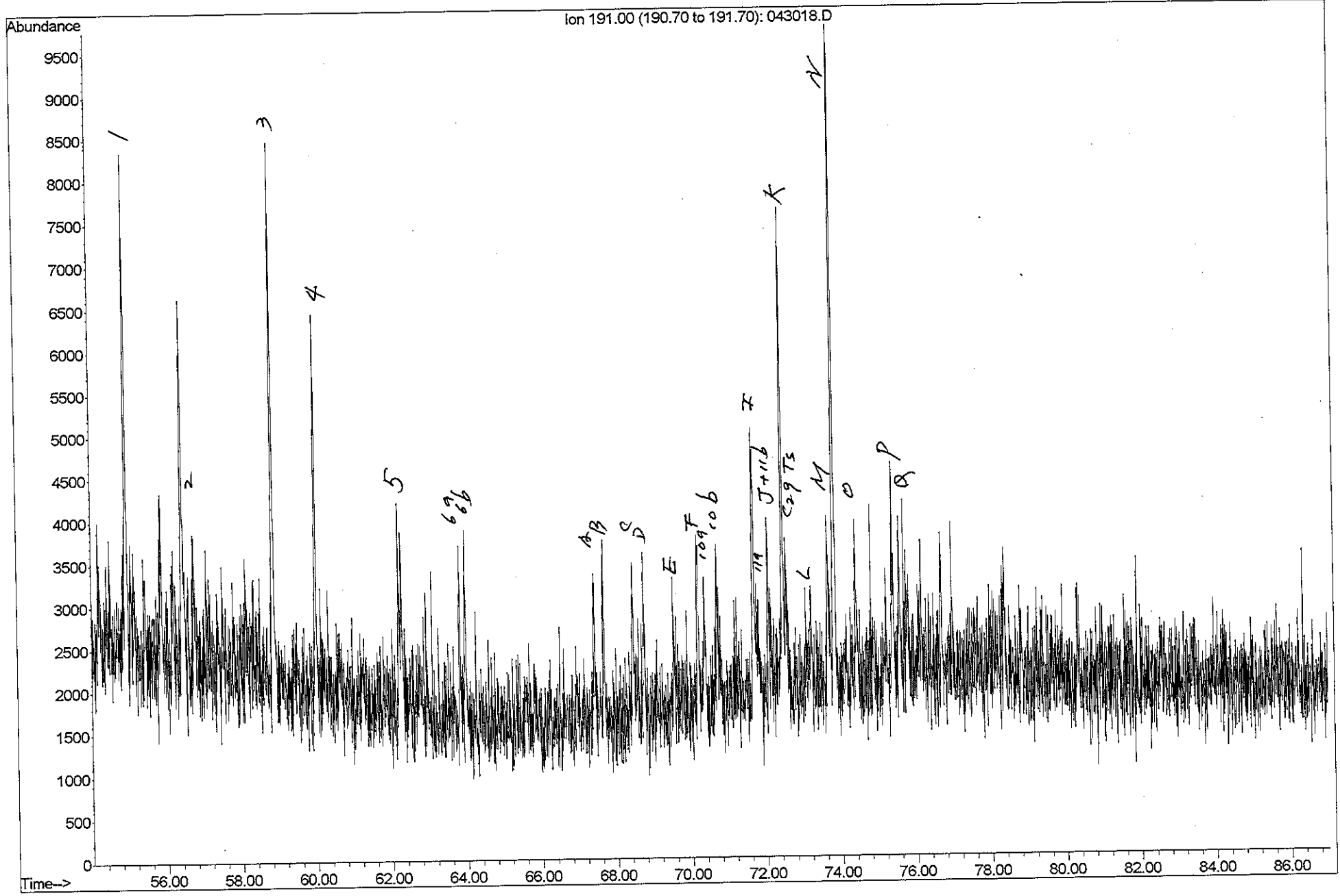


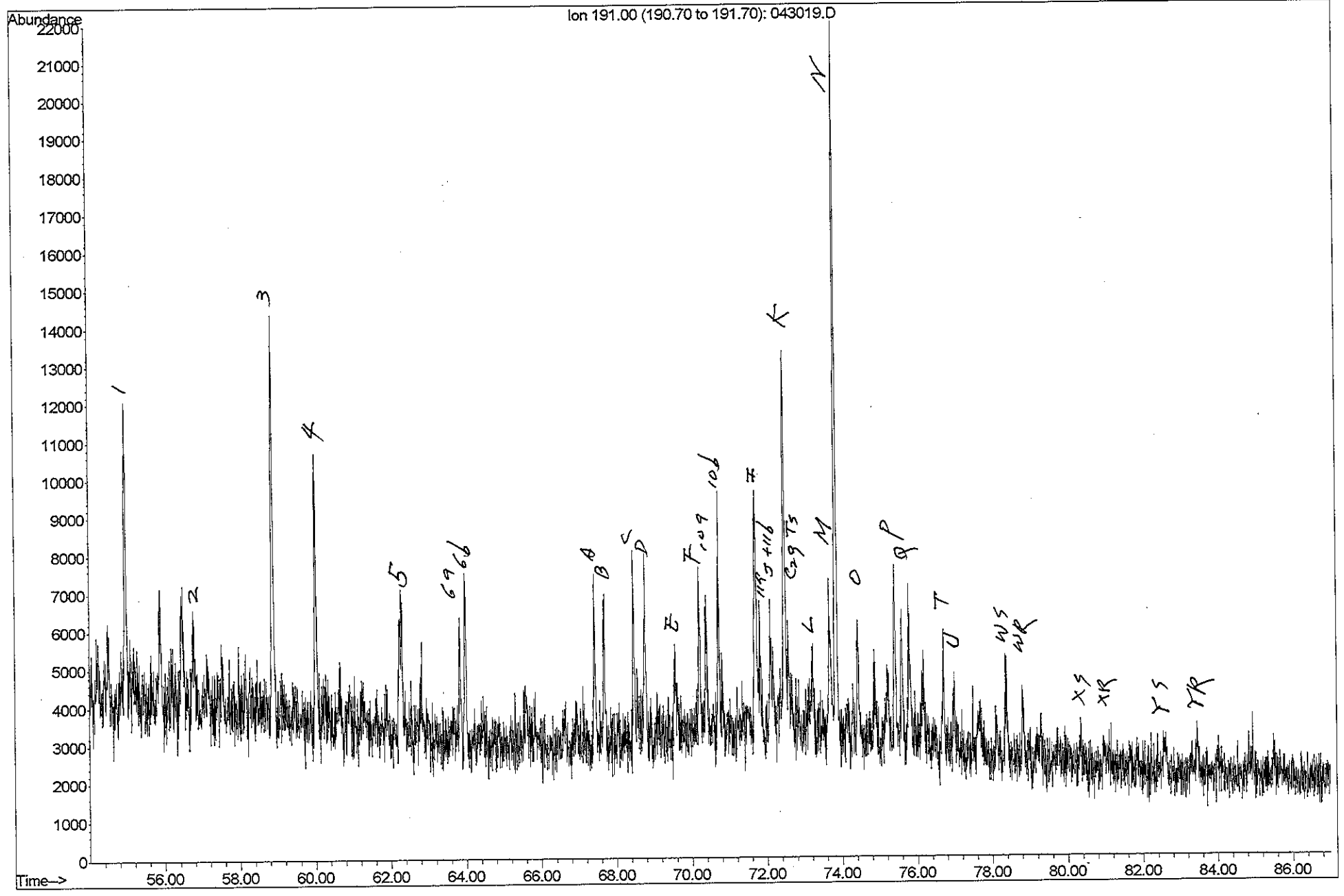


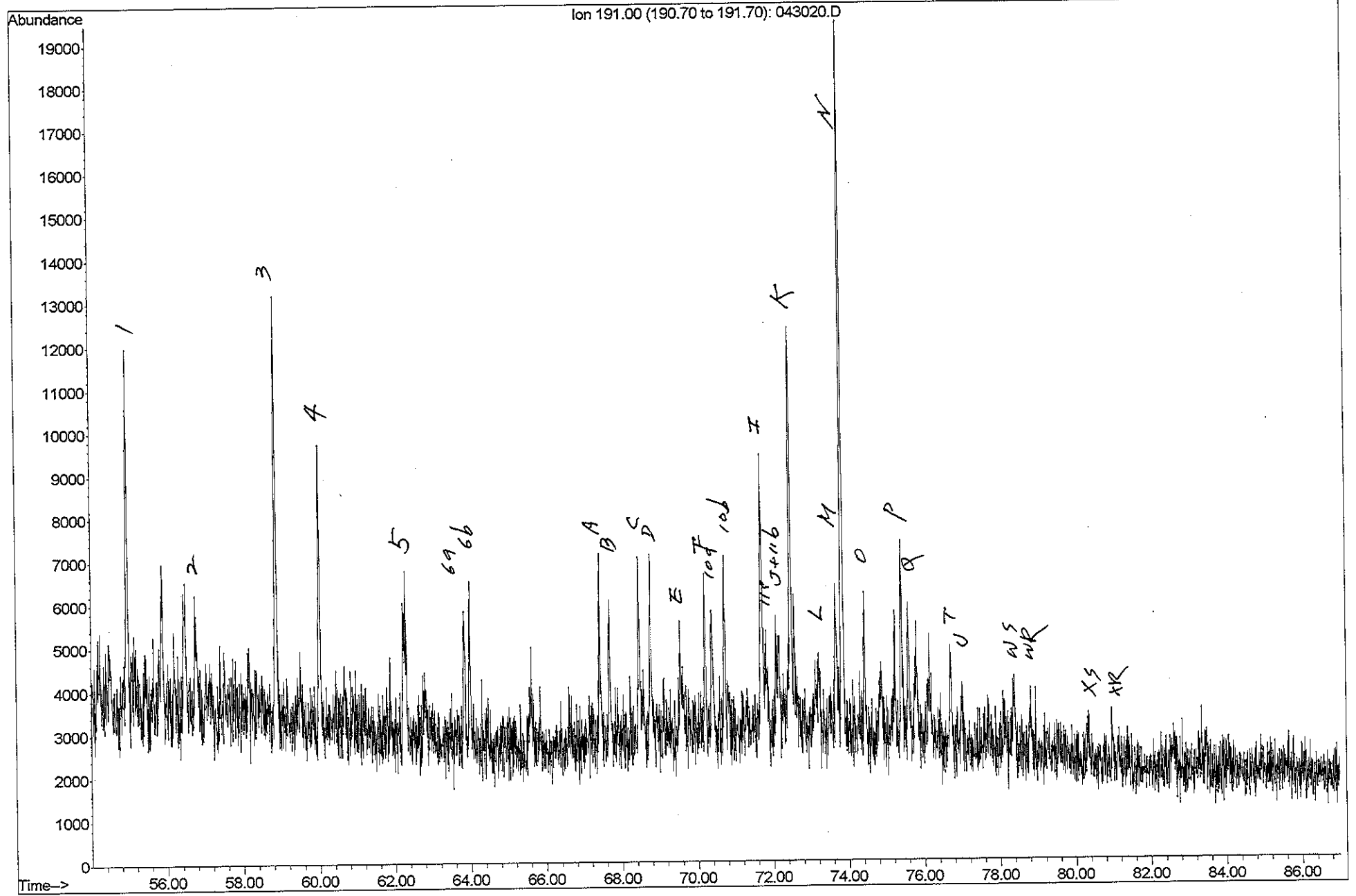


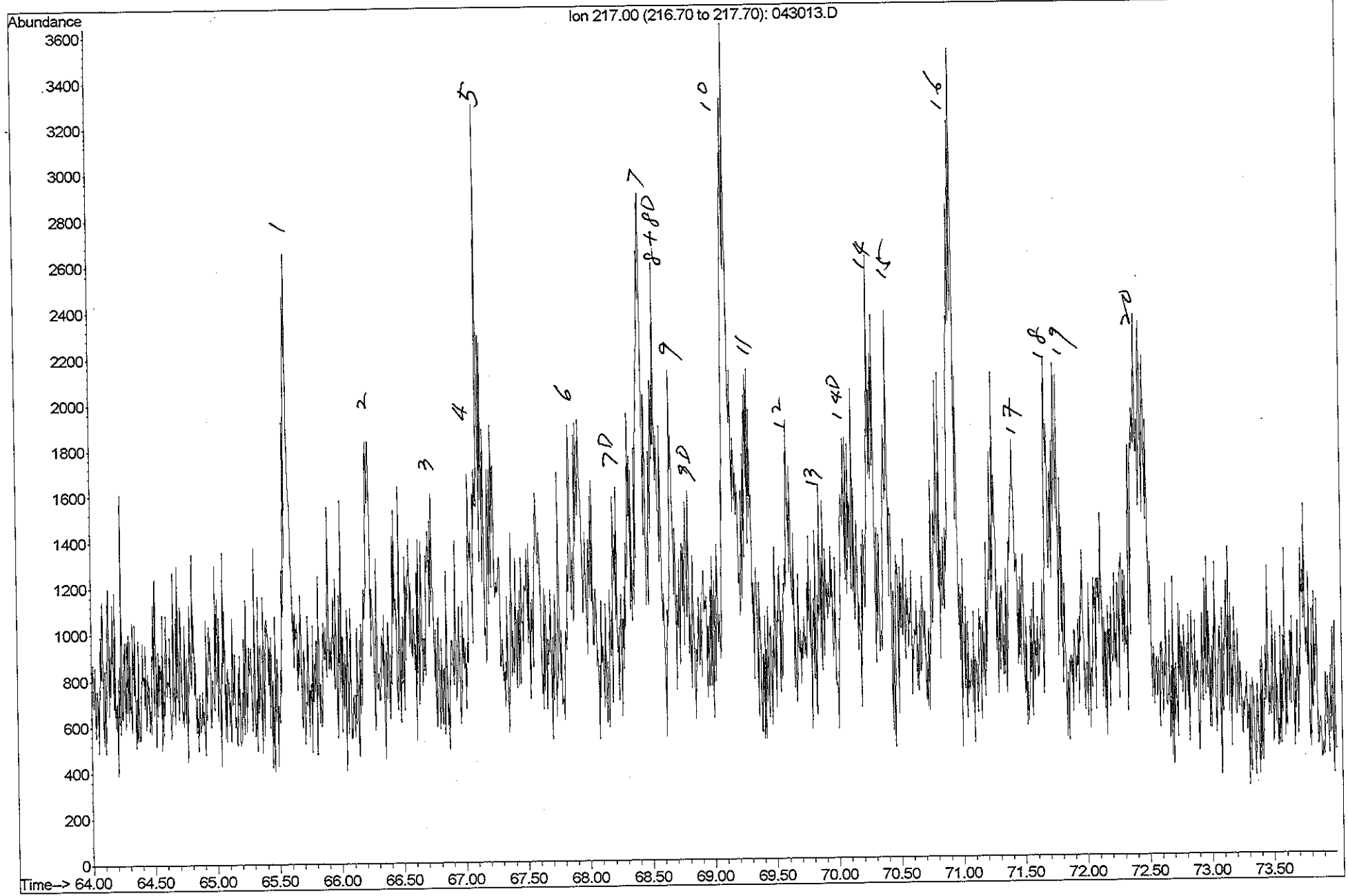


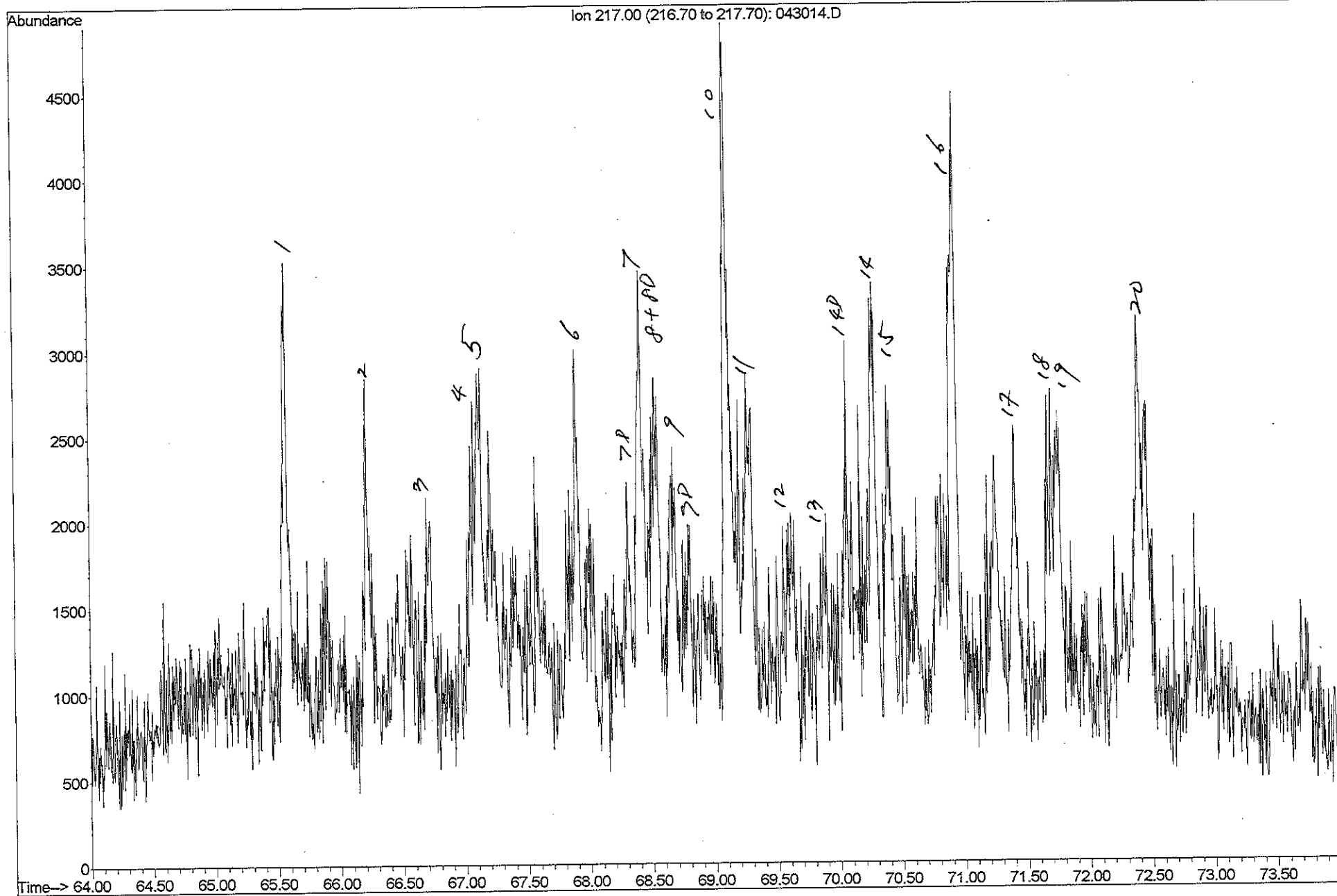


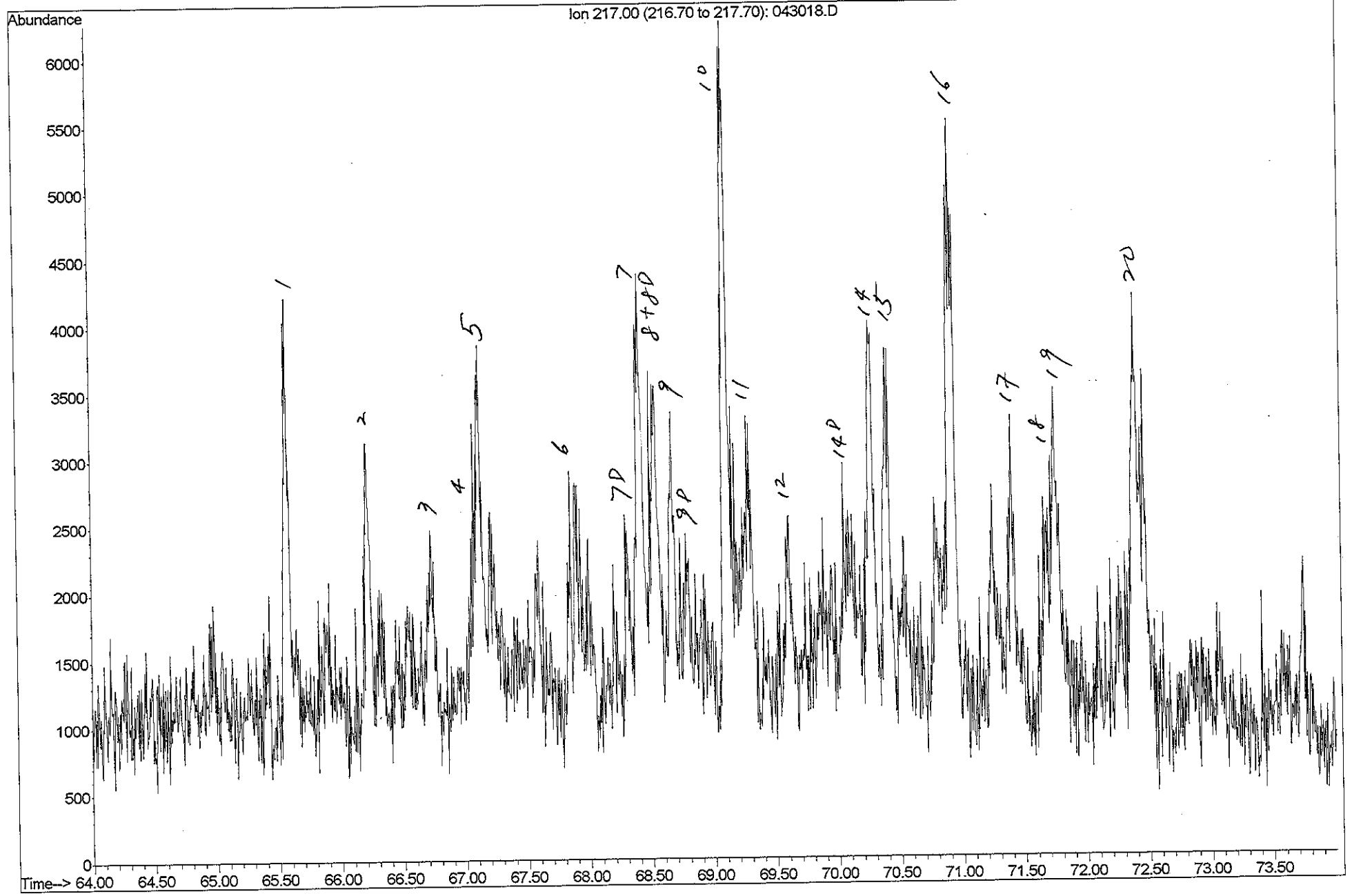


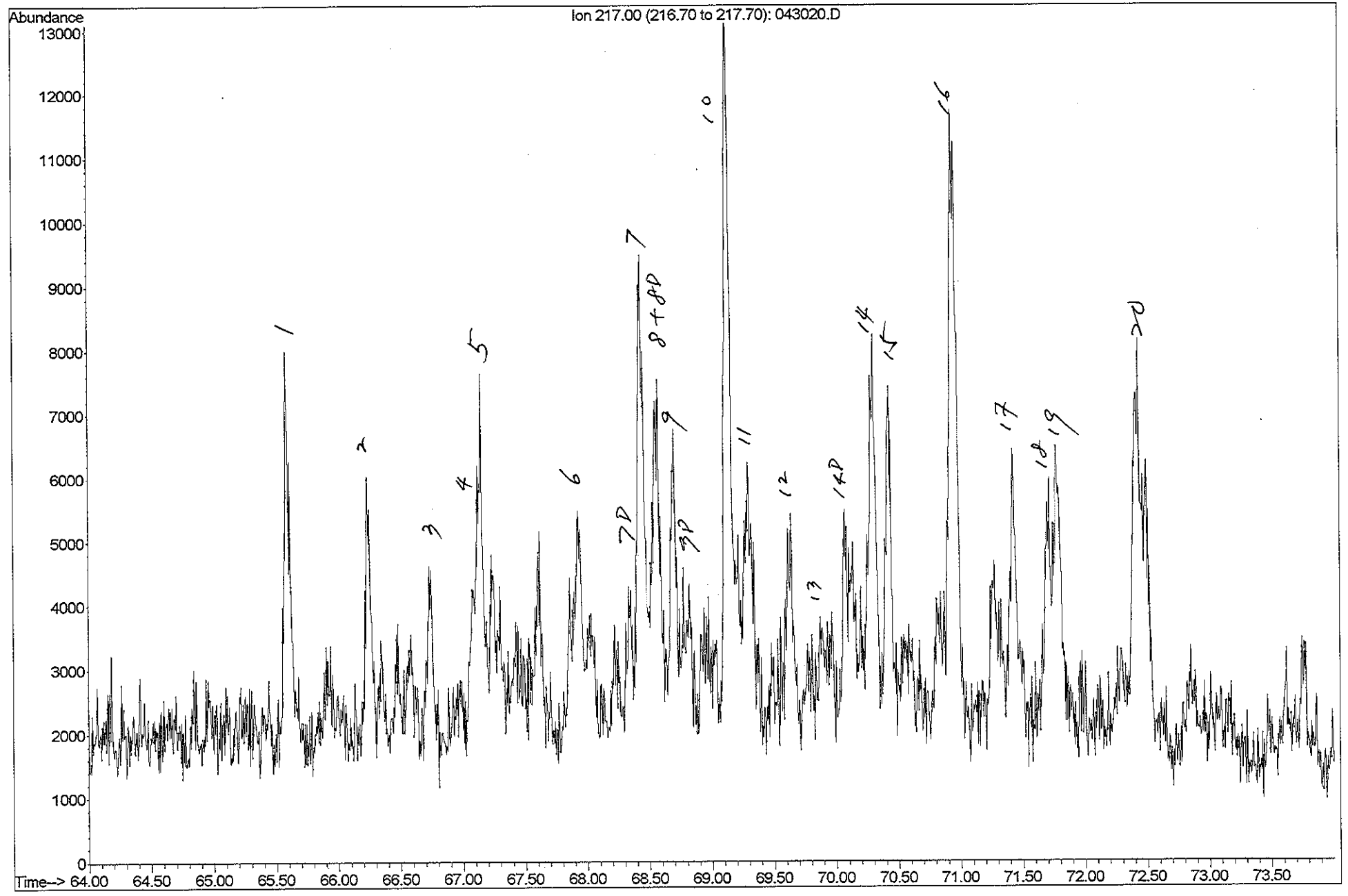


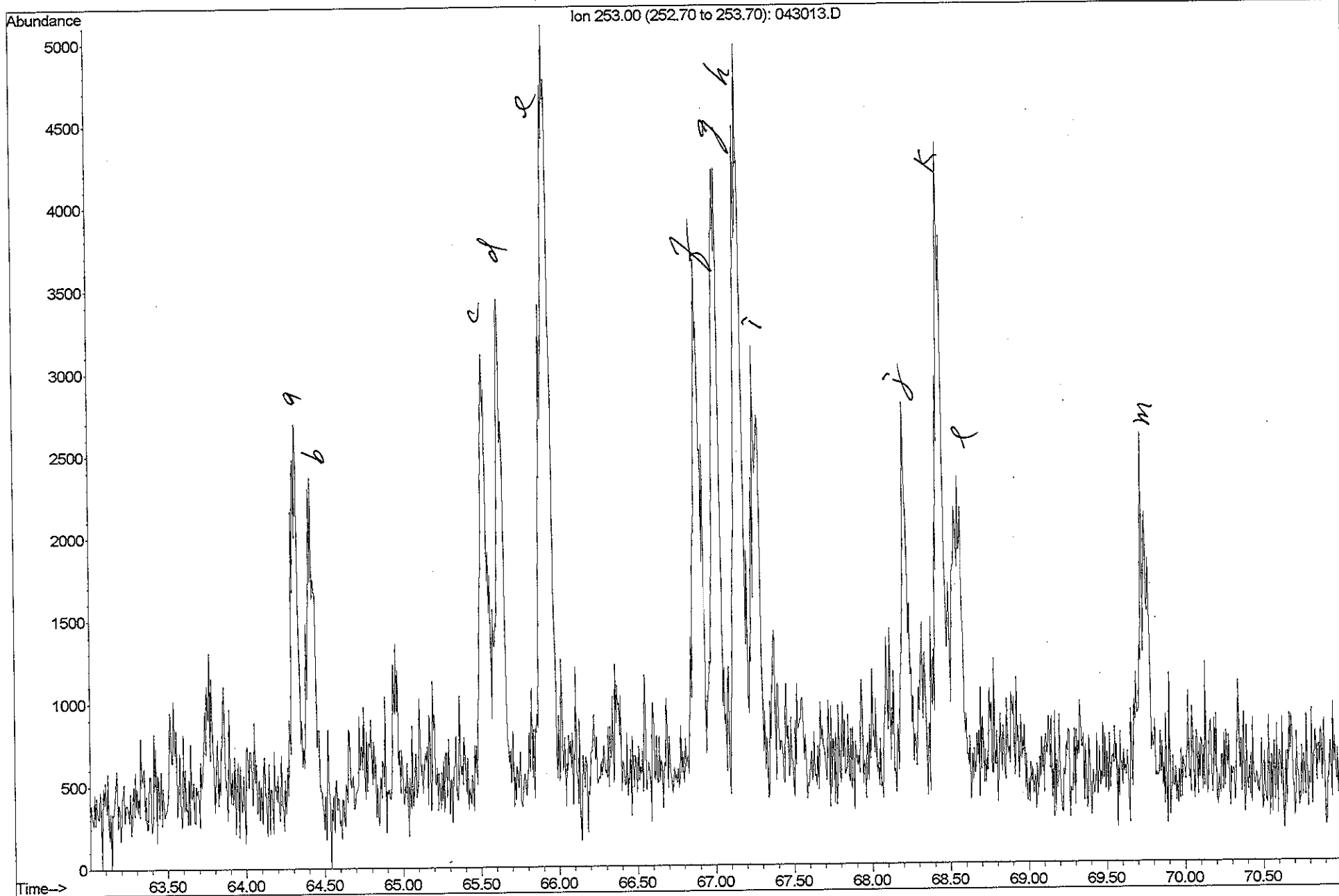


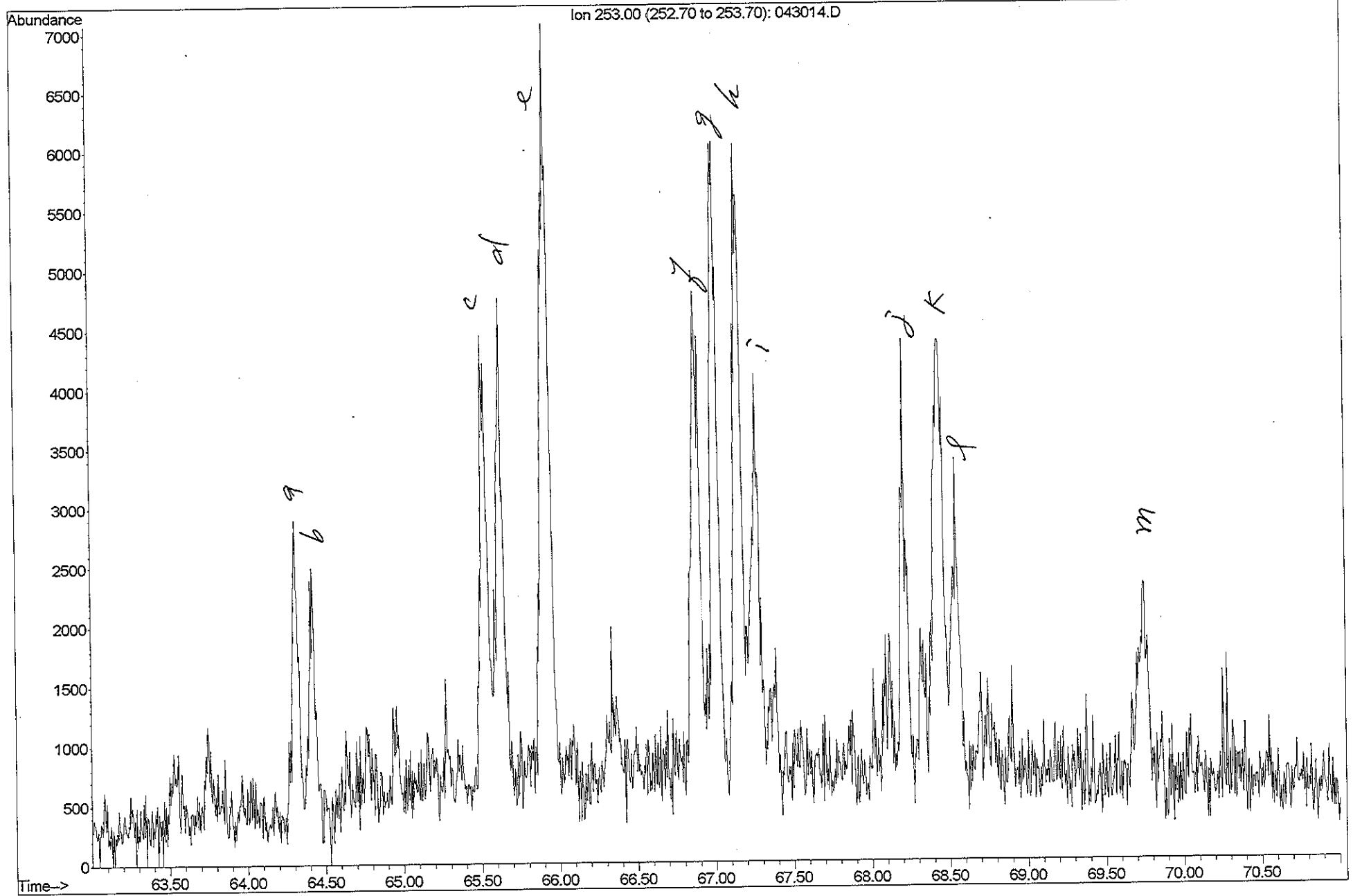


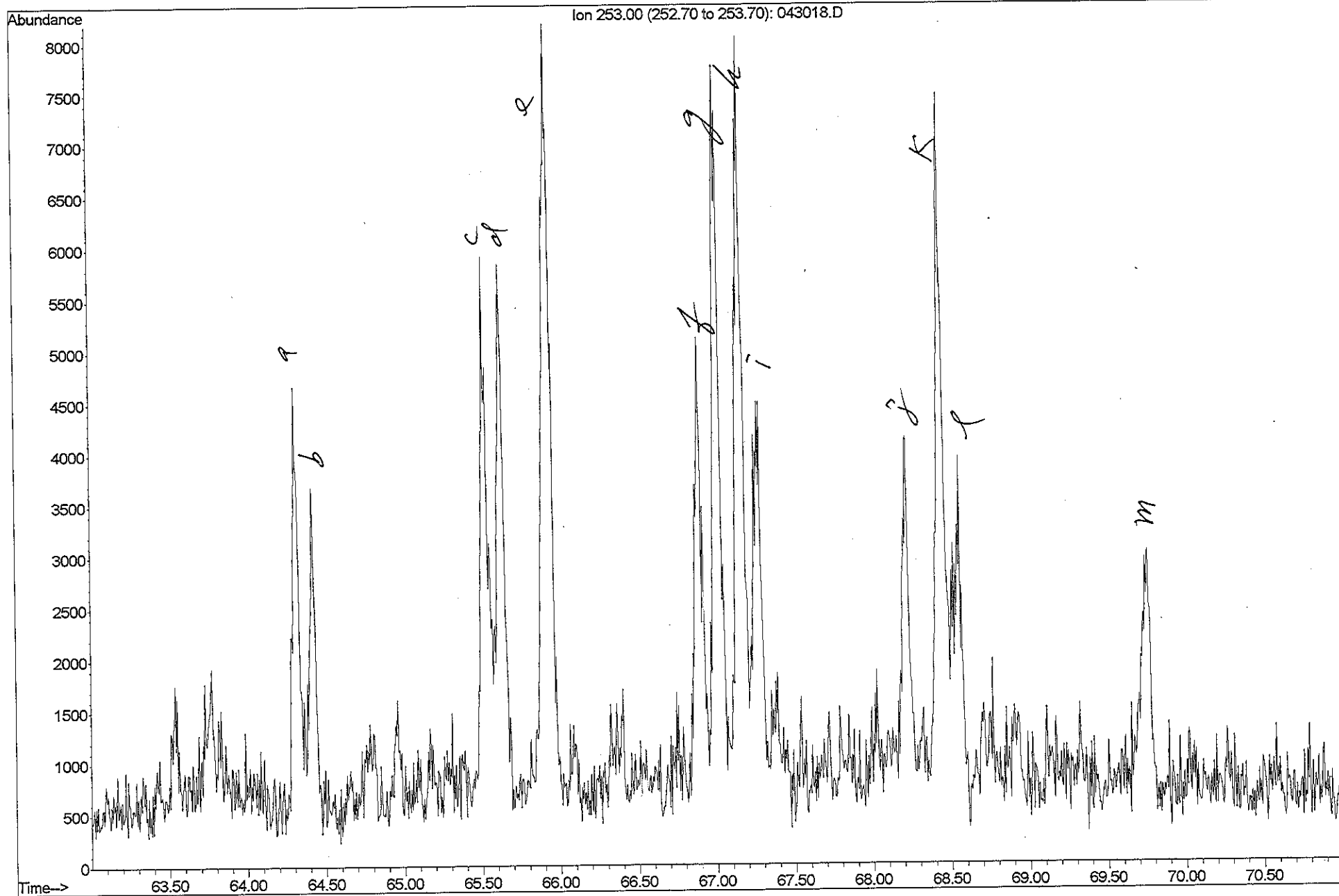


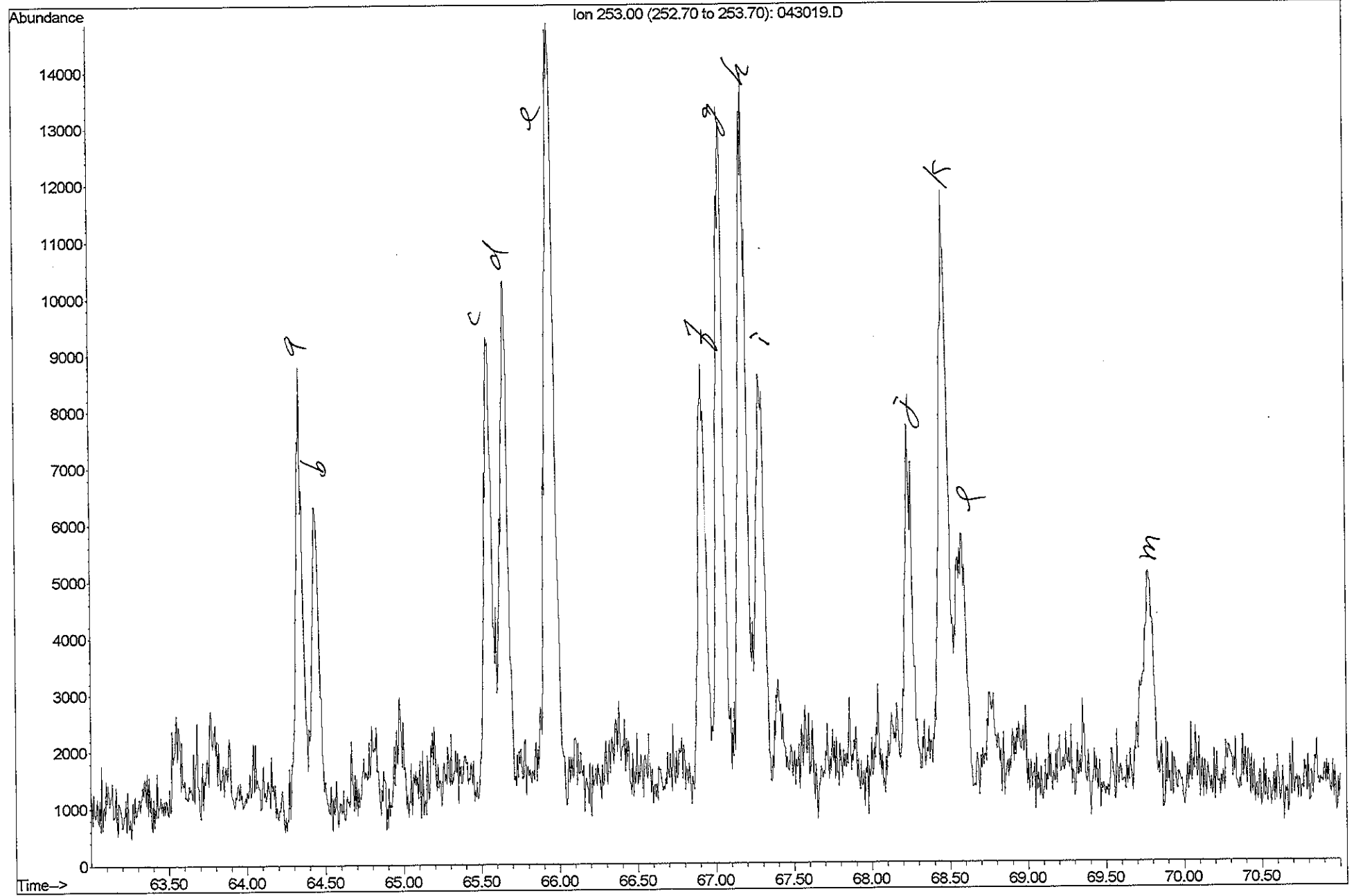


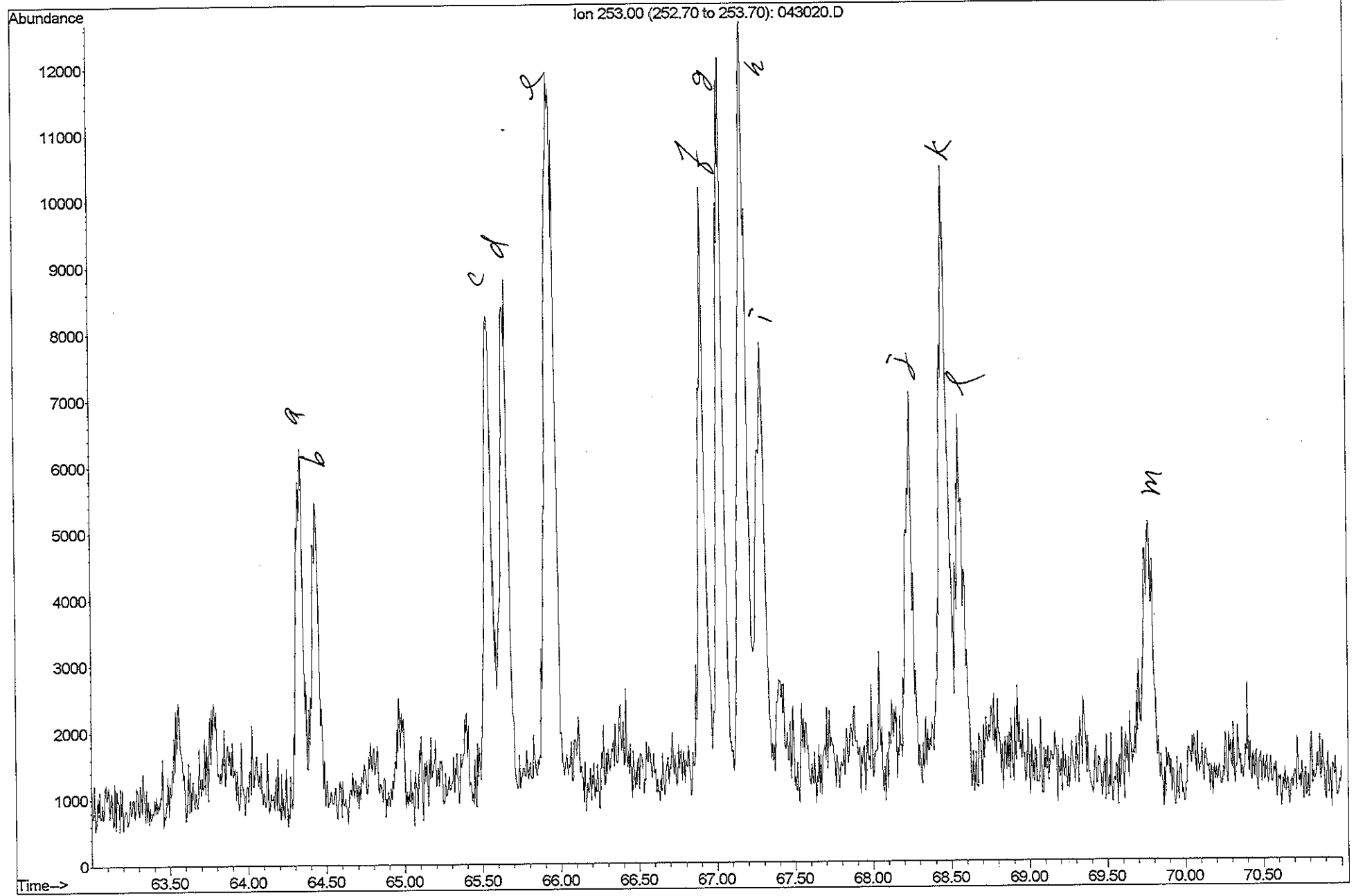


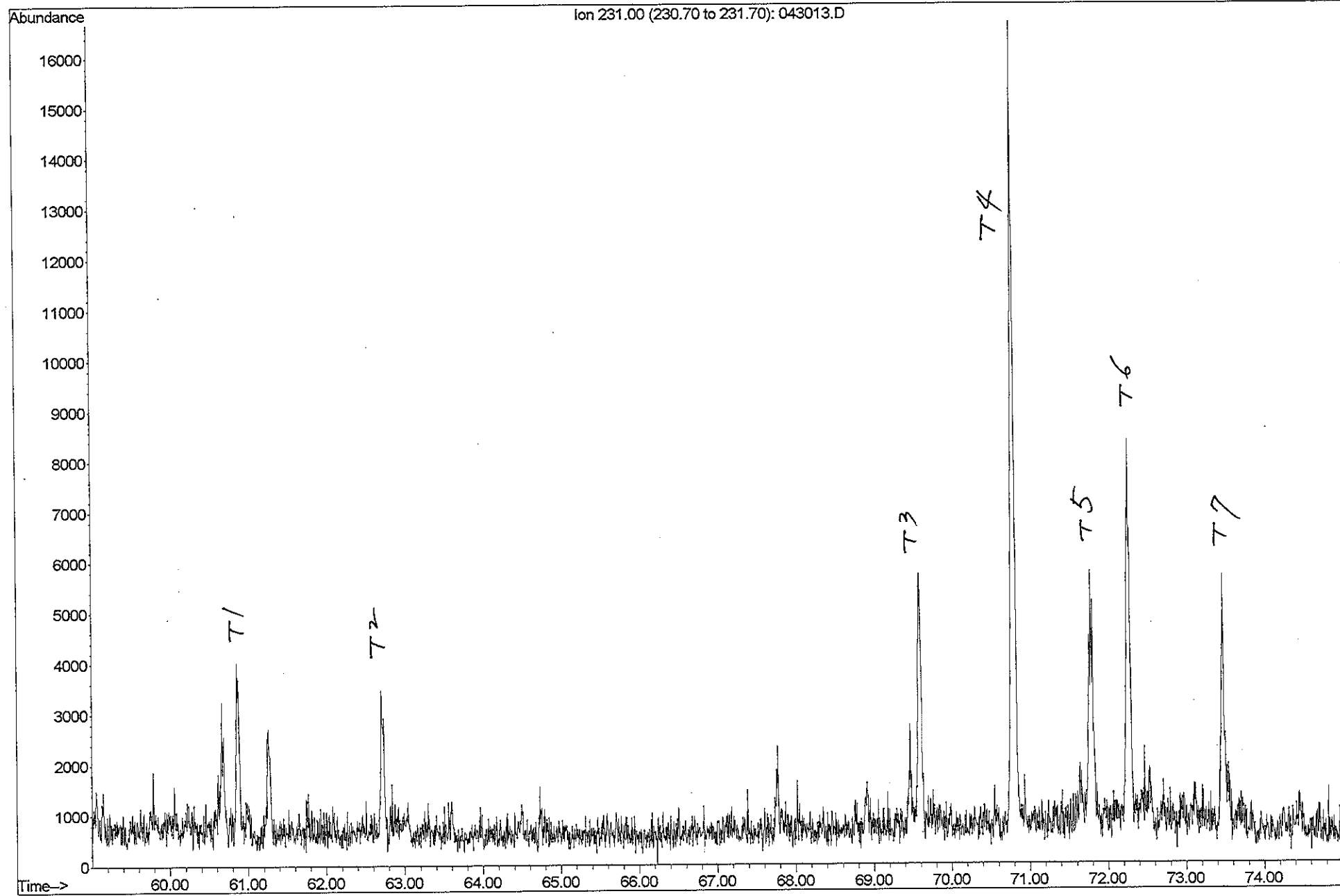


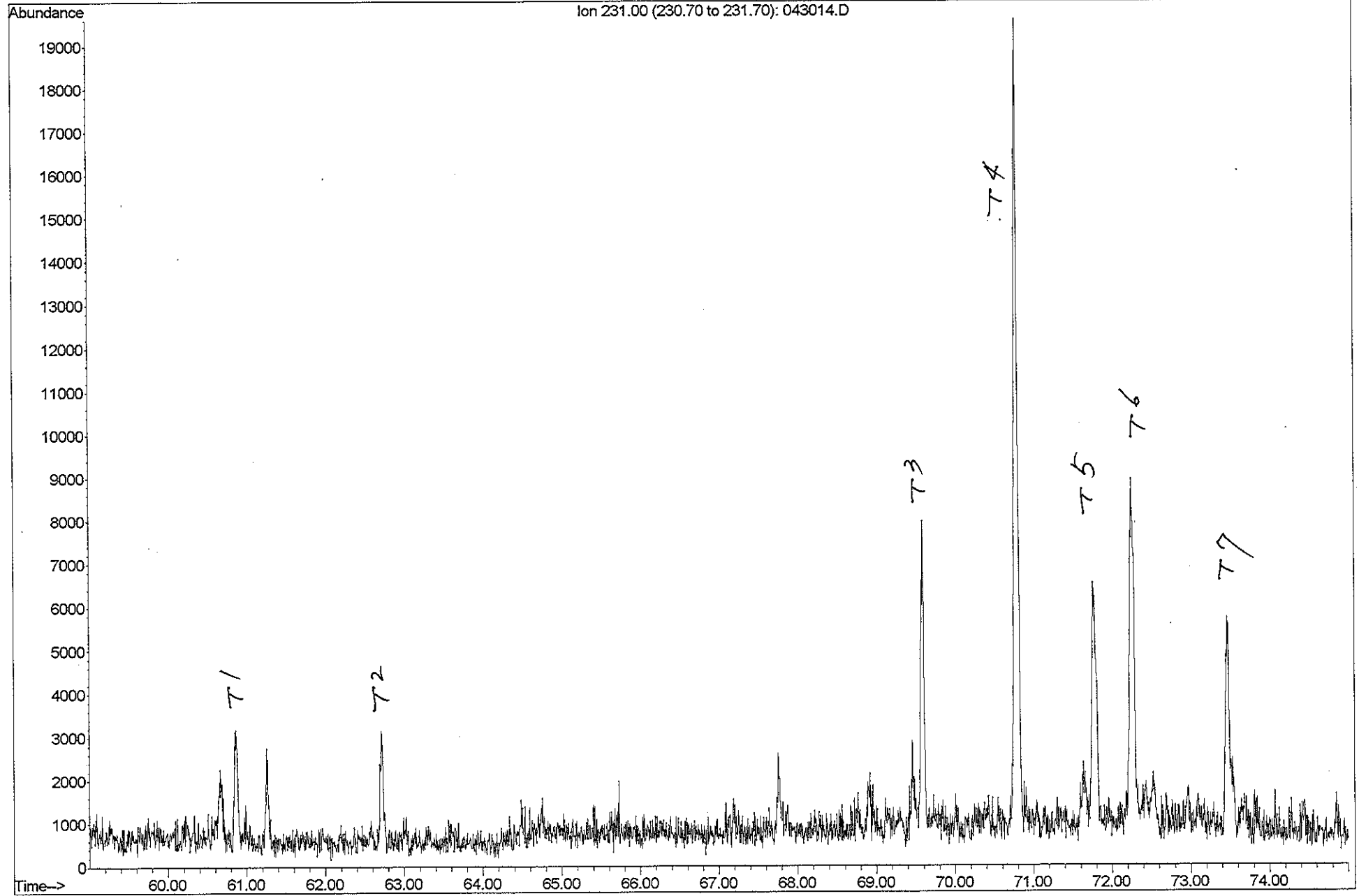


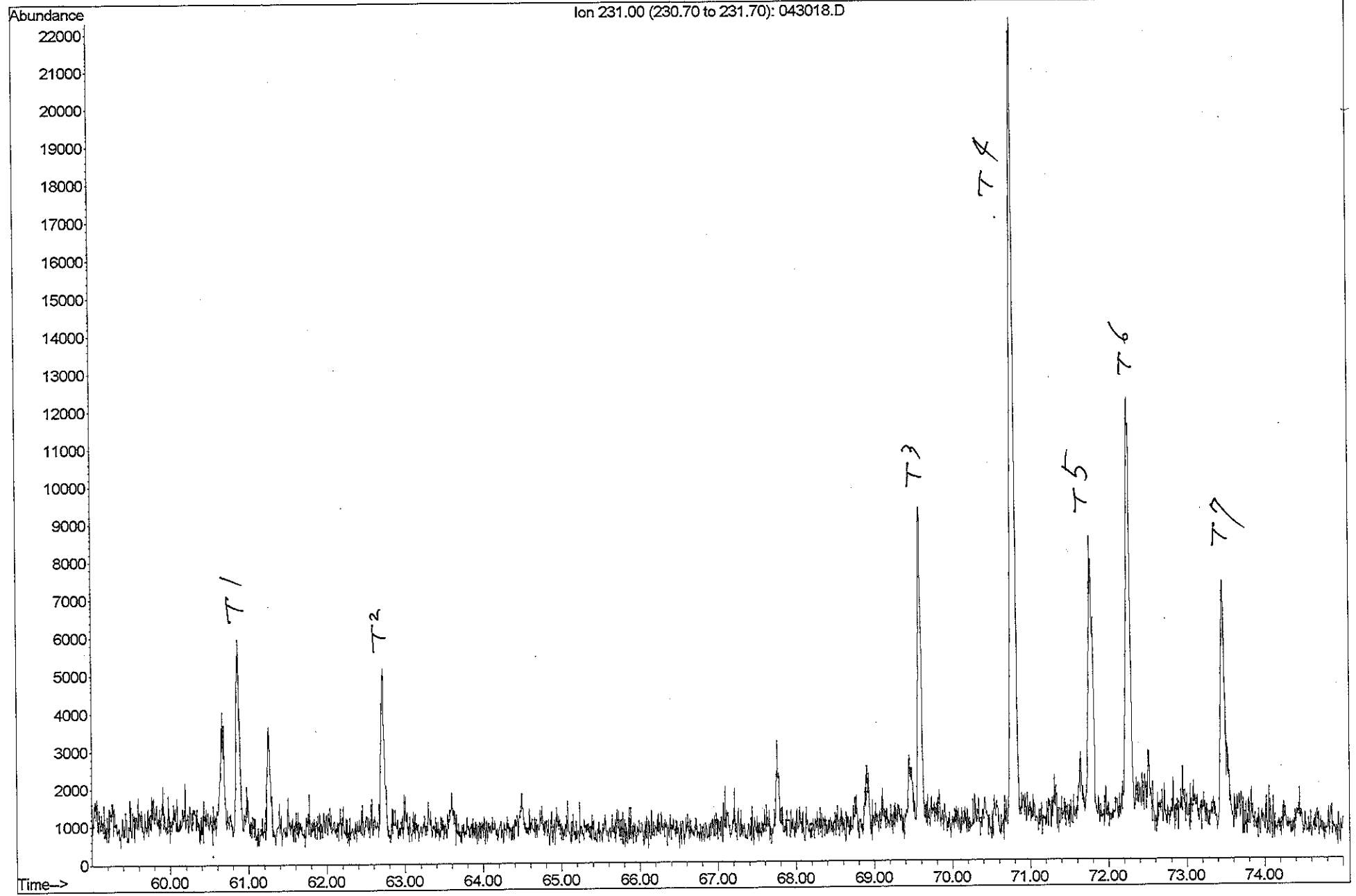


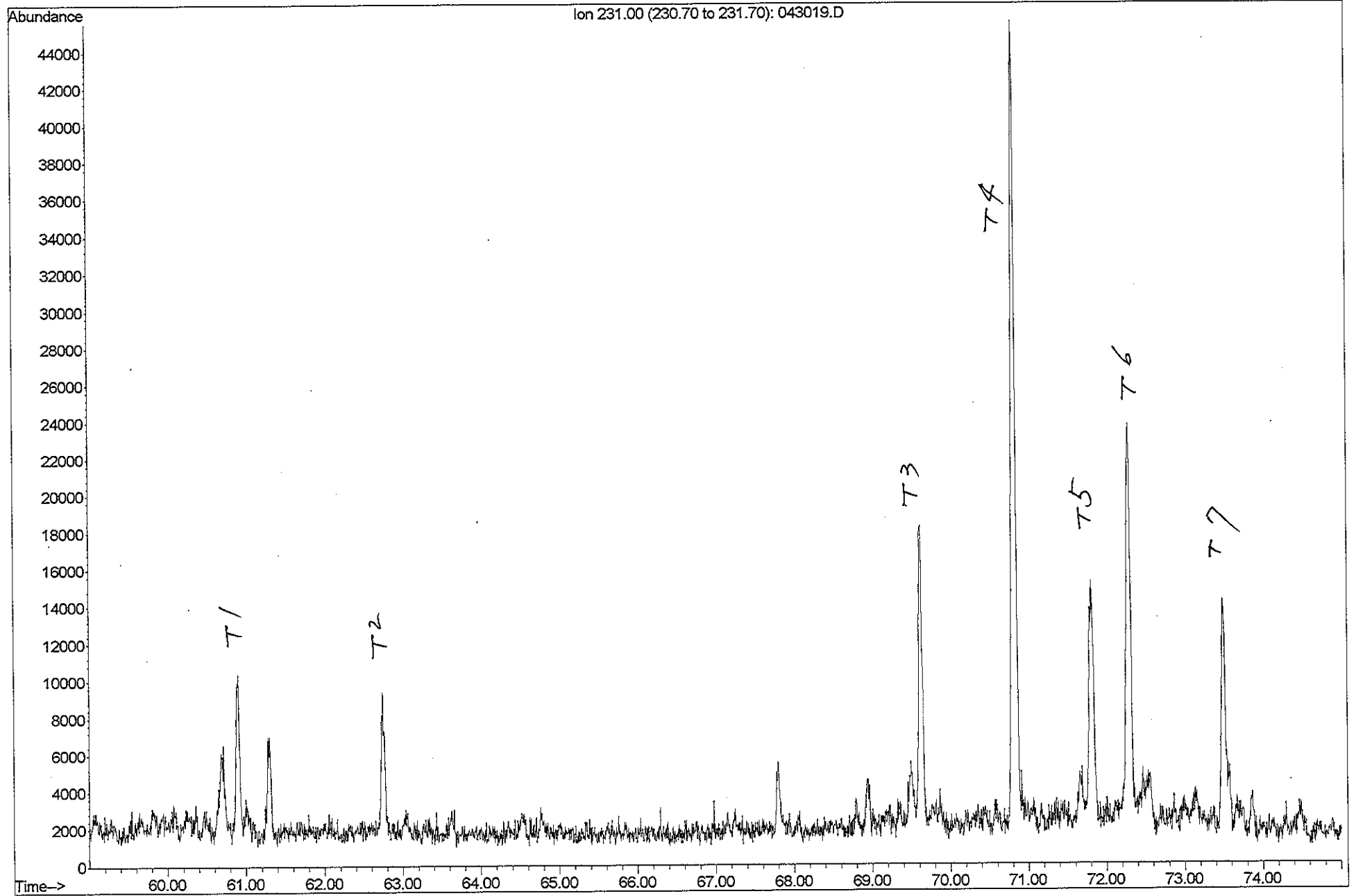


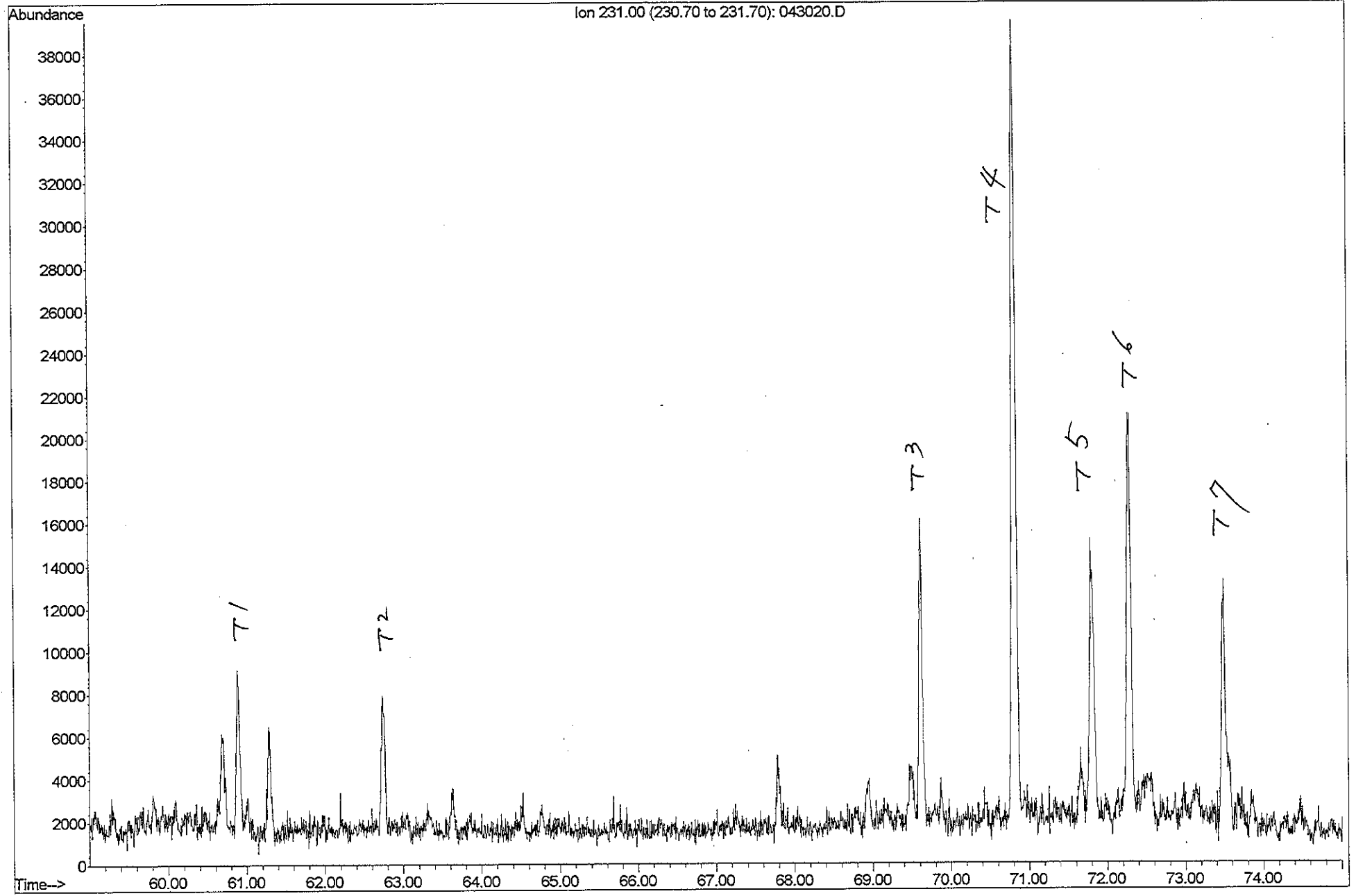






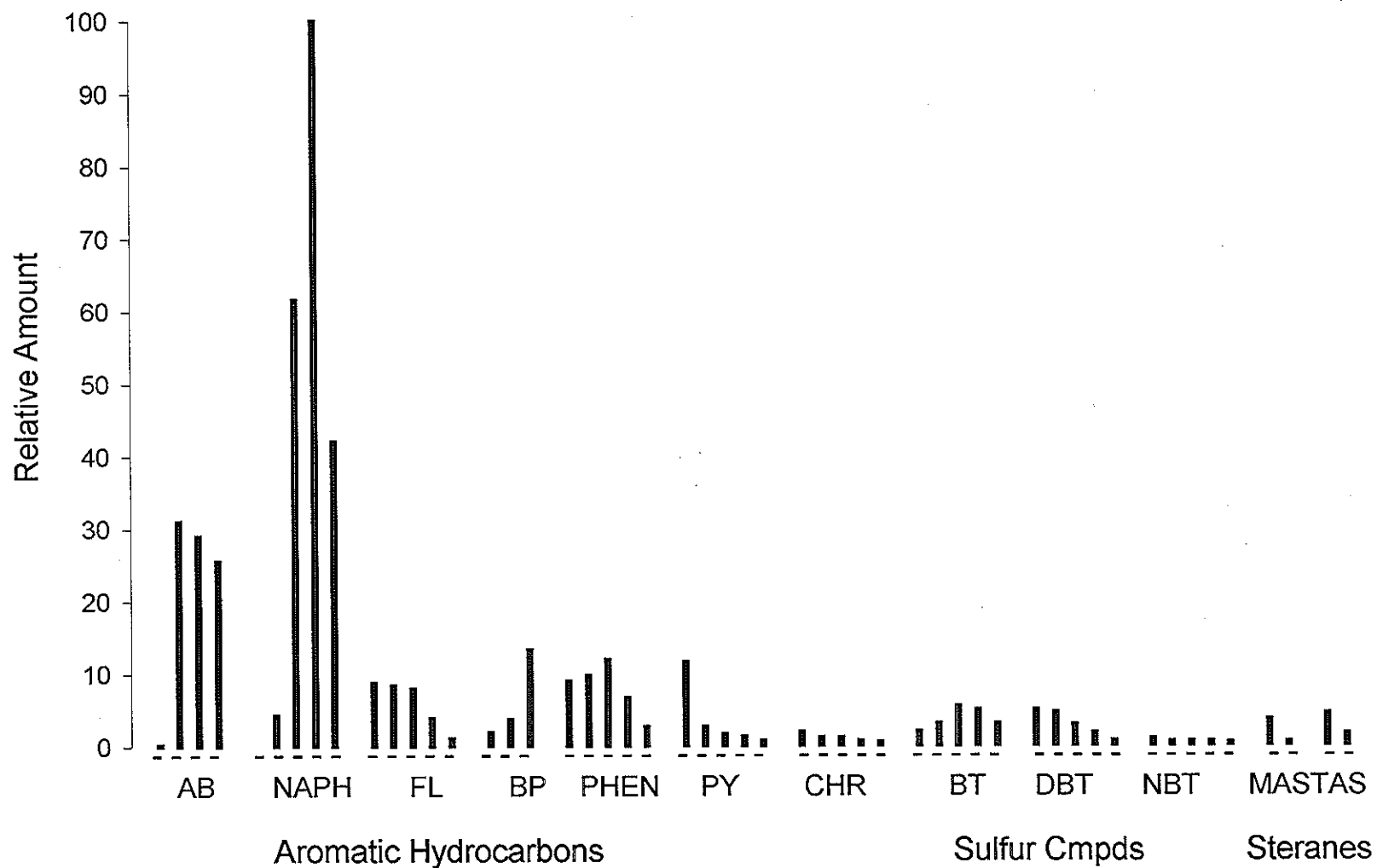




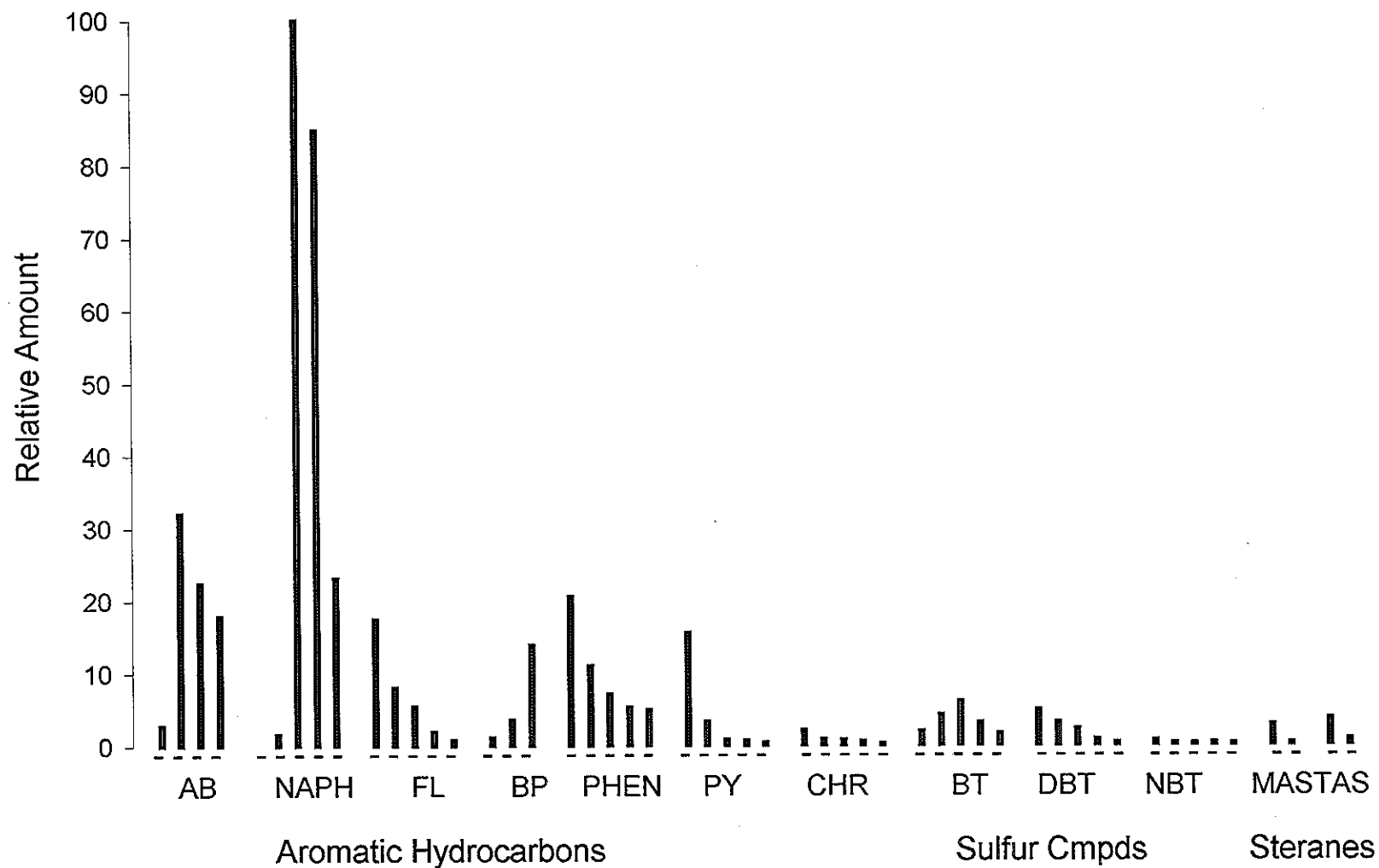


Aromatic Hydrocarbon Distribution

PZ-13

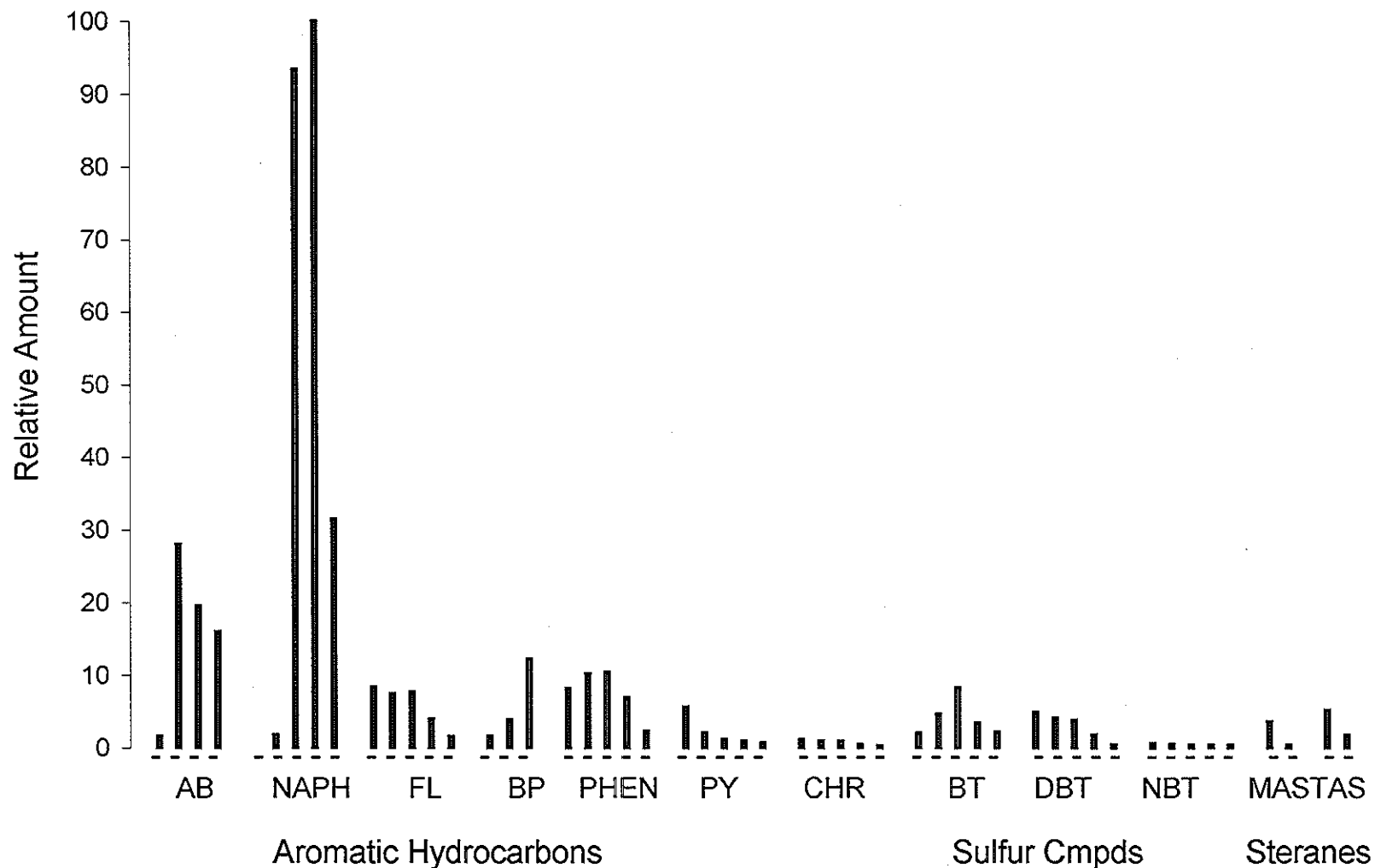


Aromatic Hydrocarbon Distribution PZ-11.5



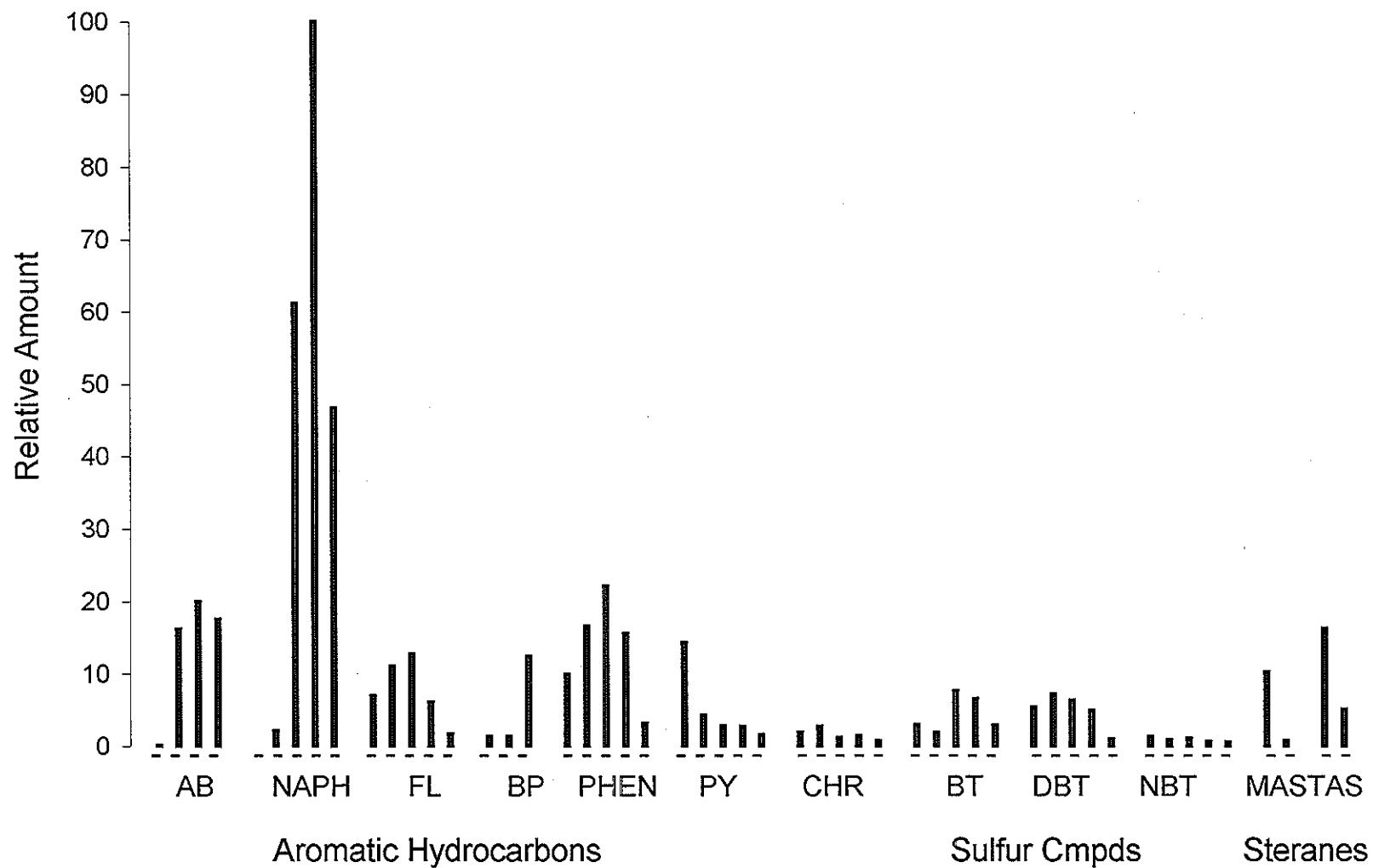
Aromatic Hydrocarbon Distribution

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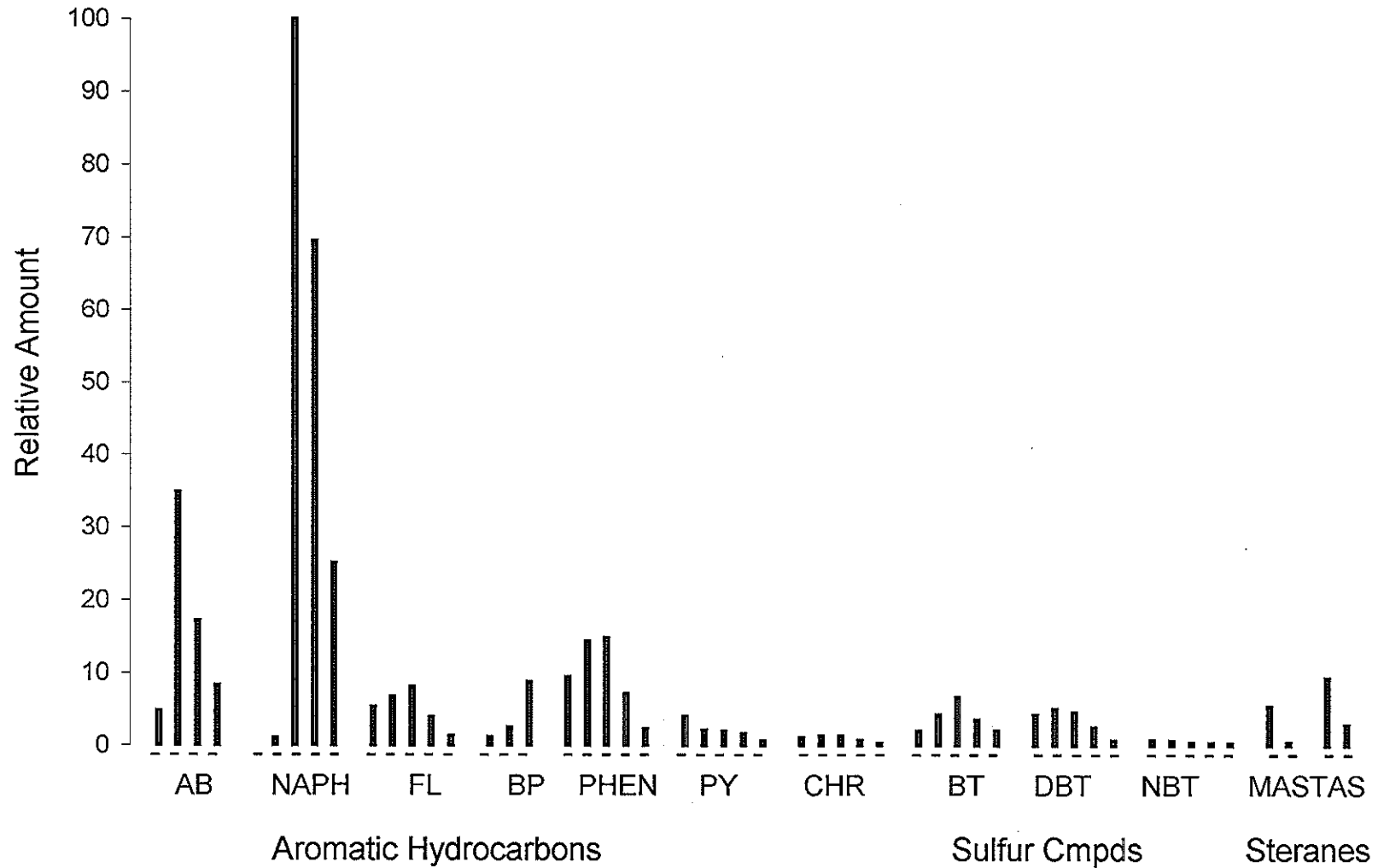
Aromatic Hydrocarbon Distribution

PZ-6



Aromatic Hydrocarbon Distribution

PZ-4.5





8100 Secura Way • Santa Fe Springs, CA 90670
Telephone (562) 347-2500 • Fax (562) 907-3610

May 29, 2014

Rebecca Andresen
ARCADIS
1100 Olive Way
Seattle, WA 98101

Re: PTS File No: 44284
Physical Properties Data
Seattle Terminal; B0045363.0005

Dear Ms. Andresen:

Please find enclosed report for Physical Properties analyses conducted upon samples received from your Seattle Terminal; B0045363.0005 project. All analyses were performed by applicable ASTM, EPA, or API methodologies. An electronic version of the report has previously been sent to your attention via the internet. The samples are currently in storage and will be retained for thirty days past completion of testing at no charge. Please note that the samples will be disposed of at that time. You may contact me regarding storage, disposal, or return of the samples.

PTS Laboratories appreciates the opportunity to be of service. If you have any questions or require additional information, please give me a call at (562) 347-2502.

Sincerely,
PTS Laboratories, Inc.

Michael Mark Brady, P.G.
District Manager

Encl.

Project Name: Seattle Terminal
Project Number: B0045363.0005

PTS File No: 44284
Client: ARCADIS

TEST PROGRAM - 20140514

FLUID ID	Date	Time	Fluid Type	Fluid Properties Pkg.	Fluid Cleaning			Comments
			Method: ASTM D1481, 445, 971		Proprietary			
Date Received: 20140514								
PZ-4.5	20140505	1135	NAPL/Water	X	X			
PZ-10.5	20140505	1225	NAPL/Water	X	X			
PZ-11.5	20140505	1240	NAPL/Water	X	X			
TOTALS:	3 bottles			3	3			

Laboratory Test Program Notes

Standard TAT for basic analysis is 10 business days.

Fluid Properties Package - LNAPL & Water: Includes dynamic viscosity and fluid density at three temperatures (70, 100, 130°F), surface tension for each fluid, and interfacial tensions (three phase pairs; oil/water, oil/air, and water/air (at ambient laboratory temperature)).

PTS File No: 44284
 Client: ARCADIS
 Report Date: 05/29/14

VISCOSITY, DENSITY, and SPECIFIC GRAVITY DATA
 (METHODOLOGY: ASTM D445, ASTM D1481, API RP40)

Project Name: Seattle Terminal
 Project No: B0045363.0005

SAMPLE ID	MATRIX	TEMPERATURE, °F	SPECIFIC GRAVITY	DENSITY, g/cc	VISCOSITY	
					centistokes	centipoise
PZ-4.5	Water	70	1.000	0.9983	1.06	1.06
		100	1.002	0.9954	0.733	0.730
		130	1.002	0.9881	0.547	0.540
PZ-4.5	NAPL	70	0.8777	0.8759	9.63	8.44
		100	0.8727	0.8667	5.82	5.05
		130	0.8643	0.8522	3.84	3.27
PZ-10.5	Water	70	1.000	0.9982	1.13	1.13
		100	1.002	0.9954	0.785	0.781
		130	1.002	0.9880	0.583	0.576
PZ-10.5	NAPL	70	0.8584	0.8567	4.81	4.12
		100	0.8539	0.8480	3.21	2.72
		130	0.8437	0.8318	2.29	1.90
PZ-11.5	Water	70	1.000	0.9984	1.02	1.02
		100	1.003	0.9957	0.713	0.709
		130	1.001	0.9866	0.535	0.528
PZ-11.5	NAPL	70	0.8495	0.8478	3.65	3.10
		100	0.8449	0.8390	2.54	2.13
		130	0.8344	0.8227	1.87	1.54

QUALITY CONTROL DATA

Date: 05/15/14	05/15/14	05/22/14
FLUID TYPE: Cannon® CVS S3	DI Water	Cannon® CVS S3
TEMPERATURE, °F: 70	70	70
DENSITY, MEASURED: 0.8652	0.9981	0.8650
DENSITY, PUBLISHED: 0.8649	0.9980	0.8649
RPD: 0.03	0.01	0.01
VISCOSITY, MEASURED:	1.00	4.79
VISCOSITY, PUBLISHED:	0.977	4.63
RPD:	2.76	3.36
CVS Lot #: 13401	CVS = Certified Viscosity Standard	

PTS File No: 44284
 Client: ARCADIS
 Report Date: 05/29/14

INTERFACIAL / SURFACE TENSION DATA
 (METHODOLOGY: DuNuoy Method - ASTM D971)

Project Name: Seattle Terminal
 Project No: B0045363.0005

PHASE PAIR		TEMPERATURE, °F	INTERFACIAL TENSION, Dynes/centimeter
SAMPLE ID / PHASE	SAMPLE ID / PHASE		
PZ-4.5 / Water	Air	75	69.4
PZ-4.5 / NAPL	Air	75	26.7
PZ-4.5 / Water	PZ-4.5 / NAPL	75	8.0
PZ-10.5 / Water	Air	75	63.3
PZ-10.5 / NAPL	Air	75	26.3
PZ-10.5 / Water	PZ-10.5 / NAPL	75	8.3
PZ-11.5 / Water	Air	74	68.3
PZ-11.5 / NAPL	Air	74	25.5
PZ-11.5 / Water	PZ-11.5 / NAPL	74	7.5

QUALITY CONTROL DATA

Date: 05/27/14
 PHASE PAIR: DIWATER / AIR
 TEMPERATURE, °F: 74
 IFT, MEASURED: 69.7
 IFT, PUBLISHED: 72.2
 RPD: -3.50

COMPANY ARCADIS				ANALYSIS REQUEST														PO#	
ADDRESS 1100 OLIVE WAY		CITY SEATTLE		ZIP CODE 98101		NUMBER OF SAMPLES SOIL PROPERTIES PACKAGE HYDRAULIC CONDUCTIVITY PACKAGE PORE FLUID SATURATIONS PACKAGE TCEQ/INRCC PROPERTIES PACKAGE CAPILLARITY PACKAGE FLUID PROPERTIES PACKAGE PHOTOLOG: CORE PHOTOGRAPHY MOISTURE CONTENT, ASTM D2216 POROSITY: TOTAL, API RP40 POROSITY: EFFECTIVE, ASTM D425M SPECIFIC GRAVITY, ASTM D854 BULK DENSITY (DRY), API RP40 or ASTM D2937 AIR PERMEABILITY, API RP40 HYDRAULIC CONDUCTIVITY, EPA9100, API RP40, D5084 GRAIN SIZE DISTRIBUTION, ASTM D422/4464M TOC: WALKLEY-BLACK ATTERBERG LIMITS, ASTM D4318	TURNAROUND TIME 24 HOURS <input type="checkbox"/> 5 DAYS <input checked="" type="checkbox"/> 48 HOURS <input type="checkbox"/> NORMAL <input checked="" type="checkbox"/> 72 HOURS <input type="checkbox"/>		OTHER:										
PROJECT MANAGER REBECCA ANDRESEN				PHONE NUMBER 206-726-1703			SAMPLE INTEGRITY (CHECK): INTACT <input checked="" type="checkbox"/> ON ICE <input checked="" type="checkbox"/> (75.5 °F)												
PROJECT NAME SEATTLE TERMINAL				FAX NUMBER 206-325-8218			PTS QUOTE NO.												
PROJECT NUMBER 30045363.0005				SITE LOCATION 3001 Elliot Avenue, Seattle, Washington			PTS FILE: 44284												
SAMPLER SIGNATURE SEAMAS MCGUIRE				COMMENTS															
SAMPLE ID NUMBER	DATE	TIME	DEPTH, FT																
PZ-9.5	5-5-14	1135	—	1															.5L LNAPL .5L WATER } AMBER
PZ-10.5	5-5-14	1225	—	1															.5L LNAPL .5L WATER } AMBER
PZ-11.5	5-5-14	1240	—	1															.5L LNAPL .5L WATER } AMBER
1. RELINQUISHED BY SEAMAS MCGUIRE				2. RECEIVED BY FEDEX				3. RELINQUISHED BY				4. RECEIVED BY							
COMPANY ARCADIS				COMPANY				COMPANY				COMPANY PTS LABS							
DATE 5-12-14		TIME 1600		DATE 5-12-14		TIME 1600		DATE		TIME		DATE 5/14/14		TIME 10:20					



Appendix D

Field Notes



Groundwater Monitoring Well Gauging Form

Site ID: Seattle Terminal	Project #:
Site Address: 3001 Edgewater Ave	Date: 2-25-14

Well ID	Time	Sheen/Odor	LNAPL Depth	LNAPL Thickness	DTW	TD	PID	Notes
PZ-1 RW-1	1200	-	-	-	8.66 7.80	20.35 20.15	0.0 0.0	1" no cap 6"
PZ-2 RW-2	1152	-	-	-	8.14 7.54	12.17 19.70	0.0 0.0	1" no cap 6" SB
PZ-3 RW-3	1145	-	-	-	7.67	18.45	0.0	1" can't remove cap 6"
PZ-5 RW-5	1135	-	-	-	8.62 7.43	22.03 21.80	0.0 0.0	1" no cap 6"
PZ-6 RW-6	1125	HCCO	7.62	0.52	8.15 6.98	21.75 18.00	65.0 0.0	1" Black product coating tape/p 6"
RW-7	1115	-	-	-	7.40	20.00	0.0	6"
PZ-8 RW-8	1100	-	-	-	7.30 7.00	9.33 21.5	0.0 0.0	1" no cap 6" SB
PZ-9 RW-9	1050	-	-	-	7.00 6.25	45.37 46.92	0.0 0.0	1" no cap 6" SB - Bio slime
PZ-10 RW-10	1038	-	-	-	8.25 7.07	24.25 25.00	0.0 0.0	1" no cap 6" soft bottom
PZ-11 RW-11	1030	-	-	-	8.30 7.40	21.80 23.00	0.0 0.0	1" 6" - Bio cap - bio SB
RW-13	1020	-	not measurable	-	8.20	24.16	156	1" pipe copy black new tape
RW-21								
PZ-7.5	1110	-	-	-	6.09	9.12	0.0	1"
PZ-9.5	1045	-	-	-	7.06	26.20	1.7	1" Bio slime
PZ-11.5	1205	HCCO	7.78	2.72	10.50	18.70	61.9	1" - Found today Thick Black p. - re-set coating tape & Probe
PZ-61A-R								
PZ-203								
PZ-4-5 PZ-204	1315	HCCO	8.40	1.75	10.15	19.10	37.2	1" well box very poor/missing Thick black product on tape
PZ-8.5	1210	-	-	-	6.77	9.60	0.0	No cap, well box very poor condition
PZ-6.5	1220	-	-	-	6.86	17.90	0.0	1"
PZ-10.5	1240	HCCO	8.20	2.5	8.70 8.20	19.00	137	1" Thick black products on probe & tape

SB = Soft bottom
 * All product thicknesses are approximate - product very thick and stays on probe making water level difficult to gauge
 Page ___ of ___

2/18/14

SEATTLE TERMINAL UTILITY LOCATE

R. Lalrandev
S. McGuire

WEATHER

Rain/Wind
48°F

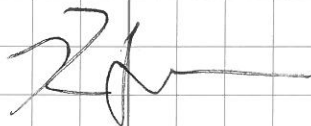
0900 Arrive on site, conduct H&S meeting, review
SOW, H&SP, JSA. Work includes utility location
near gravel path by system compound

0945 Walk and inspect area, then return & gather locating
equipment

1030 Rwl leaves work area to scout road that is planned
to be used by vac trucks for future event

1130 Rwl back on work area. Mike Benedict from geo mark out
finishes with job and takes pictures

1215 All personnel are off site



2.21.14

South Terminal Decommissioning Day 1

		WEATHER
745	Arrive at off site rally point	Cloudy 45°F
800	Conduct H&S meeting with ARCADIS, Clear Creek & SHS review traffic control JSA/JMP	
900	Leave rally point & head to site with flaggers & cars set up five vehicles	
940	Exclusion zone complete, review fence removal JSA & BSEE rules	
1000	Start remaining fencing while electrician & Sam Miles perform LOTs	
1030	Electrician confirms that all lines are dead in area of tower removal & in system compound	
1100	Start remaining trench from compound & digger to locate irrigation pipes	
1130	Irrigation pipes found in front of & behind trees ~ 3 ft from tree & 2 ft underground. It is noted that most roots end after ~ 1 ft.	
1145	Review Min. Recorder & back off. H&S w/ driver	
1200	Start vacing	
1230	Done vacing / call Sam Miles to update	
1300	Seamus McGuire on site to sign bill of lading	
1400	JSA off site	
1430	Clear site & secure area	
1515	CCC, SHS & AUS OFF SITE	

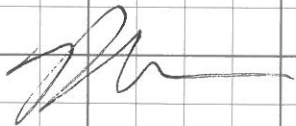
2-24-14

SEATTLE TERMINAL DECOMMISSION DAY 2

WEATHER

45° F
Rain

- | | |
|------|---|
| 730 | Arrive on site don PPE, H&S paperwork & meeting, review JWP & JSA for getting on site |
| 920 | Arrive on site, set up exclusion zone |
| 930 | Safety meeting w/ BNSF & review JSA for removing trees |
| 1015 | Remove tree tops |
| 1100 | Start air knife, shovel loosing dirt & roots around trees |
| 1200 | Finish removing trees, review plan for tomorrow & break for lunch |
| 1300 | Afternoon tailgate & review JSA/plan for moving/loading equipment from enclosure |
| 1430 | AUS & Chiron personnel back on site |
| 1500 | Start lifting large equipment |
| 1545 | Done loading equipment |
| 1615 | Clean up site |
| 1630 | End of day meeting/review of day |
| 1650 | All companies and personnel off site |



2-25-14

Seattle Terminal Decommissioning Day 3

WEATHER

730	Arrive on site don PPE, H&S paperwork	Part. Cloudy 45° F
800	H&S meeting - discussed logistics of mobilizing on site. Due to obtaining a variance for needing to break the screen of wells w/o drillers logs, but not having the variance in hand we decide to not abandon any wells therefore the drillers and water vac truck will not be needed. We will only try to locate PZ wells w/ soil vac truck.	
915	Arrive on site, conduct task specific H&S meeting.	
1010	Start gauging round on PZ & RW wells by train tracks.	
1020	CCC caps the drain pipe that used to be attached to the oil water separator	
1045	Mobilize soil vac truck onto site. It will start at the far end looking for PZ-11.5, all wells beyond it to the East are surrounded by 3 trenched lines of utilities and there is no clearance available to dig	
1200	Gauging for existing wells is done, the vac truck has been able to find PZ-11.5, 10.5, 8.5, 6.5 and 4.5. PZ-5.5 and all missing wells to the West of PZ-4.5 are in line with utilities, so there is no clearance.	
1300	Vac truck mobs off site with Sam Miles walking with it.	
1315	Gauging of all newly found wells is done.	
1320	CCC fills all holes created by the vac truck & restores the grade.	
1500	All equipment loaded, site secured CCC, Crewm, AUS & all workers off site	

2-25-14

SEATTLE TERMINAL Product Sampling

					WEATHER
1130	Arrive on site	H&S talkback review	JSD		55°F Sun
	WASP & PTW.				
1210	Meet w/ BNSF	Flaggus			
1220	Set up @	PZ-13			
1240	Sample @	PZ-13	4	VOAS	
1305	Sample @	PZ-11.5			
1330	Sample @	PZ-10.5			
1345	Call Dave Haberman w/ King County - Inspector, he thought the inspection was tomorrow, but he will come now				
1415	Sample @	PZ-6			
1500	Sample @	PZ-4.5	PL		
1430	DH inspector comes and looks at oil water separator capped line, he doesn't know if it was done right but thought it was fine,				
1500	Sample @	PZ-4.5	-	Couldn't measure product - don't know why but sampled & confirmed w/ bailer	
1515	Fix part of the temp fence that was bent, which left a little gap.				
1530	Sign BNSF Flaggus Record Forms & call Son Miles to let him know work is complete.				
1540	OFF site				



Groundwater Monitoring Well Gauging Form

Site ID: Seattle Terminal	Project #:
Site Address: 3001 Elliott Ave	Date: 2-28-14

Well ID	Time	Sheen/Odor	LNAPL Depth	LNAPL Thickness	DTW	TD	PID	Notes
PZ-1 RW-1	1200	-	-	-	8.66 7.80	20.35 20.15	0.0 0.0	1" no cap 6"
PZ-2 RW-2	1152	-	-	-	8.14 7.54	12.17 19.70	0.0 0.0	1" no cap 6" SB
PZ-3 RW-3	1145	-	-	-	7.67	18.45	0.0	1" can't remove cap 6"
PZ-5 RW-5	1135	-	-	-	8.62 7.48	22.03 21.80	0.0 0.0	1" no cap 6"
PZ-6 RW-6	1125	HCLD	7.62	0.53	8.15 6.98	21.75 18.00	65.0 0.0	1" Black product coating tape/p 6"
RW-7	1115	-	-	-	7.40	20.00	0.0	6"
PZ-8 RW-8	1100	-	-	-	7.30 7.00	9.33 21.5	0.0 0.0	1" no cap 6" SB
PZ-9 RW-9	1050	-	-	-	7.00 6.25	45.37 46.32	0.0 0.0	1" no cap 6" SB - Bio slime
PZ-10 RW-10	1038	-	-	-	8.25 7.07	24.25 25.00	0.0 0.0	1" - No cap 6" soft bottom
PZ-11 RW-11	1030	-	-	-	8.30 7.40	21.80 23.00	0.0 0.0	1" 6" - Bio cap - bugs SB
RW-13	1020	-	not measurable	-	8.26	24.16	156	1" pipe Coopy black new tape
RW-21								
PZ-7.5	1110	-	-	-	6.09	9.12	0.0	1"
PZ-9.5	1045	-	-	-	9.06	26.20	1.7	1" Bio slime
PZ-11.5	1205	HCLD	7.78	2.72	10.50	18.70	61.9	1" - Found today Thick Black p. retest coating tape & Probe
PZ-61A-R								
PZ-203								
PZ-4.5 PZ-204	1315	HCLD	8.40	1.75	10.15	19.10	37.2	1" well box very poor/missing Thick black product on tape
PZ-8.5	1210	-	-	-	6.77	9.60	0.0	No cap, well box very poor condition
PZ-6.5	1220	-	-	-	6.86	17.90	0.0	1"
PZ-10.5	1240	HCLD	8.20	2.05	10.70 8.20 20	19.00	137	1" Thick black products on probe & tape

SB = Soft bottom

* All product thicknesses are approximate - product very thick and stays on probe making water level difficult to gauge

5-5-14

SEATTLE TERMINAL LNAPL SAMPLING

S. McGUIRE

- 0745 → SCM arrives onsite. Reviews SOW and hazards for day.
Meets
- 0800 → Meet BNSF Flesser onsite. Conduct tailgate meeting. Prepare equipment for gauging round.
- 0840 → Gauging round!

WELL	TIME	DTW	DTP	PRODUCT	PID
RW-1	0845	7.30	—	—	0.0
PZ-1	0850	8.13	—	—	0.0
RW-2	0855	7.00	—	—	0.0
PZ-2	0859	7.71	—	—	0.0
RW-3	0904	7.50	—	—	0.0
PZ-3	0908	→ UNABLE TO OPEN WELL / WILL BREAK IT			
RW-4	0913	→ UNABLE TO LOCATE			
PZ-4	0915	→ UNABLE TO LOCATE			
PZ-4.5	0921	10.30	8.51	1.79	71.6
RW-5	0927	7.23	—	—	0.0
PZ-5	0931	8.43	—	—	0.0
RW-6	0936	7.02	—	—	0.2
PZ-6	0940	7.97	7.70	0.27	51.2
RW-7	0946	7.40	—	—	0.0
PZ-6.5	0951	6.88	—	—	2.3
PZ-7.5	0957	6.14	—	—	0.0
RW-8	1004	7.11	—	—	0.0
PZ-8	1008	7.37	—	—	0.1
PZ-8.5	1013	6.90	—	—	0.0
RW-9	1018	6.70	—	—	0.0
PZ-9	1025	7.37	—	—	2.1
PZ-9.5	1028	7.44	—	—	1.7
RW-10	1033	7.22	—	—	0.0
PZ-10	1036	8.33	—	—	0.0
PZ-10.5	1041	10.30	8.29	2.01	119.5
RW-11	1045	7.51	—	—	0.0
PZ-11	1048	8.38	—	—	0.0
PZ-11.5	1052	10.34	7.84	2.50	68.0
RW-13	1100	7.65	—	—	0.0
PZ-13	1103	8.75	8.68	.07	144

1105 → Finish gauging round.

5-5-14 SEATTLE TERMINAL LNAPL SAMPLING CONTINUED

1115 → Prepare equipment to LNAPL sample.

1135 → PZ-7.5 sampled.

1200 → PZ-6 sampled. Not enough for sample.

1225 → PZ-10.5 sampled.

1240 → PZ-11.5 sampled.

1300 → PZ-13 not enough LNAPL to sample.

1315 → Start to clean up site. Get stuck with train in yard, need to wait 30 minutes to get equipment from W side.

1345 → Get all equipment. Leave site.

James McLean

6-9-14

SEATTLE TERMINAL WELL DECOMMISSION

S. MCGUIRE

0710 → SCM / RL of Arcadis meet DH of BNSF (FOGGLER) at Bay St.
Lead DH to meeting location near Centennial park.

ECONOMY REGULATOR

0800 → Arcadis, Clear Creek, Chevron and Emerald all meet at North meeting location and hold H/S final meeting. Discuss all major hazard for day and review fence removal JCA. Also discuss how to mobilize big trucks on to site.

0900 → Clear Creek mobilizes down to the site & sets up exclusion zone

0930 → Vac trucks & Clear Creek mobilizes from North entrance

1000 → Start gauging all RW & PZ wells - see gauging sheet

1030 → Start vacing well casings → if possible, de-water RW 6" well and continue to vac after de-watered for ~2 min. If it does not de-water, vac for ~4 min. 1" PZ wells vac for 3-5 min.

WELL ID	VAC DURATION (min)	Approx. Vac Vol (GAL)	
RW-13	3	~25	- Recharge slowly
PZ-13	2	~1	
PZ-11.5	3	~1	
RW-11	3	~22	- No recharge
PZ-11	2	~1	
PZ-10.5	2	~1	
RW-10	3	~24	- No recharge
PZ-10	2	~1	
PZ-9.5	3	~1	
RW-9	4	~80-100	- Did not de-water
PZ-9	2	~3	
PZ-8.5	3	~1	
RW-8	5	~20	- No recharge
PZ-8	2	~1	

1230 Break for lunch & mobilize soil vac truck to start uncovering lateral system lines

6/9/14 Seattle Decommission Continuation

1245 Mid day safety meeting

1300 Start work up 2 crews, 1 soil vac & 1 well vac
 - Soil vac will clear lines at end of line & at RW-9 (which has a separate system line) and try to blow air through them to verify line integrity

VAC

<u>WELL ID</u>	<u>VAC DURATION (MIN)</u>	<u>APPROX VAC VOL (GAL)</u>
PZ-7.5	~3	~1
RW-7	~ 3 4	~18 - No seepage
PZ-6.5	~3	~1
RW-6	~3	~15 - No seepage
PZ-6	~2	~1
RW-5	~3	~22 - No seepage
PZ-5	~2	~1
PZ-4.5	~5	~3
RW-3	~3	~15 - No seepage
PZ-3	~2	~1
RW-2	~4	~30 → Did not de-water
PZ-2	~2	~1
RW-1	~3	~17 - No seepage
PZ-1	~2	~1

TOTAL ESTIMATED VOL = 309 - 329 gal

TOTAL VOL = 353 gal

- All wells purged at least 1 well vol

1400 Ident. find a break in system lateral lines between RW-6 & RW-7, appears some kind of utility was installed below lateral lines, so lines were cut there. Utility not seen or uncovered, just locate tape. Lateral lines accounted for from vault to end of lines @ signal lite,

1500 Vac trucks off site, replace fence, post work debrief/meeting
 1530 Clear Creek & AUS off site

6.10.14

SEATTLE TERMINAL WELL DECOMMISSION

S. MCGUIRE

- 0745 → Clear Creek and ARCADIS meet at site. Discuss work.
- 0800 → Holt has difficulty finding meet-up location. CCC directs.
- 0815 → Holt arrives on site.
- 0830 → Conduct H&S tailgate meeting. Review SOW and site specific hazards. Primary hazards today will be Bine/ train traffic, STIF and chemical hazards. Site access is discussed.
- 0910 → Clear Creek mobs to site to set up traffic control.
- 0930 → Large trucks mob to site from N side.
- 0945 → Site walk through with Holt. Review Holt growing JSA.
- 1015 → Setup on RW-13/PZ-13 location. Decommission wells.
- 1130 → Setup on RW-11/PZ-11 location. Decommission wells. STOP WORK. Filling PZ-11 crew stops work as pump down well is too fast for such small well diameter. Slurry will be placed in well with gravity feed and a funnel. PZ-11 is completed this way.
- 1200 → Decommission ~~PZ-11.5~~ PZ-11.5.
- 1220 → Decommission PZ-10.5.
- 1315 → Lunch. Mid-day meeting.
- 1345 → Decommission RW-10/PZ-10.
- 1415 → Decommission PZ-9.5.
- 1445 → Decommission RW-9.
- 1500
~~1530~~ → Start cleanup.
- 1530 → Mob off site. End of day meeting.

James McGuire
Call on the radio.

6-11-14

SEATTLE TERMINAL

Well Decommission

S. McGUIRE

0745	→ Clear Creek, Holt Drilling, Arcadis and Chevron meet on site.
0800	→ conduct H&S meeting. Review today's hazards. Review serious injury and fatality book. Review SOW for day. Review process for mobilization on site.
0845	→ Clear Creek mobs on site to setup exclusion zone. Arcadis mobs to site.
0915	→ All trucks moved on site. Review group JSA.
0945	→ STOP WORK. Fix leaky valve. Decommission RW-8. Pump valve tight and fixed.
1000	→ Decommission PZ-8.
1030	→ Decommission PZ-7.5
1115	→ Decommission RW-7. While working at RW-7 STOP WORK as mid wanders into pvc side security exclusion area while he is chasing a bird. Leaves exclusion zone, but fence in between pvc side and truck side security is enhanced. - Chris (Chevron) discusses this STOP WORK & solution with Kim Jolitz (Chevron PM)
1145	Decommission RW-6 - STOP WORK - need whip check on goat tubing while pumping. Fix w/ extra whip checks
1120	Decom. PZ-6.5 - STOP WORK - same valve as previous stop work starts to leak again, instead of fixing, replace with new valve
1250	Start grouting lateral lines - lines to the north ending in vault are not grouting properly, grout not making it, must be a break in the line. We will grout from the vault to the south.
1400	Decom RW-5 & PZ-4.5
1500	End of day safety debrief - discuss STOP WORKS/Activities
1515	Clean site, CCC & Holt off site via North exit. AUS out

- 0745 → Clear Creek, Arcadis/hoit and Chevron meet at North meeting ^{area} facility. Hold H's tailgate meeting. Review SOU for day and associated hazards. Review fatality head body for human performance.
- 0830 → Sign HASP. Clear Creek men to site for exclusion zone setup.
- 0900 → Mob Hilt vehicles onto site.
- 0915 → Meet up on site to review grant JSA.
- 1000 → Grouted final 1/3 of lateral lines. Lateral line grouting is complete.
- 1015 → Maura O'Brien (regulator) arrives on site with Theria Levanovitz (DOE Public Relations). Talks to BL/SM of Arcadis and Chris of Chevron. Discuss how DOE would like to write up report on happenings on site as well as potentially post pictures to site. Chris discusses how all pictures etc will need to go through Chevron public relations team before being released to DOE. ~~Chris~~ ^{APLADP} agrees to send pictures etc to Kim Jolite before anything goes to DOE. Maura and Theria leave site.
- 1050 → Decommission RW-2/PZ-2.
- 1115 → Decommission RW-1/PZ-1.
- 1130 → CDF truck arrives onsite. Driver is given safety briefing and rail training is confirmed. Moved onto site and drops CDF in Vault. Vault is filled.
- 1140 → ^{CDF} Truck moves offsite. Decommission PZ-203 in path. Patch.
- 1150 → Decommission PZ-204 in path.
- 1210 → Mid-day Safety meeting.
- 1245 → Decommission RW-3/PZ-3.
- 1300 → Start patching all RW/PZ wells with concrete to grade.

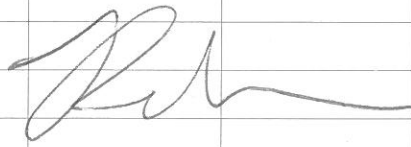
6/12/14 Seattle Terminal Trench Decom. Continued

1500 Mobilize CCC & Holt to opposite side of tracks by Bay Street

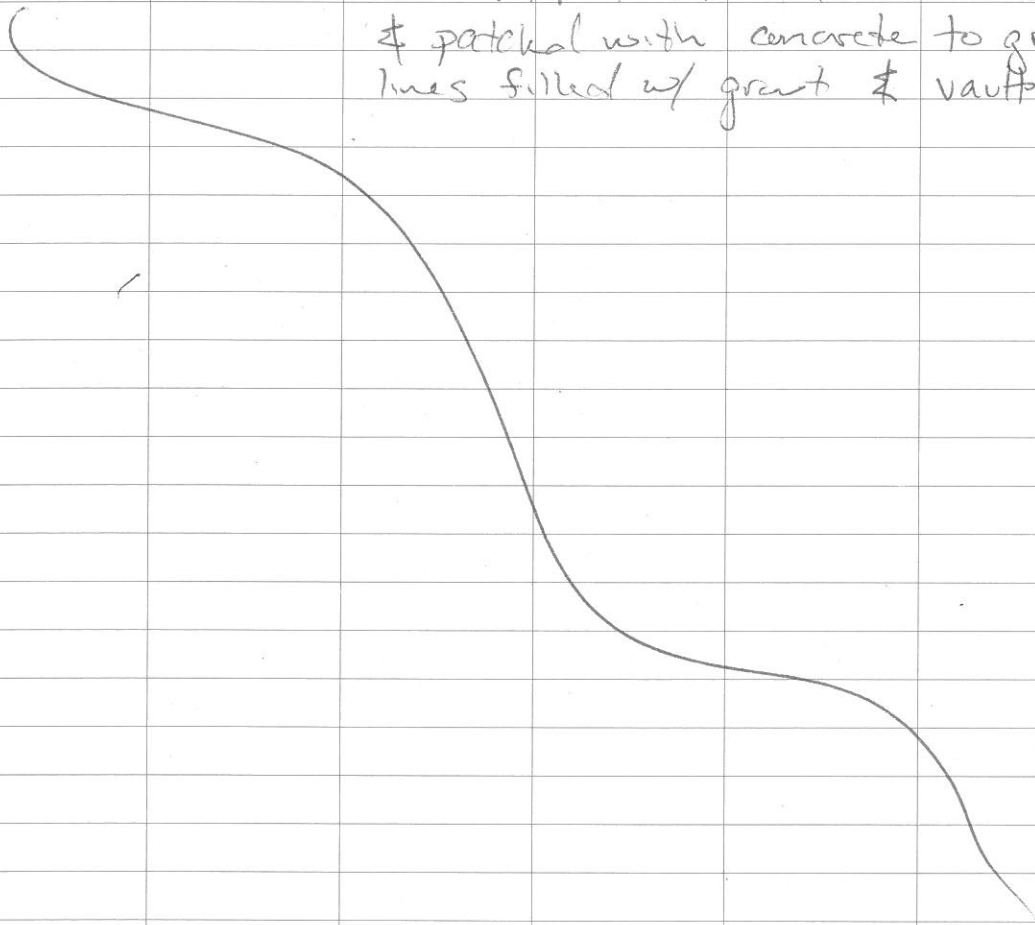
1530 Decommission PZ-6A-R along Eliot Ave

1615 Decommission RW-21

1700 End of day safety debrief, Chevron, CCC, Holt and Arcadis off site



SUMMARY: All RW & PZ wells decommissioned & patched with concrete to grade, lateral lines filled w/ grout & vaulted w/ CDF



6/13/14 Seattle Terminal Trench D

R. LeClerc

WEATHER

Rain 60°F

800 Arrive on site/meeting area for tailgate
H&S meeting

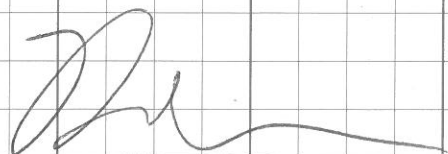
900 Arrive on site @ SAM set up exclusion
zone and signs

930 Remove temporary fence, replace irrigation
sprinkler head

1015 Replace permanent fence

1115 Spread mulch around access area/new fence

1145 Take down exclusion zone & move off site





Appendix E

Mobility Worksheets



SITE/PROJECT INFORMATION

Date: 7/14/2014
 Site Name: Former Unocal Seattle Marketing Terminal
 Site Location (City, ST): Seattle WA

CASE STUDY ASSUMPTIONS

Case Name: PZ-4.5
 LNAPL Type: Literature assumptions based on Fuel Oil #3
 Geology Type: Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	Symbol	Value	Units	Source
Site Data				
Monitoring Well LNAPL Thickness	b_o	1.79	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00529	cm/s	field/site data (RW-3)
Water Hydraulic Gradient	J_w	0.017	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	ρ_o	0.89	g/cm ³	literature (API)
LNAPL Viscosity	μ_o	0.0591	g/cm-s	literature (API)
Water Density	ρ_w	0.9989	g/cm ³	field/site data
Water Viscosity	μ_w	0.013	g/cm-s	field/site data
Surface Tension	S_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	S_{ao}	27.5	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	S_{ow}	21.4	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	α	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	Symbol	Value	Units	API 4760 Equation
Air-Water Interface in Subsurface	Z_{aw}	0.0	ft	datum
Density Ratio	ρ_r	0.891	dimensionless	
Air-LNAPL Interface in Well	Z_{ao}	0.195	ft	2.19
LNAPL-Water Interface in Well	Z_{ow}	-1.595	ft	2.20
Maximum Free LNAPL in Subsurface	Z_{max}	0.529	ft	2.38
LNAPL vertical extent in subsurface		2.124	ft	
vG Alpha scaled to oil-water interactions	α_{ow}	0.317	1/ft	2.25
vG Alpha scaled to oil-air interactions	α_{ao}	2.018	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	η	4.546	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00104	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.019	dimensionless	
Intrinsic Permeability	k	7.02E-08	cm ²	



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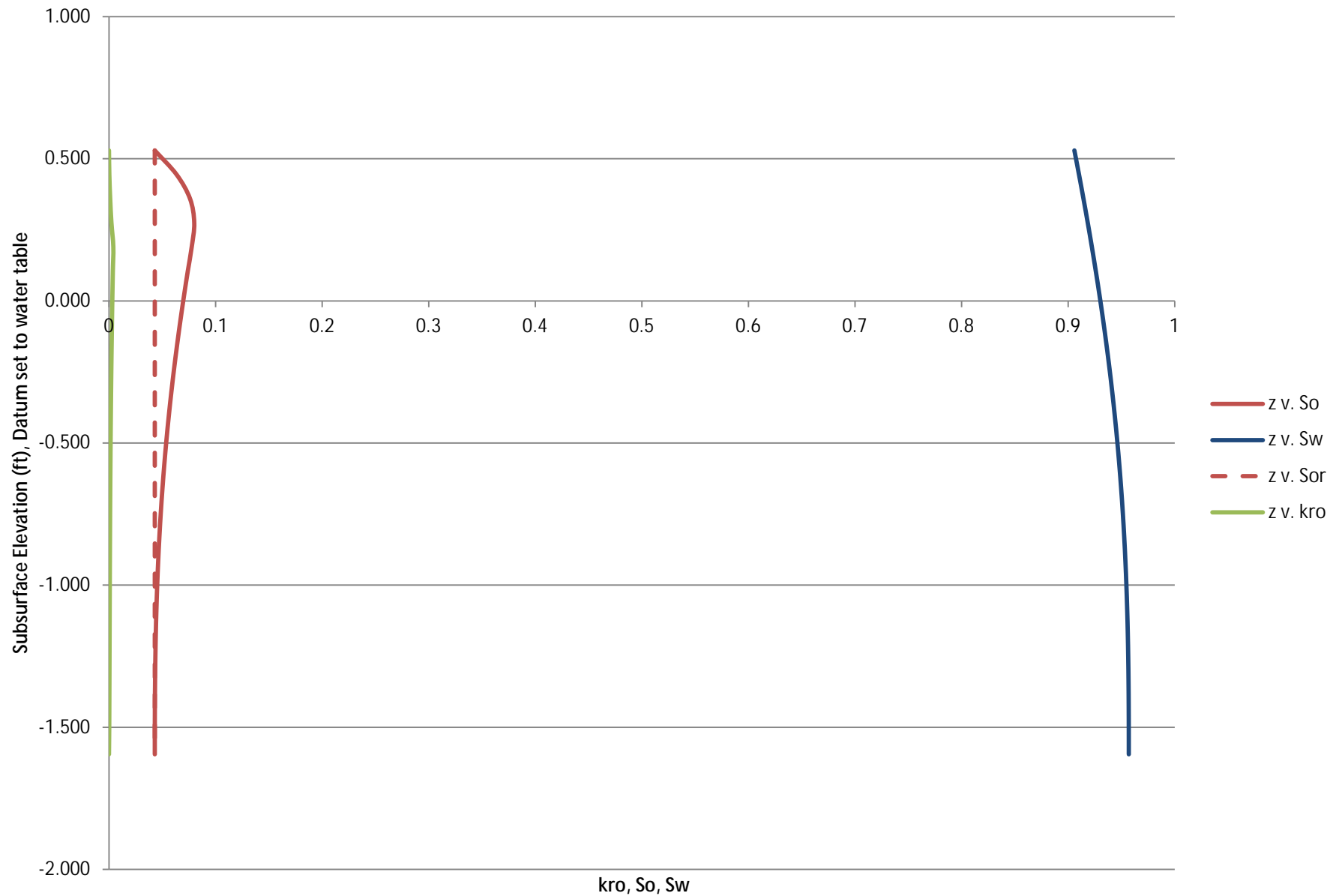
PROFILE CALCULATIONS

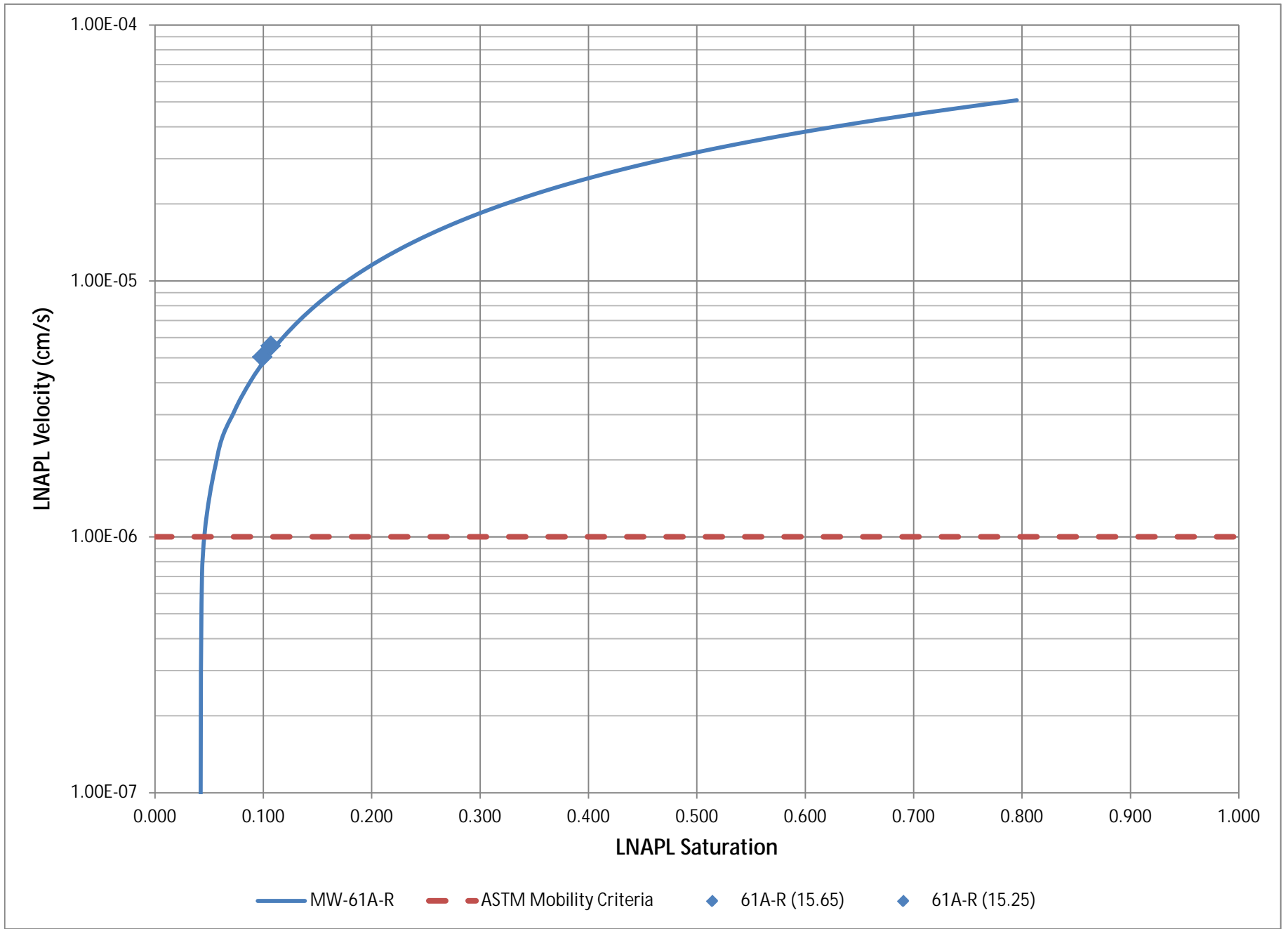
Scale	z	S _{e(w)} (z)	S _w (z)	S _{e(t)} (z)	S _o (z)	S _{or}	k _{ro} (S _w , S _o)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T _o (b _o) (cm ² /s)	Step Calc for D _o (b _o) (cm ² /cm ²)	Step Calc for R _o (cm ³ /cm ²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.529	0.932187225	0.90593698	0.932187225	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
1	0.444	0.937943913	0.910271767	0.965134735	0.063474688	0.043	3.34E-04	3.35E-07	2.59	8.96E-07	0.051	1.64E-02
2	0.359	0.943508294	0.914461746	0.987429034	0.076072317	0.043	1.15E-03	9.62E-07	2.59	3.08E-06	0.061	2.65E-02
3	0.274	0.948864148	0.918494703	0.998049273	0.0800364	0.043	2.31E-03	1.84E-06	2.59	6.19E-06	0.064	2.97E-02
4	0.189	0.953995889	0.922358904	1	0.077641096	0.043	4.10E-03	3.37E-06	2.59	1.10E-05	0.062	2.78E-02
5	0.104	0.958888801	0.926043267	1	0.073956733	0.043	3.63E-03	3.14E-06	2.59	9.76E-06	0.059	2.49E-02
6	0.019	0.963529271	0.929537541	1	0.070462459	0.043	3.22E-03	2.91E-06	2.59	8.64E-06	0.057	2.20E-02
7	-0.066	0.967905029	0.932832487	1	0.067167513	0.043	2.84E-03	2.70E-06	2.59	7.63E-06	0.054	1.94E-02
8	-0.151	0.972005373	0.935920046	1	0.064079954	0.043	2.51E-03	2.50E-06	2.59	6.75E-06	0.051	1.69E-02
9	-0.236	0.97582139	0.938793507	1	0.061206493	0.043	2.22E-03	2.31E-06	2.59	5.96E-06	0.049	1.46E-02
10	-0.320	0.979346156	0.941447656	1	0.058552344	0.043	1.96E-03	2.14E-06	2.59	5.27E-06	0.047	1.25E-02
11	-0.405	0.982574908	0.943878906	1	0.056121094	0.043	1.74E-03	1.97E-06	2.59	4.66E-06	0.045	1.05E-02
12	-0.490	0.985505193	0.946085411	1	0.053914589	0.043	1.54E-03	1.82E-06	2.59	4.13E-06	0.043	8.76E-03
13	-0.575	0.988136992	0.948067155	1	0.051932845	0.043	1.36E-03	1.68E-06	2.59	3.66E-06	0.042	7.17E-03
14	-0.660	0.990472802	0.94982602	1	0.05017398	0.043	1.21E-03	1.54E-06	2.59	3.25E-06	0.040	5.76E-03
15	-0.745	0.992517695	0.951365824	1	0.048634176	0.043	1.08E-03	1.42E-06	2.59	2.90E-06	0.039	4.52E-03
16	-0.830	0.994279353	0.952692353	1	0.047307647	0.043	9.60E-04	1.30E-06	2.59	2.58E-06	0.038	3.46E-03
17	-0.915	0.99576808	0.953813364	1	0.046186636	0.043	8.55E-04	1.18E-06	2.59	2.30E-06	0.037	2.56E-03
18	-1.000	0.996996802	0.954738592	1	0.045261408	0.043	7.59E-04	1.07E-06	2.59	2.04E-06	0.036	1.82E-03
19	-1.085	0.997981083	0.955479755	1	0.044520245	0.043	6.71E-04	9.62E-07	2.59	1.80E-06	0.036	1.22E-03
20	-1.170	0.998739164	0.95605059	1	0.04394941	0.043	5.87E-04	8.53E-07	2.59	1.58E-06	0.035	7.62E-04
21	-1.255	0.999292085	0.95646694	1	0.04353306	0.043	5.05E-04	7.41E-07	2.59	1.36E-06	0.035	4.28E-04
22	-1.340	0.999663951	0.956746955	1	0.043253045	0.043	4.20E-04	6.21E-07	2.59	1.13E-06	0.035	2.03E-04
23	-1.425	0.999882514	0.956911533	1	0.043088467	0.043	3.28E-04	4.86E-07	2.59	8.81E-07	0.035	7.10E-05
24	-1.510	0.999980528	0.956985337	1	0.043014663	0.043	2.17E-04	3.22E-07	2.59	5.82E-07	0.035	1.18E-05
25	-1.595	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	2.59	0.00E+00	0.035	0.00E+00

SUMMARY CALCULATIONS (common units)

Equation:	Average S _o	Maximum LNAPL velocity (cm/s)	T _o (b _o) (ft ² /day)	U _{nx} (ft ² /yr)	D _o (b _o) (gal/ft ²)	R _o (gal/ft ²)
0.055366972	3.37E-06	3.31	3.32	2.40	2.41	6.33E-02

Relative Permeability and Saturation against Subsurface Elevation





	S_o	S_w	S_a	$S_{e[t]}$	$S_{e[w]}$	$K_{ro}(S_w, S_o)$ Burdine (sand)	Permeability to NAPL (in the presence of water)	LNAPL Velocity
Scale	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(cm ²)	(cm/s)
0	0.043	0.957		1	1.000	0.000	5.55E-14	1.17E-09
1%>Sor	0.043	0.957		1	0.999	0.000	3.36E-11	7.03E-07
1	0.058	0.942		1	0.980	0.002	1.34E-10	2.11E-06
2	0.073	0.927		1	0.960	0.004	2.48E-10	3.08E-06
3	0.088	0.912		1	0.940	0.006	3.93E-10	4.05E-06
4	0.103	0.897		1	0.920	0.008	5.70E-10	5.02E-06
5	0.118	0.882		1	0.900	0.011	7.82E-10	6.01E-06
6	0.133	0.867		1	0.880	0.015	1.03E-09	7.01E-06
7	0.148	0.852		1	0.860	0.019	1.31E-09	8.02E-06
8	0.163	0.837		1	0.840	0.023	1.62E-09	9.04E-06
9	0.179	0.821		1	0.820	0.028	1.98E-09	1.01E-05
10	0.194	0.806		1	0.800	0.034	2.36E-09	1.11E-05
11	0.209	0.791		1	0.780	0.040	2.78E-09	1.21E-05
12	0.224	0.776		1	0.760	0.046	3.24E-09	1.32E-05
13	0.239	0.761		1	0.740	0.053	3.73E-09	1.42E-05
14	0.254	0.746		1	0.720	0.061	4.25E-09	1.52E-05
15	0.269	0.731		1	0.700	0.069	4.81E-09	1.63E-05
16	0.284	0.716		1	0.680	0.077	5.40E-09	1.73E-05
17	0.299	0.701		1	0.660	0.086	6.03E-09	1.83E-05
18	0.314	0.686		1	0.640	0.095	6.69E-09	1.94E-05
19	0.329	0.671		1	0.620	0.105	7.38E-09	2.04E-05
20	0.344	0.656		1	0.600	0.115	8.10E-09	2.14E-05
21	0.359	0.641		1	0.580	0.126	8.86E-09	2.24E-05
22	0.374	0.626		1	0.560	0.137	9.65E-09	2.34E-05
23	0.389	0.611		1	0.540	0.149	1.05E-08	2.45E-05
24	0.404	0.596		1	0.520	0.161	1.13E-08	2.55E-05
25	0.420	0.581		1	0.500	0.174	1.22E-08	2.65E-05
26	0.435	0.565		1	0.480	0.187	1.31E-08	2.75E-05
27	0.450	0.550		1	0.460	0.201	1.41E-08	2.85E-05
28	0.465	0.535		1	0.440	0.215	1.51E-08	2.95E-05
29	0.480	0.520		1	0.420	0.229	1.61E-08	3.05E-05
30	0.495	0.505		1	0.400	0.244	1.71E-08	3.15E-05
31	0.510	0.490		1	0.380	0.259	1.82E-08	3.24E-05
32	0.525	0.475		1	0.360	0.275	1.93E-08	3.34E-05
33	0.540	0.460		1	0.340	0.291	2.04E-08	3.44E-05
34	0.555	0.445		1	0.320	0.308	2.16E-08	3.54E-05
35	0.570	0.430		1	0.300	0.325	2.28E-08	3.63E-05
36	0.585	0.415		1	0.280	0.342	2.40E-08	3.73E-05
37	0.600	0.400		1	0.260	0.360	2.53E-08	3.83E-05
38	0.615	0.385		1	0.240	0.378	2.66E-08	3.93E-05
39	0.630	0.370		1	0.220	0.397	2.79E-08	4.02E-05
40	0.645	0.355		1	0.200	0.416	2.92E-08	4.12E-05
41	0.660	0.340		1	0.180	0.436	3.06E-08	4.22E-05
42	0.676	0.324		1	0.160	0.456	3.20E-08	4.31E-05
43	0.691	0.309		1	0.140	0.477	3.35E-08	4.41E-05
44	0.706	0.294		1	0.120	0.498	3.50E-08	4.50E-05
45	0.721	0.279		1	0.100	0.519	3.65E-08	4.60E-05
46	0.736	0.264		1	0.080	0.541	3.80E-08	4.70E-05
47	0.751	0.249		1	0.060	0.564	3.96E-08	4.79E-05
48	0.766	0.234		1	0.040	0.587	4.12E-08	4.89E-05
49	0.781	0.219		1	0.020	0.610	4.28E-08	4.98E-05
50	0.795	0.205		1	0.001	0.632	4.44E-08	5.08E-05

$$z_{an} - z_{aw} = (1 - \rho_r) b_n \quad (2.19)$$

$$z_{aw} - z_{mv} = \rho_r b_n \quad (2.20)$$

The elevation z_{\max} is the maximum elevation of free LNAPL due to capillary rise. Above this elevation, any LNAPL is present at residual saturation and is not mobile.

$$z_{\max} = z_{an} + \frac{(1 - \rho_r)(\sigma_{an}/\sigma_{mv})}{\rho_r - (1 - \rho_r)(\sigma_{an}/\sigma_{mv})} b_n \quad (2.38)$$

$$S_{e[w]}(z) = (1 + (\alpha_{mv}(z - z_{mv}))^N)^{-M} \quad (2.24)$$

$$\alpha_{mv} = (1 - \rho_r) \frac{\sigma_{aw}}{\sigma_{mv}} \alpha \quad (2.25)$$

$$\text{Mualem: } M = 1 - 1/N \quad ; \quad N > 1 \quad (2.6)$$

$$\text{Burdine: } M = 1 - 2/N \quad ; \quad N > 2 \quad (2.5)$$

$$S_w(z) = S_{wr} + (1 - S_{wr} - S_{mr}) S_{e[w]}(z) \quad (2.27)$$

For elevations $z < z_{an}$, the pore space not occupied by water will be filled with LNAPL. Thus for $z < z_{an}$,

$$S_n(z) = 1 - S_w(z) \quad (2.28)$$

$$S_{e[l]}(z) = (1 + (\alpha_{an}(z - z_{an}))^N)^{-M} \quad (2.30)$$

$$\alpha_{an} = \rho_r \frac{\sigma_{aw}}{\sigma_{an}} \alpha \quad (2.31)$$

$$S_n(z) = S_{nr} + (1 - S_{nr} - S_{nr})(S_{e[l]} - S_{e[w]}) \quad (2.33)$$

Similar changes are made to the tortuosity term for the three-phase equations, which become

$$k_m(S_w, S_n) = (S_n)^2 \times \left((1 - S_{e[w]}^{1/M})^M - (1 - S_{e[l]}^{1/M})^M \right) \quad (3.13)$$

$$k_m(S_w, S_n) = \sqrt{S_n} \times \left((1 - S_{e[w]}^{1/M})^M - (1 - S_{e[l]}^{1/M})^M \right)^2 \quad (3.14)$$

$$D_n(b_n) = \int_{z_{nw}}^{z_{max}} n S_n(z) dz \quad (2.40)$$

$$K_{nz} = K_{wz} \frac{\rho_r}{\mu_r} \quad (3.2)$$

eqn 3.32 also shows the relationship between water hydraulic gradient and oil hydraulic gradient.

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

This calculation may be made by defining the LNAPL-layer transmissibility as follows:

$$T_n(b_n) = \frac{\rho_r}{\mu_r} \int_{z_{nw}}^{z_{max}} K_{wz}(z) k_m(S_w, S_n) dz \quad (3.31)$$

In terms of the transmissibility, the lens unit flux (in the x-direction) is calculated from

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

$$q_{nx} = \frac{K_{wz} k_m J_{wx}}{\mu_r} = \frac{k_{rn} q_{wx}}{k_{rw} \mu_r} \quad (3.27)$$

$$R_n(b_n) = \int_{z_{nw}}^{z_{max}} n (S_n(z) - S_w(z)) dz \quad (2.41)$$



SITE/PROJECT INFORMATION

Date: 9/10/2010
 Site Name: Former Unocal Seattle Marketing Terminal
 Site Location (City, ST): Seattle WA

CASE STUDY ASSUMPTIONS

Case Name: PZ-6
 LNAPL Type: Literature assumptions based on California Crude
 Geology Type: Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	Symbol	Value	Units	Source
Site Data				
Monitoring Well LNAPL Thickness	b_o	0.53	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00529	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.017	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	r_o	0.85	g/cm ³	literature (API)
LNAPL Viscosity	m_b	340	g/cm-s	literature (API)
Water Density	r_w	0.9989	g/cm ³	field/site data
Water Viscosity	m_w	0.013	g/cm-s	field/site data
Surface Tension	s_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	s_{ao}	37	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	s_{ow}	25	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	a	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	Symbol	Value	Units	API 4760 Equation
Air-Water Interface in Subsurface	Z_{aw}	0	ft	datum
Density Ratio	r_r	0.851	dimensionless	
Air-LNAPL Interface in Well	Z_{ao}	0.079	ft	2.19
LNAPL-Water Interface in Well	Z_{ow}	-0.451	ft	2.20
Maximum Free LNAPL in Subsurface	Z_{max}	0.265	ft	2.38
LNAPL vertical extent in subsurface		0.716	ft	
vG Alpha scaled to oil-water interactions	a_{ow}	0.371	1/ft	2.25
vG Alpha scaled to oil-air interactions	a_{ao}	1.432	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	m_j	26153.846	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00000	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.020	dimensionless	
Intrinsic Permeability	k	7.02E-08	cm ²	



SITE/PROJECT INFORMATION

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CASE STUDY ASSUMPTIONS

Case Name: PZ-6
 LNAPL Type: Literature assumptions based on California Crude
 Geology Type: Medium grained sand - based on grain size analysis

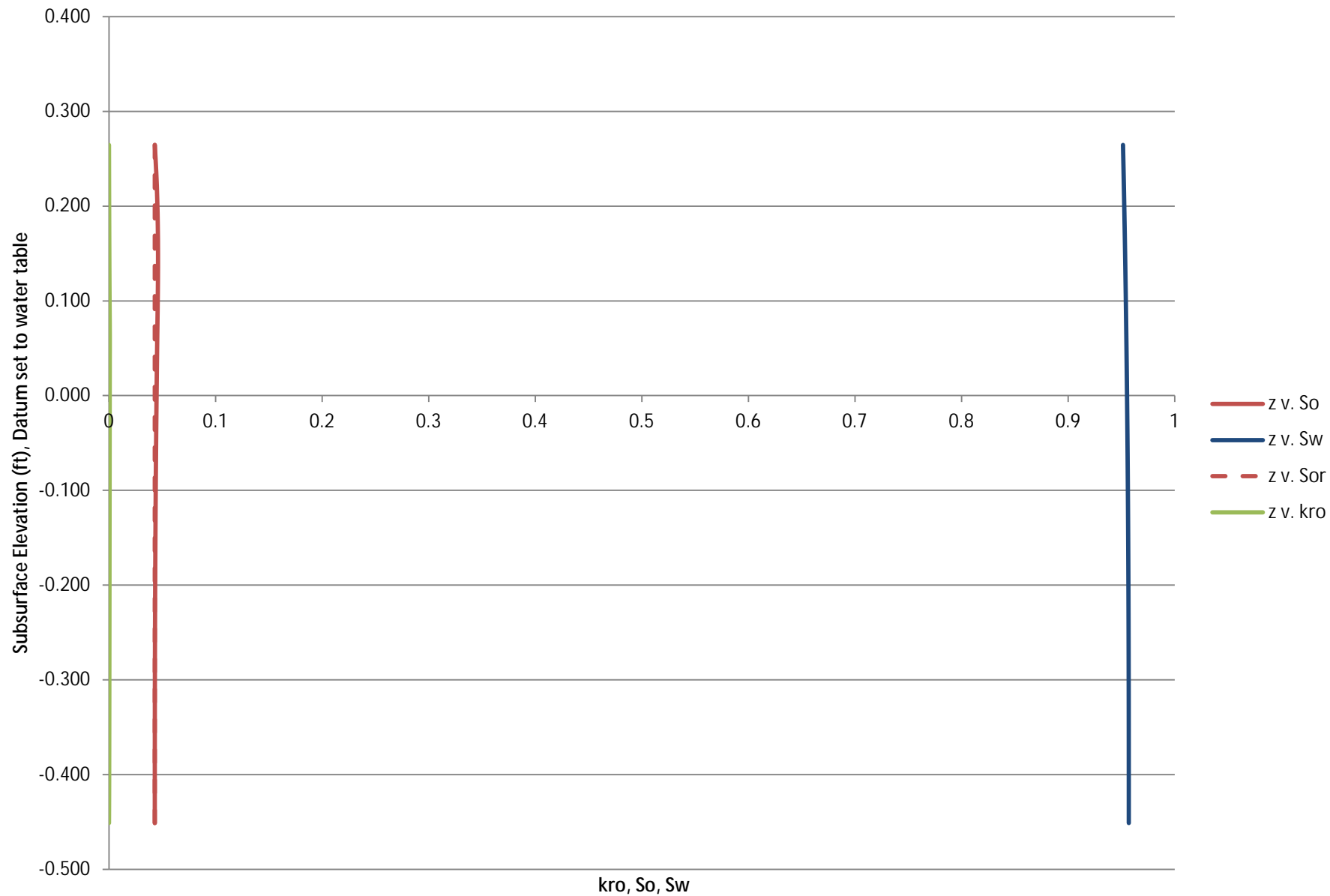
PROFILE CALCULATIONS

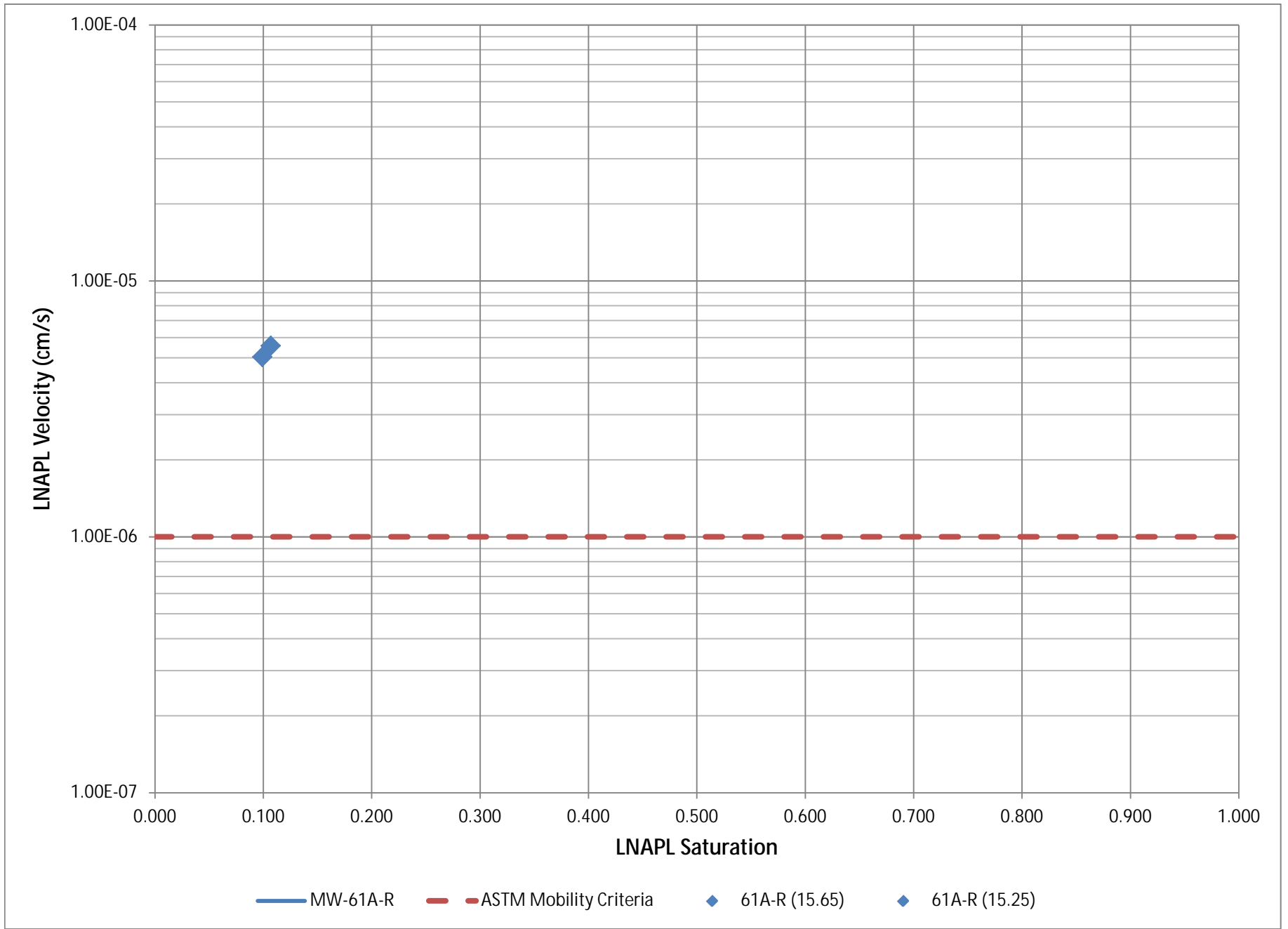
Scale	z	S _{e[w]} (z)	S _w (z)	S _{e[t]} (z)	S _o (z)	S _{or}	k _{ro} (S _w , S _o)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T _o (b _o) (cm ² /s)	Step Calc for D _o (b _o) (cm ² /cm ²)	Step Calc for R _o (cm ³ /cm ²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.265	0.992786812	0.95156847	0.992786812	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
1	0.236	0.993498863	0.952104644	0.995297292	0.044354218	0.043	6.15E-05	1.54E-11	0.87	9.24E-12	0.012	3.66E-04
2	0.207	0.994167664	0.952608251	0.997196378	0.045280622	0.043	1.35E-04	3.32E-11	0.87	2.03E-11	0.012	6.17E-04
3	0.179	0.994793885	0.953079795	0.998538125	0.045819413	0.043	2.21E-04	5.36E-11	0.87	3.33E-11	0.012	7.62E-04
4	0.150	0.995378258	0.953519828	0.999391094	0.046021666	0.043	3.20E-04	7.73E-11	0.87	4.81E-11	0.012	8.17E-04
5	0.121	0.99592158	0.95392895	0.999839994	0.045950566	0.043	4.38E-04	1.06E-10	0.87	6.58E-11	0.012	7.98E-04
6	0.093	0.99642471	0.954307806	0.9999132	0.045685657	0.043	6.02E-04	1.46E-10	0.87	9.04E-11	0.012	7.26E-04
7	0.064	0.996888571	0.954657094	1	0.045342906	0.043	7.68E-04	1.88E-10	0.87	1.15E-10	0.012	6.34E-04
8	0.036	0.99731415	0.954977555	1	0.045022445	0.043	7.32E-04	1.80E-10	0.87	1.10E-10	0.012	5.47E-04
9	0.007	0.997702499	0.955269982	1	0.044730018	0.043	6.98E-04	1.73E-10	0.87	1.05E-10	0.012	4.68E-04
10	-0.022	0.998054734	0.955535215	1	0.044464785	0.043	6.64E-04	1.66E-10	0.87	9.97E-11	0.012	3.96E-04
11	-0.050	0.998372038	0.955774144	1	0.044225856	0.043	6.30E-04	1.58E-10	0.87	9.47E-11	0.012	3.32E-04
12	-0.079	0.99865566	0.955987712	1	0.044012288	0.043	5.98E-04	1.51E-10	0.87	8.98E-11	0.012	2.74E-04
13	-0.108	0.998906921	0.956176911	1	0.043823089	0.043	5.65E-04	1.43E-10	0.87	8.49E-11	0.012	2.23E-04
14	-0.136	0.999127211	0.95634279	1	0.04365721	0.043	5.33E-04	1.35E-10	0.87	8.00E-11	0.012	1.78E-04
15	-0.165	0.999317998	0.956486453	1	0.043513547	0.043	5.00E-04	1.28E-10	0.87	7.51E-11	0.012	1.39E-04
16	-0.193	0.99948083	0.956609065	1	0.043390935	0.043	4.67E-04	1.20E-10	0.87	7.02E-11	0.012	1.06E-04
17	-0.222	0.999617342	0.956711858	1	0.043288142	0.043	4.34E-04	1.11E-10	0.87	6.52E-11	0.012	7.79E-05
18	-0.251	0.999729263	0.956796135	1	0.043203865	0.043	3.99E-04	1.03E-10	0.87	6.00E-11	0.012	5.51E-05
19	-0.279	0.999818434	0.956863281	1	0.043136719	0.043	3.63E-04	9.34E-11	0.87	5.46E-11	0.012	3.70E-05
20	-0.308	0.999886821	0.956914776	1	0.043085224	0.043	3.25E-04	8.38E-11	0.87	4.89E-11	0.012	2.30E-05
21	-0.337	0.99993654	0.956952214	1	0.043047786	0.043	2.84E-04	7.33E-11	0.87	4.27E-11	0.012	1.29E-05
22	-0.365	0.999969903	0.956977337	1	0.043022663	0.043	2.40E-04	6.18E-11	0.87	3.60E-11	0.012	6.13E-06
23	-0.394	0.999989483	0.956992081	1	0.043007919	0.043	1.88E-04	4.86E-11	0.87	2.83E-11	0.012	2.14E-06
24	-0.422	0.999998257	0.956998688	1	0.043001312	0.043	1.25E-04	3.22E-11	0.87	1.87E-11	0.012	3.55E-07
25	-0.451	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	0.87	0.00E+00	0.012	0.00E+00

SUMMARY CALCULATIONS (common units)

Equation:	Average S _o	Maximum LNAPL velocity (cm/s)	T _o (b _o) (ft ² /day)	U _{nx} (ft ² /yr)	D _o (b _o) (gal/ft ²)	R _o (gal/ft ²)
	0.04408034	1.88E-10	3.31 1.44E-07	3.32 1.05E-06	2.40 0.073	2.41 1.86E-03

Relative Permeability and Saturation against Subsurface Elevation





	S_o	S_w	S_a	$S_{e[t]}$	$S_{e[w]}$	$K_{ro}(S_w, S_o)$ Burdine (sand)	Permeability to NAPL (in the presence of water)	LNAPL Velocity
Scale	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(cm ²)	(cm/s)
0	0.043	0.957		1	1.000	0.000	5.55E-14	2.04E-13
1%>Sor	0.043	0.957		1	0.999	0.000	3.36E-11	1.22E-10
1	0.058	0.942		1	0.980	0.002	1.34E-10	3.66E-10
2	0.073	0.927		1	0.960	0.004	2.48E-10	5.36E-10
3	0.088	0.912		1	0.940	0.006	3.93E-10	7.04E-10
4	0.103	0.897		1	0.920	0.008	5.70E-10	8.73E-10
5	0.118	0.882		1	0.900	0.011	7.82E-10	1.04E-09
6	0.133	0.867		1	0.880	0.015	1.03E-09	1.22E-09
7	0.148	0.852		1	0.860	0.019	1.31E-09	1.39E-09
8	0.163	0.837		1	0.840	0.023	1.62E-09	1.57E-09
9	0.179	0.821		1	0.820	0.028	1.98E-09	1.75E-09
10	0.194	0.806		1	0.800	0.034	2.36E-09	1.93E-09
11	0.209	0.791		1	0.780	0.040	2.78E-09	2.11E-09
12	0.224	0.776		1	0.760	0.046	3.24E-09	2.29E-09
13	0.239	0.761		1	0.740	0.053	3.73E-09	2.47E-09
14	0.254	0.746		1	0.720	0.061	4.25E-09	2.65E-09
15	0.269	0.731		1	0.700	0.069	4.81E-09	2.83E-09
16	0.284	0.716		1	0.680	0.077	5.40E-09	3.01E-09
17	0.299	0.701		1	0.660	0.086	6.03E-09	3.19E-09
18	0.314	0.686		1	0.640	0.095	6.69E-09	3.36E-09
19	0.329	0.671		1	0.620	0.105	7.38E-09	3.54E-09
20	0.344	0.656		1	0.600	0.115	8.10E-09	3.72E-09
21	0.359	0.641		1	0.580	0.126	8.86E-09	3.90E-09
22	0.374	0.626		1	0.560	0.137	9.65E-09	4.08E-09
23	0.389	0.611		1	0.540	0.149	1.05E-08	4.25E-09
24	0.404	0.596		1	0.520	0.161	1.13E-08	4.43E-09
25	0.420	0.581		1	0.500	0.174	1.22E-08	4.60E-09
26	0.435	0.565		1	0.480	0.187	1.31E-08	4.78E-09
27	0.450	0.550		1	0.460	0.201	1.41E-08	4.95E-09
28	0.465	0.535		1	0.440	0.215	1.51E-08	5.12E-09
29	0.480	0.520		1	0.420	0.229	1.61E-08	5.30E-09
30	0.495	0.505		1	0.400	0.244	1.71E-08	5.47E-09
31	0.510	0.490		1	0.380	0.259	1.82E-08	5.64E-09
32	0.525	0.475		1	0.360	0.275	1.93E-08	5.81E-09
33	0.540	0.460		1	0.340	0.291	2.04E-08	5.98E-09
34	0.555	0.445		1	0.320	0.308	2.16E-08	6.15E-09
35	0.570	0.430		1	0.300	0.325	2.28E-08	6.32E-09
36	0.585	0.415		1	0.280	0.342	2.40E-08	6.49E-09
37	0.600	0.400		1	0.260	0.360	2.53E-08	6.66E-09
38	0.615	0.385		1	0.240	0.378	2.66E-08	6.82E-09
39	0.630	0.370		1	0.220	0.397	2.79E-08	6.99E-09
40	0.645	0.355		1	0.200	0.416	2.92E-08	7.16E-09
41	0.660	0.340		1	0.180	0.436	3.06E-08	7.33E-09
42	0.676	0.324		1	0.160	0.456	3.20E-08	7.49E-09
43	0.691	0.309		1	0.140	0.477	3.35E-08	7.66E-09
44	0.706	0.294		1	0.120	0.498	3.50E-08	7.83E-09
45	0.721	0.279		1	0.100	0.519	3.65E-08	8.00E-09
46	0.736	0.264		1	0.080	0.541	3.80E-08	8.16E-09
47	0.751	0.249		1	0.060	0.564	3.96E-08	8.33E-09
48	0.766	0.234		1	0.040	0.587	4.12E-08	8.50E-09
49	0.781	0.219		1	0.020	0.610	4.28E-08	8.66E-09
50	0.795	0.205		1	0.001	0.632	4.44E-08	8.82E-09

$$z_{m1} - z_{m0} = (1 - \rho_r) b_n \quad (2.19)$$

$$z_{m0} - z_{m0} = \rho_r b_n \quad (2.20)$$

The elevation z_{\max} is the maximum elevation of free LNAPL due to capillary rise. Above this elevation, any LNAPL is present at residual saturation and is not mobile.

$$z_{\max} = z_{m1} + \frac{(1 - \rho_r)(\sigma_{m1}/\sigma_{m0})}{\rho_r - (1 - \rho_r)(\sigma_{m1}/\sigma_{m0})} b_n \quad (2.38)$$

$$S_{q[n]}(z) = \left(1 + (\alpha_{m1}(z - z_{m0}))^N\right)^{-M} \quad (2.24)$$

$$\alpha_{m1} = (1 - \rho_r) \frac{\sigma_{m1}}{\sigma_{m0}} \alpha \quad (2.25)$$

$$\text{Mualem: } M = 1 - 1/N \quad ; \quad N > 1 \quad (2.6)$$

$$\text{Burdine: } M = 1 - 2/N \quad ; \quad N > 2 \quad (2.5)$$

$$S_w(z) = S_{w1} + (1 - S_{w1} - S_{w0}) S_{q[n]}(z) \quad (2.27)$$

For elevations $z < z_{m1}$, the pore space not occupied by water will be filled with LNAPL. Thus for $z < z_{m1}$,

$$S_n(z) = 1 - S_w(z) \quad (2.28)$$

$$S_{dij}(z) = \left(1 + (\alpha_{en}(z - z_{en}))^n\right)^{-M} \quad (2.30)$$

$$\alpha_{en} = \rho_r \frac{\sigma_{en}}{\sigma_{en}} \alpha \quad (2.31)$$

$$S_n(z) = S_w + (1 - S_w - S_o)(S_{dij} - S_{dij}) \quad (2.33)$$

Similar changes are made to the tortuosity term for the three-phase equations, which become

$$k_m(S_w, S_n) = (S_n)^2 \times \left(\left(1 - S_{dij}^{YM}\right)^M - \left(1 - S_{dij}^{YM}\right)^M \right) \quad (3.13)$$

$$k_m(S_w, S_n) = \sqrt{S_n} \times \left(\left(1 - S_{dij}^{YM}\right)^M - \left(1 - S_{dij}^{YM}\right)^M \right)^2 \quad (3.14)$$

$$D_x(b_n) = \int_{z_w}^{z_{top}} n S_n(z) dz \quad (2.40)$$

$$K_{nz} = K_{nz} \frac{\rho_r}{\mu_r} \quad (3.2)$$

$$U_{nz} = \int_{z_w}^{z_{top}} q_{nz} dz = T_x(b_n) J_{nz} = \frac{T_x(b_n) J_{nz}}{\rho_r} \quad (3.32)$$

eqn 3.32 also shows the relationship between water hydraulic gradient and oil hydraulic gradient.

This calculation may be made by defining the LNAPL-layer transmissibility as follows:

$$T_x(b_n) = \frac{\rho_r}{\mu_r} \int_{z_w}^{z_{top}} K_{nz}(z) k_m(S_w, S_n) dz \quad (3.31)$$

In terms of the transmissibility, the lens unit flux (in the x-direction) is calculated from

$$U_{nz} = \int_{z_w}^{z_{top}} q_{nz} dz = T_x(b_n) J_{nz} = \frac{T_x(b_n) J_{nz}}{\rho_r} \quad (3.32)$$

$$q_{nz} = \frac{K_{nz} k_m J_{nz}}{\mu_r} = \frac{k_{rn} q_{nz}}{k_{rn} \mu_r} \quad (3.27)$$

$$R_x(b_n) = \int_{z_w}^{z_{top}} n (S_n(z) - S_w(z)) dz \quad (2.41)$$



SITE/PROJECT INFORMATION

Date: 7/14/2014
 Site Name: Former Unocal Seattle Marketing Terminal
 Site Location (City, ST): Seattle WA

CASE STUDY ASSUMPTIONS

Case Name: RW-3
 LNAPL Type: Literature assumptions based on Fuel Oil #3
 Geology Type: Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	Symbol	Value	Units	Source
Site Data				
Monitoring Well LNAPL Thickness	b_o	2.56	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00529	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.017	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	r_o	0.89	g/cm ³	literature (API)
LNAPL Viscosity	m_b	0.0591	g/cm-s	literature (API)
Water Density	r_w	0.9989	g/cm ³	field/site data
Water Viscosity	m_w	0.013	g/cm-s	field/site data
Surface Tension	s_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	s_{ao}	27.5	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	s_{ow}	21.4	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	a	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	Symbol	Value	Units	API 4760 Equation
Air-Water Interface in Subsurface	z_{aw}	0	ft	datum
Density Ratio	r_r	0.891	dimensionless	
Air-LNAPL Interface in Well	z_{ao}	0.279	ft	2.19
LNAPL-Water Interface in Well	z_{ow}	-2.281	ft	2.20
Maximum Free LNAPL in Subsurface	z_{max}	0.757	ft	2.38
LNAPL vertical extent in subsurface		3.038	ft	
vG Alpha scaled to oil-water interactions	a_{ow}	0.317	1/ft	2.25
vG Alpha scaled to oil-air interactions	a_{ao}	2.018	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	η	4.546	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00104	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.019	dimensionless	
Intrinsic Permeability	k	7.02E-08	cm ²	



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CASE STUDY ASSUMPTIONS

Case Name: RW-3
 LNAPL Type: Literature assumptions based on Fuel Oil #3
 Geology Type: Medium grained sand - based on grain size analysis

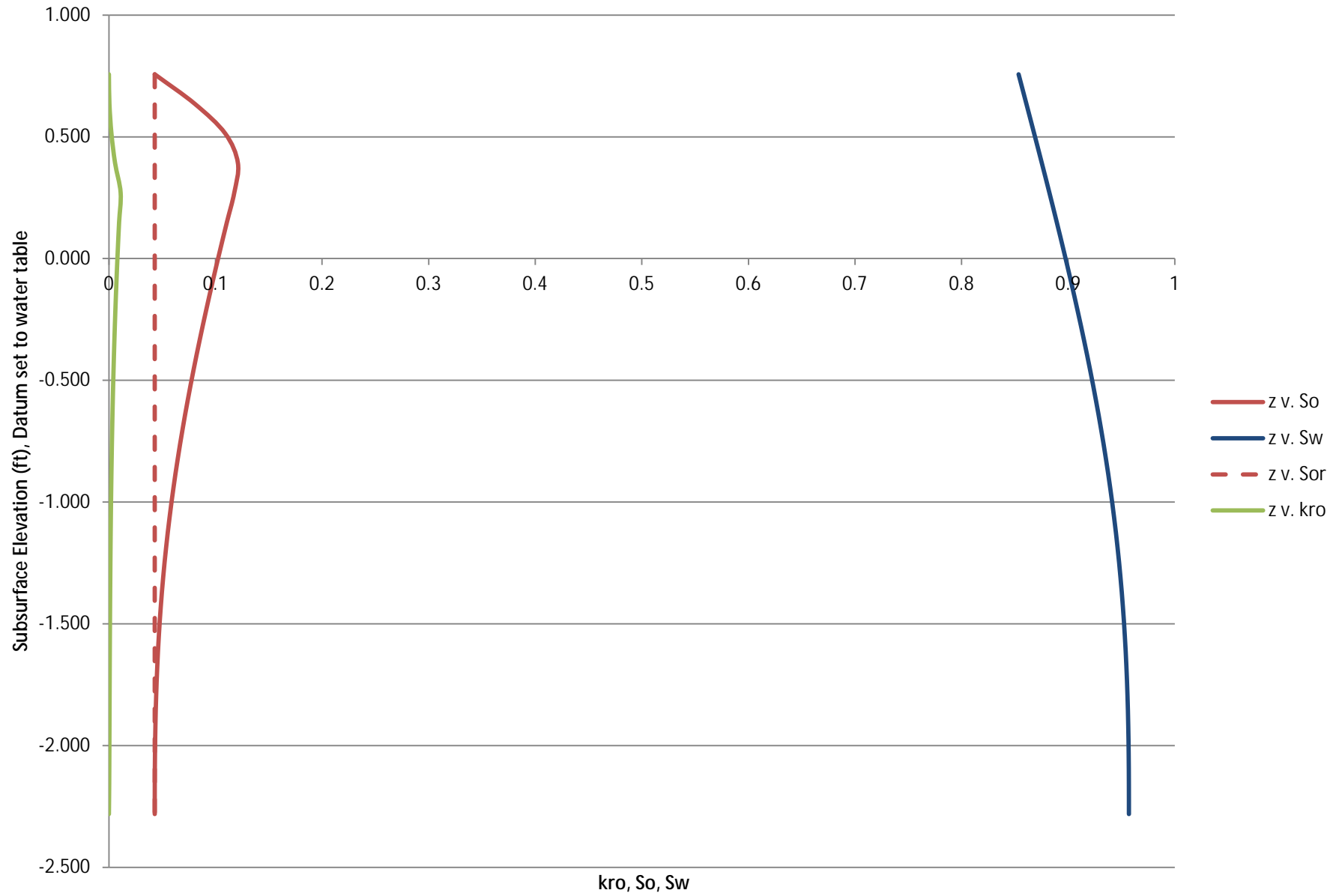
PROFILE CALCULATIONS

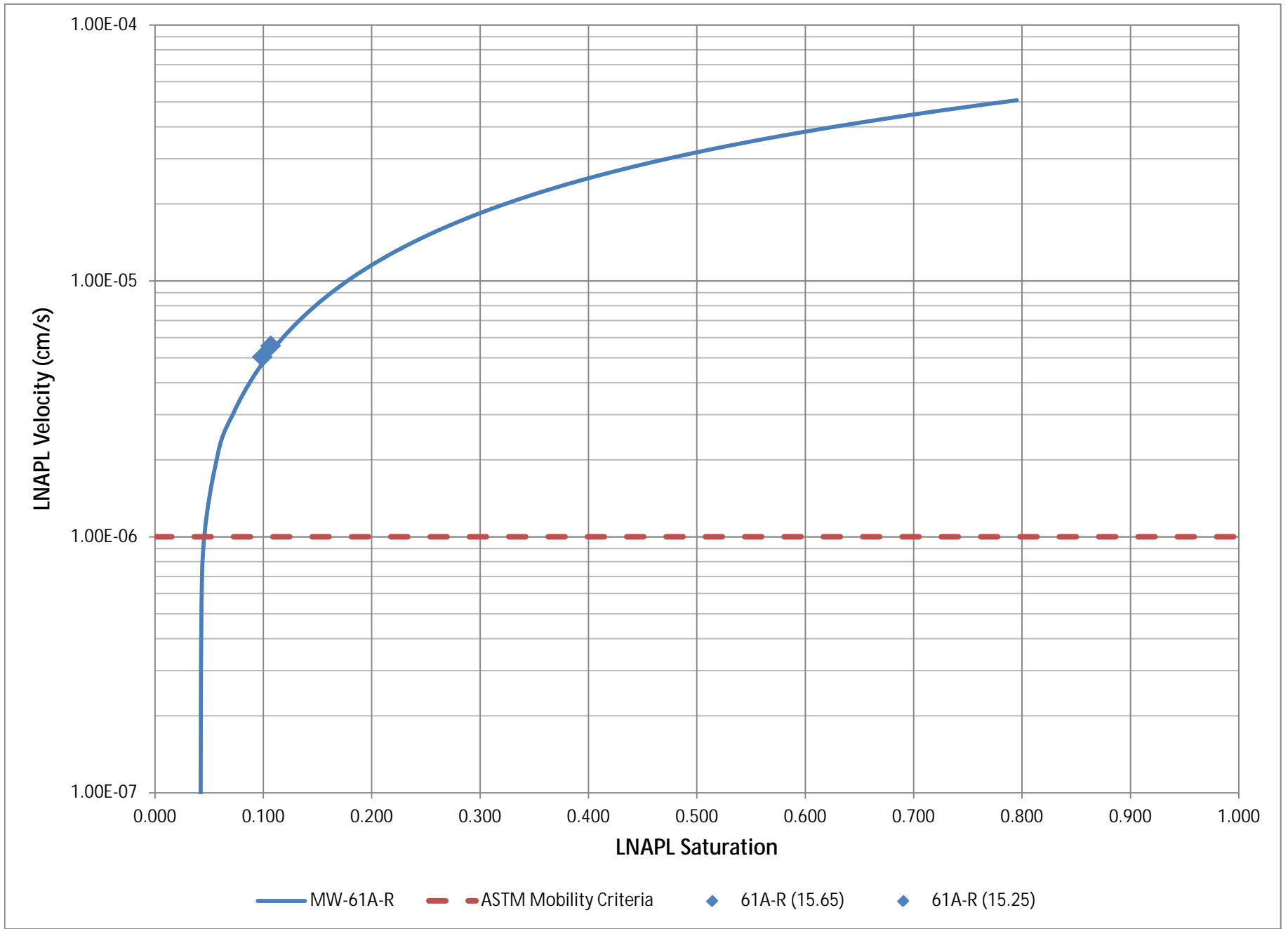
Scale	z	S _{elw} (z)	S _w (z)	S _{elt} (z)	S _o (z)	S _{or}	k _{ro} (S _w , S _o)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T _o (b _o) (cm ² /s)	Step Calc for D _o (b _o) (cm ³ /cm ²)	Step Calc for R _o (cm ³ /cm ²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.757	0.862533558	0.853487769	0.862533558	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
1	0.635	0.872258362	0.860810546	0.922259904	0.080651162	0.043	4.87E-04	3.86E-07	3.70	1.87E-06	0.093	4.32E-02
2	0.514	0.881918131	0.868084352	0.96973116	0.109123211	0.043	2.37E-03	1.39E-06	3.70	9.10E-06	0.125	7.59E-02
3	0.392	0.891474499	0.875280298	0.995105362	0.12103404	0.043	5.78E-03	3.05E-06	3.70	2.22E-05	0.139	8.96E-02
4	0.271	0.900885907	0.882367088	1	0.117632912	0.043	1.10E-02	5.97E-06	3.70	4.22E-05	0.135	8.57E-02
5	0.149	0.910107943	0.889311281	1	0.110688719	0.043	9.56E-03	5.51E-06	3.70	3.67E-05	0.127	7.77E-02
6	0.028	0.919093852	0.896077671	1	0.103922329	0.043	8.25E-03	5.07E-06	3.70	3.17E-05	0.119	6.99E-02
7	-0.094	0.927795218	0.902629799	1	0.097370201	0.043	7.08E-03	4.64E-06	3.70	2.72E-05	0.112	6.24E-02
8	-0.215	0.936162833	0.908930613	1	0.091069387	0.043	6.04E-03	4.23E-06	3.70	2.32E-05	0.105	5.52E-02
9	-0.337	0.944147739	0.914943247	1	0.085056753	0.043	5.13E-03	3.85E-06	3.70	1.97E-05	0.098	4.83E-02
10	-0.458	0.951702429	0.920631929	1	0.079368071	0.043	4.33E-03	3.48E-06	3.70	1.66E-05	0.091	4.18E-02
11	-0.580	0.958782171	0.925962975	1	0.074037025	0.043	3.64E-03	3.14E-06	3.70	1.40E-05	0.085	3.56E-02
12	-0.701	0.965346407	0.930905844	1	0.069094156	0.043	3.06E-03	2.83E-06	3.70	1.17E-05	0.079	3.00E-02
13	-0.823	0.97136016	0.935434201	1	0.064565799	0.043	2.56E-03	2.53E-06	3.70	9.84E-06	0.074	2.48E-02
14	-0.944	0.976795396	0.939526933	1	0.060473067	0.043	2.15E-03	2.27E-06	3.70	8.25E-06	0.069	2.01E-02
15	-1.066	0.981632244	0.94316908	1	0.05683092	0.043	1.80E-03	2.02E-06	3.70	6.92E-06	0.065	1.59E-02
16	-1.187	0.985860043	0.946352612	1	0.053647388	0.043	1.51E-03	1.80E-06	3.70	5.81E-06	0.062	1.22E-02
17	-1.309	0.989478138	0.949077038	1	0.050922962	0.043	1.28E-03	1.60E-06	3.70	4.90E-06	0.058	9.10E-03
18	-1.430	0.992496428	0.95134981	1	0.04865019	0.043	1.08E-03	1.42E-06	3.70	4.15E-06	0.056	6.49E-03
19	-1.552	0.994935658	0.95318655	1	0.04681345	0.043	9.15E-04	1.25E-06	3.70	3.51E-06	0.054	4.38E-03
20	-1.673	0.996827531	0.954611131	1	0.045388869	0.043	7.73E-04	1.09E-06	3.70	2.97E-06	0.052	2.74E-03
21	-1.795	0.998214755	0.95565571	1	0.04434429	0.043	6.47E-04	9.32E-07	3.70	2.49E-06	0.051	1.54E-03
22	-1.916	0.99915125	0.956360891	1	0.043639109	0.043	5.29E-04	7.74E-07	3.70	2.03E-06	0.050	7.34E-04
23	-2.038	0.999703002	0.95677636	1	0.04322364	0.043	4.08E-04	6.03E-07	3.70	1.57E-06	0.050	2.57E-04
24	-2.159	0.999950755	0.956962919	1	0.043037081	0.043	2.68E-04	3.98E-07	3.70	1.03E-06	0.049	4.26E-05
25	-2.281	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	3.70	0.00E+00	0.049	0.00E+00

SUMMARY CALCULATIONS (common units)

Equation:	Average S _o	Maximum LNAPL velocity (cm/s)	T _o (b _o) (ft ² /day)	U _{nx} (ft ² /yr)	D _o (b _o) (gal/ft ²)	R _o (gal/ft ²)
	0.070253259	5.97E-06	2.88E-02	2.01E-01	0.503	2.00E-01

Relative Permeability and Saturation against Subsurface Elevation





	S_o	S_w	S_a	$S_{e[t]}$	$S_{e[w]}$	$K_{ro}(S_w, S_o)$ Burdine (sand)	Permeability to NAPL (in the presence of water)	LNAPL Velocity
Scale	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(cm ²)	(cm/s)
0	0.043	0.957		1	1.000	0.000	5.55E-14	1.17E-09
1%>Sor	0.043	0.957		1	0.999	0.000	3.36E-11	7.03E-07
1	0.058	0.942		1	0.980	0.002	1.34E-10	2.11E-06
2	0.073	0.927		1	0.960	0.004	2.48E-10	3.08E-06
3	0.088	0.912		1	0.940	0.006	3.93E-10	4.05E-06
4	0.103	0.897		1	0.920	0.008	5.70E-10	5.02E-06
5	0.118	0.882		1	0.900	0.011	7.82E-10	6.01E-06
6	0.133	0.867		1	0.880	0.015	1.03E-09	7.01E-06
7	0.148	0.852		1	0.860	0.019	1.31E-09	8.02E-06
8	0.163	0.837		1	0.840	0.023	1.62E-09	9.04E-06
9	0.179	0.821		1	0.820	0.028	1.98E-09	1.01E-05
10	0.194	0.806		1	0.800	0.034	2.36E-09	1.11E-05
11	0.209	0.791		1	0.780	0.040	2.78E-09	1.21E-05
12	0.224	0.776		1	0.760	0.046	3.24E-09	1.32E-05
13	0.239	0.761		1	0.740	0.053	3.73E-09	1.42E-05
14	0.254	0.746		1	0.720	0.061	4.25E-09	1.52E-05
15	0.269	0.731		1	0.700	0.069	4.81E-09	1.63E-05
16	0.284	0.716		1	0.680	0.077	5.40E-09	1.73E-05
17	0.299	0.701		1	0.660	0.086	6.03E-09	1.83E-05
18	0.314	0.686		1	0.640	0.095	6.69E-09	1.94E-05
19	0.329	0.671		1	0.620	0.105	7.38E-09	2.04E-05
20	0.344	0.656		1	0.600	0.115	8.10E-09	2.14E-05
21	0.359	0.641		1	0.580	0.126	8.86E-09	2.24E-05
22	0.374	0.626		1	0.560	0.137	9.65E-09	2.34E-05
23	0.389	0.611		1	0.540	0.149	1.05E-08	2.45E-05
24	0.404	0.596		1	0.520	0.161	1.13E-08	2.55E-05
25	0.420	0.581		1	0.500	0.174	1.22E-08	2.65E-05
26	0.435	0.565		1	0.480	0.187	1.31E-08	2.75E-05
27	0.450	0.550		1	0.460	0.201	1.41E-08	2.85E-05
28	0.465	0.535		1	0.440	0.215	1.51E-08	2.95E-05
29	0.480	0.520		1	0.420	0.229	1.61E-08	3.05E-05
30	0.495	0.505		1	0.400	0.244	1.71E-08	3.15E-05
31	0.510	0.490		1	0.380	0.259	1.82E-08	3.24E-05
32	0.525	0.475		1	0.360	0.275	1.93E-08	3.34E-05
33	0.540	0.460		1	0.340	0.291	2.04E-08	3.44E-05
34	0.555	0.445		1	0.320	0.308	2.16E-08	3.54E-05
35	0.570	0.430		1	0.300	0.325	2.28E-08	3.63E-05
36	0.585	0.415		1	0.280	0.342	2.40E-08	3.73E-05
37	0.600	0.400		1	0.260	0.360	2.53E-08	3.83E-05
38	0.615	0.385		1	0.240	0.378	2.66E-08	3.93E-05
39	0.630	0.370		1	0.220	0.397	2.79E-08	4.02E-05
40	0.645	0.355		1	0.200	0.416	2.92E-08	4.12E-05
41	0.660	0.340		1	0.180	0.436	3.06E-08	4.22E-05
42	0.676	0.324		1	0.160	0.456	3.20E-08	4.31E-05
43	0.691	0.309		1	0.140	0.477	3.35E-08	4.41E-05
44	0.706	0.294		1	0.120	0.498	3.50E-08	4.50E-05
45	0.721	0.279		1	0.100	0.519	3.65E-08	4.60E-05
46	0.736	0.264		1	0.080	0.541	3.80E-08	4.70E-05
47	0.751	0.249		1	0.060	0.564	3.96E-08	4.79E-05
48	0.766	0.234		1	0.040	0.587	4.12E-08	4.89E-05
49	0.781	0.219		1	0.020	0.610	4.28E-08	4.98E-05
50	0.795	0.205		1	0.001	0.632	4.44E-08	5.08E-05

$$z_{an} - z_{aw} = (1 - \rho_r) b_n \quad (2.19)$$

$$z_{aw} - z_{mw} = \rho_r b_n \quad (2.20)$$

The elevation z_{\max} is the maximum elevation of free LNAPL due to capillary rise. Above this elevation, any LNAPL is present at residual saturation and is not mobile.

$$z_{\max} = z_{an} + \frac{(1 - \rho_r)(\sigma_{an}/\sigma_{mw})}{\rho_r - (1 - \rho_r)(\sigma_{an}/\sigma_{mw})} b_n \quad (2.38)$$

$$S_{e[w]}(z) = \left(1 + (\alpha_{mw}(z - z_{mw}))^N\right)^{-M} \quad (2.24)$$

$$\alpha_{mw} = (1 - \rho_r) \frac{\sigma_{aw}}{\sigma_{mw}} \alpha \quad (2.25)$$

$$\text{Mualem: } M = 1 - 1/N \quad ; \quad N > 1 \quad (2.6)$$

$$\text{Burdine: } M = 1 - 2/N \quad ; \quad N > 2 \quad (2.5)$$

$$S_w(z) = S_{wr} + (1 - S_{wr} - S_{nr}) S_{e[w]}(z) \quad (2.27)$$

For elevations $z < z_{an}$, the pore space not occupied by water will be filled with LNAPL. Thus for $z < z_{an}$,

$$S_n(z) = 1 - S_w(z) \quad (2.28)$$

$$S_{e[l]}(z) = \left(1 + (\alpha_{an}(z - z_{an}))^N\right)^{-M} \quad (2.30)$$

$$\alpha_{an} = \rho_r \frac{\sigma_{aw}}{\sigma_{an}} \alpha \quad (2.31)$$

$$S_n(z) = S_{nr} + (1 - S_{wr} - S_{nr})(S_{e[l]} - S_{e[w]}) \quad (2.33)$$

Similar changes are made to the tortuosity term for the three-phase equations, which become

$$k_m(S_w, S_n) = (S_n)^2 \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right) \quad (3.13)$$

$$k_m(S_w, S_n) = (S_n)^2 \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right)^2$$

$$k_m(S_w, S_n) = \sqrt{S_n} \times \left((1 - S_{e[w]}^{1/M})^n - (1 - S_{e[l]}^{1/M})^n \right) \quad (3.14)$$

$$D_n(b_n) = \int_{z_{ow}}^{z_{max}} n S_n(z) dz \quad (2.40)$$

$$K_{nz} = K_{wz} \frac{\rho_r}{\mu_r} \quad (3.2)$$

$$U_{nx} = \int_{z_{ow}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

eqn 3.32 also shows the relationship between water hydraulic gradient and oil hydraulic gradient.

This calculation may be made by defining the LNAPL-layer transmissibility as follows:

$$T_n(b_n) = \frac{\rho_r}{\mu_r} \int_{z_{ow}}^{z_{max}} K_{wz}(z) k_m(S_w, S_n) dz \quad (3.31)$$

In terms of the transmissibility, the lens unit flux (in the x-direction) is calculated from

$$U_{nx} = \int_{z_{ow}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

$$q_{nx} = \frac{K_{wz} k_m J_{wx}}{\mu_r} = \frac{k_m q_{wx}}{k_{rw} \mu_r} \quad (3.27)$$

$$R_n(b_n) = \int_{z_{ow}}^{z_{max}} n(S_n(z) - S_w(z)) dz \quad (2.41)$$



SITE/PROJECT INFORMATION

Date: 9/10/2010
 Site Name: Former Unocal Seattle Marketing Terminal
 Site Location (City, ST): Seattle WA

CASE STUDY ASSUMPTIONS

Case Name: RW-3
 LNAPL Type: Literature assumptions based on California Crude
 Geology Type: Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	Symbol	Value	Units	Source
Site Data				
Monitoring Well LNAPL Thickness	b_o	2.72	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00529	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.017	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	ρ_o	0.89	g/cm ³	literature (API)
LNAPL Viscosity	μ_o	0.0591	g/cm-s	literature (API)
Water Density	ρ_w	0.9989	g/cm ³	field/site data
Water Viscosity	μ_w	0.013	g/cm-s	field/site data
Surface Tension	S_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	S_{ao}	27.5	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	S_{ow}	21.4	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	α	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	Symbol	Value	Units	API 4760 Equation
Air-Water Interface in Subsurface	Z_{aw}	0	ft	datum
Density Ratio	ρ_r	0.891	dimensionless	
Air-LNAPL Interface in Well	Z_{ao}	0.297	ft	2.19
LNAPL-Water Interface in Well	Z_{ow}	-2.423	ft	2.20
Maximum Free LNAPL in Subsurface	Z_{max}	0.804	ft	2.38
LNAPL vertical extent in subsurface		3.227	ft	
vG Alpha scaled to oil-water interactions	α_{ow}	0.317	1/ft	2.25
vG Alpha scaled to oil-air interactions	α_{ao}	2.018	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	η	4.546	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00104	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.019	dimensionless	
Intrinsic Permeability	k	7.02E-08	cm ²	



SITE/PROJECT INFORMATION

Date: 9/10/2010
 Site Name: Former Unocal Seattle Marketing Terminal
 Site Location (City, ST): Seattle WA

CASE STUDY ASSUMPTIONS

Case Name: RW-3
 LNAPL Type: Literature assumptions based on California Crude
 Geology Type: Medium grained sand - based on grain size analysis

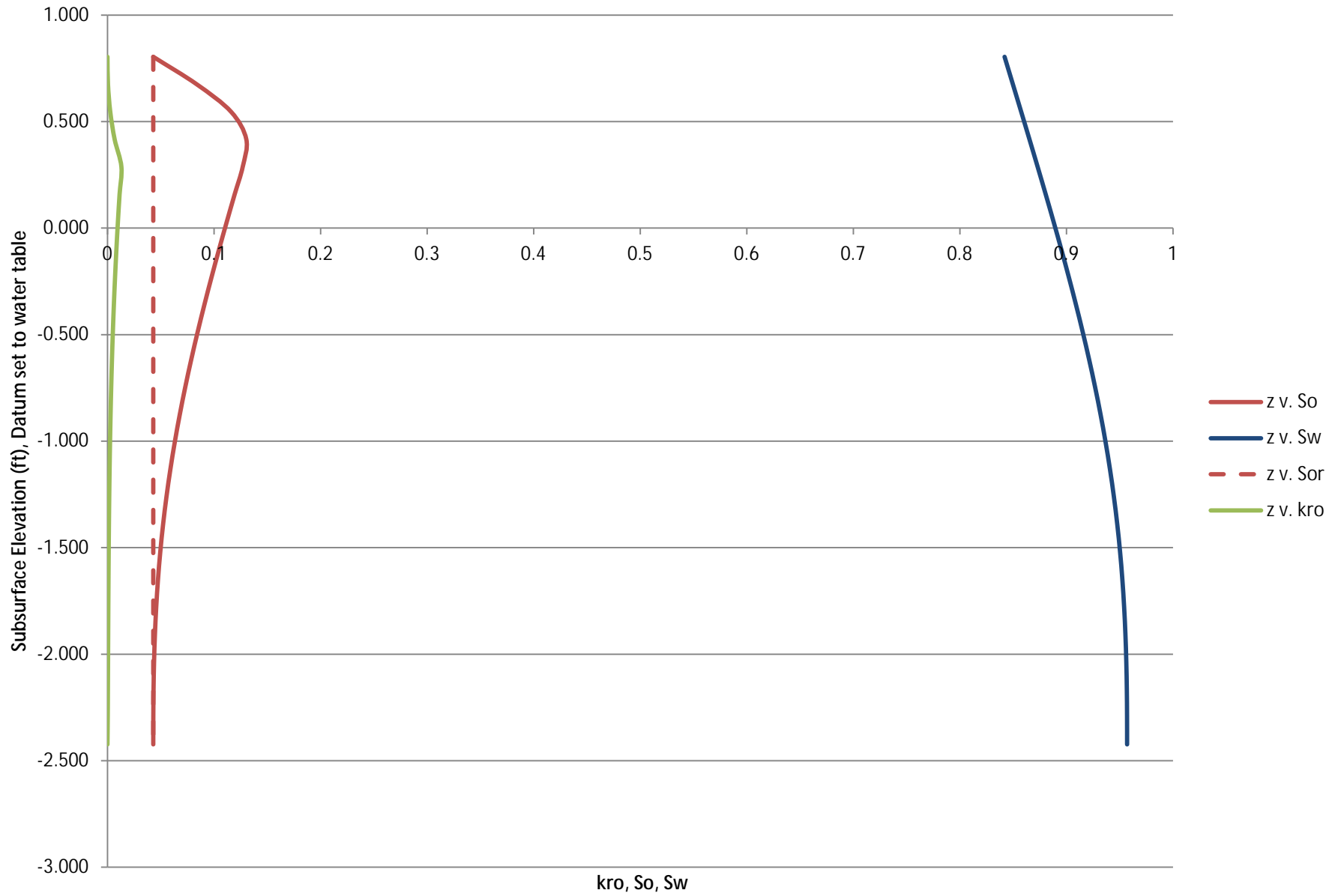
PROFILE CALCULATIONS

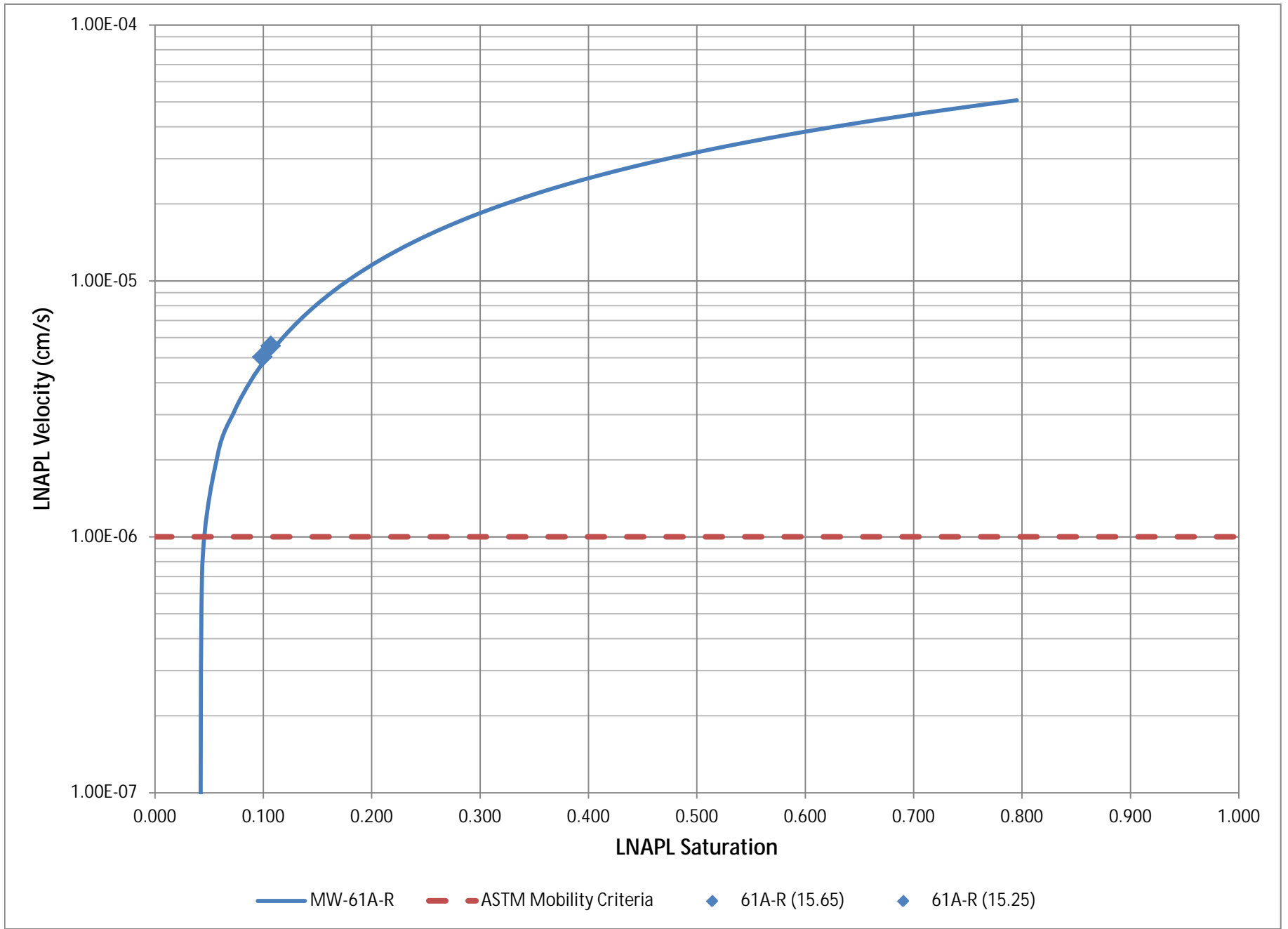
Scale	z	S _{e(w)} (z)	S _w (z)	S _{e(t)} (z)	S _o (z)	S _{or}	k _{ro} (S _w , S _o)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T _o (b _o) (cm ² /s)	Step Calc for D _o (b _o) (cm ² /cm ²)	Step Calc for R _o (cm ³ /cm ²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.804	0.847290334	0.842009621	0.847290334	0.043	0.043	4.11E-19	6.09E-22		0.00E+00	0.000	0.00E+00
1	0.675	0.857657832	0.849816347	0.911878262	0.083827984	0.043	5.06E-04	3.85E-07	3.93	2.07E-06	0.102	4.98E-02
2	0.546	0.868009621	0.857611244	0.965044071	0.116066941	0.043	2.64E-03	1.45E-06	3.93	1.08E-05	0.142	8.91E-02
3	0.417	0.878305701	0.865364193	0.994284737	0.130332213	0.043	6.74E-03	3.30E-06	3.93	2.75E-05	0.159	1.07E-01
4	0.288	0.888501692	0.873041774	1	0.126958226	0.043	1.31E-02	6.58E-06	3.93	5.34E-05	0.155	1.02E-01
5	0.159	0.89854903	0.880607419	1	0.119392581	0.043	1.14E-02	6.08E-06	3.93	4.64E-05	0.146	9.32E-02
6	0.029	0.908395361	0.888021707	1	0.111978293	0.043	9.82E-03	5.60E-06	3.93	4.01E-05	0.137	8.41E-02
7	-0.100	0.91798517	0.895242833	1	0.104757167	0.043	8.41E-03	5.12E-06	3.93	3.43E-05	0.128	7.53E-02
8	-0.229	0.927260649	0.902227268	1	0.097772732	0.043	7.15E-03	4.67E-06	3.93	2.92E-05	0.119	6.68E-02
9	-0.358	0.936162833	0.908930613	1	0.091069387	0.043	6.04E-03	4.23E-06	3.93	2.47E-05	0.111	5.86E-02
10	-0.487	0.944632992	0.915308643	1	0.084691357	0.043	5.07E-03	3.82E-06	3.93	2.07E-05	0.103	5.09E-02
11	-0.616	0.952614248	0.921318529	1	0.078681471	0.043	4.24E-03	3.44E-06	3.93	1.73E-05	0.096	4.35E-02
12	-0.745	0.960053372	0.926920189	1	0.073079811	0.043	3.53E-03	3.08E-06	3.93	1.44E-05	0.089	3.67E-02
13	-0.874	0.966902677	0.932077715	1	0.067922285	0.043	2.93E-03	2.75E-06	3.93	1.19E-05	0.083	3.04E-02
14	-1.003	0.973121923	0.936760808	1	0.063239192	0.043	2.42E-03	2.45E-06	3.93	9.90E-06	0.077	2.47E-02
15	-1.132	0.97868012	0.94094613	1	0.05905387	0.043	2.01E-03	2.17E-06	3.93	8.20E-06	0.072	1.96E-02
16	-1.262	0.983557124	0.944618514	1	0.055381486	0.043	1.67E-03	1.92E-06	3.93	6.81E-06	0.068	1.51E-02
17	-1.391	0.987744937	0.947771937	1	0.052228063	0.043	1.39E-03	1.70E-06	3.93	5.67E-06	0.064	1.13E-02
18	-1.520	0.991248653	0.950410236	1	0.049589764	0.043	1.16E-03	1.50E-06	3.93	4.74E-06	0.060	8.04E-03
19	-1.649	0.994087032	0.952547535	1	0.047452465	0.043	9.73E-04	1.31E-06	3.93	3.97E-06	0.058	5.43E-03
20	-1.778	0.996292757	0.954208446	1	0.045791554	0.043	8.15E-04	1.14E-06	3.93	3.33E-06	0.056	3.41E-03
21	-1.907	0.997912507	0.955428118	1	0.044571882	0.043	6.78E-04	9.71E-07	3.93	2.77E-06	0.054	1.92E-03
22	-2.036	0.99900713	0.956252369	1	0.043747631	0.043	5.51E-04	8.04E-07	3.93	2.25E-06	0.053	9.12E-04
23	-2.165	0.999652483	0.95673832	1	0.04326168	0.043	4.24E-04	6.25E-07	3.93	1.73E-06	0.053	3.19E-04
24	-2.294	0.999942372	0.956956606	1	0.043043394	0.043	2.78E-04	4.13E-07	3.93	1.14E-06	0.053	5.29E-05
25	-2.423	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	3.93	0.00E+00	0.052	0.00E+00

SUMMARY CALCULATIONS (common units)

Equation:	Average S _o	Maximum LNAPL velocity (cm/s)	T _o (b _o) (ft ² /day)	U _{nx} (ft ² /yr)	D _o (b _o) (gal/ft ²)	R _o (gal/ft ²)
0.073841978	6.58E-06	3.56E-02	3.31	3.32	2.40	2.41
			3.56E-02	2.48E-01	0.562	2.40E-01

Relative Permeability and Saturation against Subsurface Elevation





	S_o	S_w	S_a	$S_{e[t]}$	$S_{e[w]}$	$K_{ro}(S_w, S_o)$ Burdine (sand)	Permeability to NAPL (in the presence of water)	LNAPL Velocity	
Scale	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(cm ²)	(cm/s)	
0	0.043	0.957			1	1.000	0.000	5.55E-14	1.17E-09
1%>Sor	0.043	0.957			1	0.999	0.000	3.36E-11	7.03E-07
1	0.058	0.942			1	0.980	0.002	1.34E-10	2.11E-06
2	0.073	0.927			1	0.960	0.004	2.48E-10	3.08E-06
3	0.088	0.912			1	0.940	0.006	3.93E-10	4.05E-06
4	0.103	0.897			1	0.920	0.008	5.70E-10	5.02E-06
5	0.118	0.882			1	0.900	0.011	7.82E-10	6.01E-06
6	0.133	0.867			1	0.880	0.015	1.03E-09	7.01E-06
7	0.148	0.852			1	0.860	0.019	1.31E-09	8.02E-06
8	0.163	0.837			1	0.840	0.023	1.62E-09	9.04E-06
9	0.179	0.821			1	0.820	0.028	1.98E-09	1.01E-05
10	0.194	0.806			1	0.800	0.034	2.36E-09	1.11E-05
11	0.209	0.791			1	0.780	0.040	2.78E-09	1.21E-05
12	0.224	0.776			1	0.760	0.046	3.24E-09	1.32E-05
13	0.239	0.761			1	0.740	0.053	3.73E-09	1.42E-05
14	0.254	0.746			1	0.720	0.061	4.25E-09	1.52E-05
15	0.269	0.731			1	0.700	0.069	4.81E-09	1.63E-05
16	0.284	0.716			1	0.680	0.077	5.40E-09	1.73E-05
17	0.299	0.701			1	0.660	0.086	6.03E-09	1.83E-05
18	0.314	0.686			1	0.640	0.095	6.69E-09	1.94E-05
19	0.329	0.671			1	0.620	0.105	7.38E-09	2.04E-05
20	0.344	0.656			1	0.600	0.115	8.10E-09	2.14E-05
21	0.359	0.641			1	0.580	0.126	8.86E-09	2.24E-05
22	0.374	0.626			1	0.560	0.137	9.65E-09	2.34E-05
23	0.389	0.611			1	0.540	0.149	1.05E-08	2.45E-05
24	0.404	0.596			1	0.520	0.161	1.13E-08	2.55E-05
25	0.420	0.581			1	0.500	0.174	1.22E-08	2.65E-05
26	0.435	0.565			1	0.480	0.187	1.31E-08	2.75E-05
27	0.450	0.550			1	0.460	0.201	1.41E-08	2.85E-05
28	0.465	0.535			1	0.440	0.215	1.51E-08	2.95E-05
29	0.480	0.520			1	0.420	0.229	1.61E-08	3.05E-05
30	0.495	0.505			1	0.400	0.244	1.71E-08	3.15E-05
31	0.510	0.490			1	0.380	0.259	1.82E-08	3.24E-05
32	0.525	0.475			1	0.360	0.275	1.93E-08	3.34E-05
33	0.540	0.460			1	0.340	0.291	2.04E-08	3.44E-05
34	0.555	0.445			1	0.320	0.308	2.16E-08	3.54E-05
35	0.570	0.430			1	0.300	0.325	2.28E-08	3.63E-05
36	0.585	0.415			1	0.280	0.342	2.40E-08	3.73E-05
37	0.600	0.400			1	0.260	0.360	2.53E-08	3.83E-05
38	0.615	0.385			1	0.240	0.378	2.66E-08	3.93E-05
39	0.630	0.370			1	0.220	0.397	2.79E-08	4.02E-05
40	0.645	0.355			1	0.200	0.416	2.92E-08	4.12E-05
41	0.660	0.340			1	0.180	0.436	3.06E-08	4.22E-05
42	0.676	0.324			1	0.160	0.456	3.20E-08	4.31E-05
43	0.691	0.309			1	0.140	0.477	3.35E-08	4.41E-05
44	0.706	0.294			1	0.120	0.498	3.50E-08	4.50E-05
45	0.721	0.279			1	0.100	0.519	3.65E-08	4.60E-05
46	0.736	0.264			1	0.080	0.541	3.80E-08	4.70E-05
47	0.751	0.249			1	0.060	0.564	3.96E-08	4.79E-05
48	0.766	0.234			1	0.040	0.587	4.12E-08	4.89E-05
49	0.781	0.219			1	0.020	0.610	4.28E-08	4.98E-05
50	0.795	0.205			1	0.001	0.632	4.44E-08	5.08E-05

$$z_{an} - z_{av} = (1 - \rho_r) b_n \quad (2.19)$$

$$z_{av} - z_{mv} = \rho_r b_n \quad (2.20)$$

The elevation z_{\max} is the maximum elevation of free LNAPL due to capillary rise. Above this elevation, any LNAPL is present at residual saturation and is not mobile.

$$z_{\max} = z_{an} + \frac{(1 - \rho_r)(\sigma_{an}/\sigma_{mv})}{\rho_r - (1 - \rho_r)(\sigma_{an}/\sigma_{mv})} b_n \quad (2.38)$$

$$S_{e[w]}(z) = \left(1 + (\alpha_{mv}(z - z_{mv}))^N\right)^{-M} \quad (2.24)$$

$$\alpha_{mv} = (1 - \rho_r) \frac{\sigma_{av}}{\sigma_{mv}} \alpha \quad (2.25)$$

$$\text{Mualem: } M = 1 - 1/N \quad ; \quad N > 1 \quad (2.6)$$

$$\text{Burdine: } M = 1 - 2/N \quad ; \quad N > 2 \quad (2.5)$$

$$S_w(z) = S_{wr} + (1 - S_{wr} - S_{nr}) S_{e[w]}(z) \quad (2.27)$$

For elevations $z < z_{an}$, the pore space not occupied by water will be filled with LNAPL. Thus for $z < z_{an}$,

$$S_n(z) = 1 - S_w(z) \quad (2.28)$$

$$S_{e[l]}(z) = \left(1 + (\alpha_{an}(z - z_{an}))^N\right)^{-M} \quad (2.30)$$

$$\alpha_{an} = \rho_r \frac{\sigma_{av}}{\sigma_{an}} \alpha \quad (2.31)$$

$$S_n(z) = S_{nr} + (1 - S_{wr} - S_{nr})(S_{e[l]} - S_{e[w]}) \quad (2.33)$$

Similar changes are made to the tortuosity term for the three-phase equations, which become

$$k_{rn}(S_w, S_n) = (S_n)^2 \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right) \quad (3.13)$$

$$k_{rn}(S_w, S_n) = \sqrt{S_n} \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right)^2 \quad (3.14)$$

$$D_n(b_n) = \int_{z_{nw}}^{z_{max}} n S_n(z) dz \quad (2.40)$$

$$K_{nz} = K_{wz} \frac{\rho_r}{\mu_r} \quad (3.2)$$

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

eqn 3.32 also shows the relationship between water hydraulic gradient and oil hydraulic gradient.

This calculation may be made by defining the LNAPL-layer transmissibility as follows:

$$T_n(b_n) = \frac{\rho_r}{\mu_r} \int_{z_{nw}}^{z_{max}} K_{wz}(z) k_m(S_w, S_n) dz \quad (3.31)$$

In terms of the transmissibility, the lens unit flux (in the x-direction) is calculated from

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

$$q_{nx} = \frac{K_{wz} k_m J_{wx}}{\mu_r} = \frac{k_m q_{wx}}{k_{rw} \mu_r} \quad (3.27)$$

$$R_n(b_n) = \int_{z_{nw}}^{z_{max}} n (S_n(z) - S_w(z)) dz \quad (2.41)$$



SITE/PROJECT INFORMATION						CASE STUDY ASSUMPTIONS					
Date:	9/10/2010					Case Name:	RW-3				
Site Name:	Former Unocal	Seattle Marketing Terminal				LNAPL Type:	Literature assumptions based on California Crude				
Site Location (City, ST):	Seattle	WA				Geology Type:	Medium grained sand - based on grain size analysis				
CALCULATION INPUTS						INTERIM CALCULATIONS					
Parameter		Symbol	Value	Units	Source	Parameter		Symbol	Value	Units	API 4760 Equation
Site Data						Interim Calculations					
Monitoring Well LNAPL Thickness		b_o	1.22	ft	field/site data	Air-Water Interface in Subsurface		z_{aw}	0	ft	datum
Water Hydraulic Conductivity		K_w	0.00529	cm/s	field/site data	Density Ratio		r_r	0.891	dimensionless	
Water Hydraulic Gradient		J_w	0.017	dimensionless	field/site data	Air-LNAPL Interface in Well		z_{ao}	0.133	ft	2.19
						LNAPL-Water Interface in Well		z_{ow}	-1.087	ft	2.20
						Maximum Free LNAPL in Subsurface		z_{max}	0.361	ft	2.38
Fluids Properties Data						Interim Calculations					
LNAPL Density		r_o	0.89	g/cm3	literature (API)	LNAPL vertical extent in subsurface			1.448	ft	
LNAPL Viscosity		η_b	0.0591	g/cm-s	literature (API)	vG Alpha scaled to oil-water interactions		a_{ow}	0.317	1/ft	2.25
Water Density		r_w	0.9989	g/cm3	field/site data	vG Alpha scaled to oil-air interactions		a_{ao}	2.018	1/ft	2.31
Water Viscosity		η_v	0.013	g/cm-s	field/site data	M (Burdine)		M	0.229	dimensionless	2.6
Surface Tension		s_{aw}	61.8	dyne/cm	field/site data	Viscosity Ratio		η	4.546	dimensionless	
Air-LNAPL Interfacial Tension		s_{ao}	27.5	dyne/cm	literature (API)	Oil Hydraulic Conductivity		K_o	0.00104	cm/s	3.2
LNAPL-Water Interfacial Tension		s_{ow}	21.4	dyne/cm	literature (API)	Oil Hydraulic Gradient		J_o	0.019	dimensionless	
						Intrinsic Permeability		k	7.02E-08	cm2	
Aquifer Properties Data											
van Genuchten (vG) Alpha		a	3.31E-02	1/cm	Model results from RETC						
van Genuchten (vG) Beta		N	2.593	dimensionless	Model results from RETC						
Porosity		n	0.31	dimensionless	field/site data						
Irreducible Water Saturation		S_{wr}	0.204	dimensionless	field/site data						
Residual LNAPL Saturation		S_{or}	0.043	dimensionless	field/site data						



SITE/PROJECT INFORMATION				CASE STUDY ASSUMPTIONS			
Date:	9/10/2010			Case Name:	RW-3		
Site Name:	Former Unocal	Seattle Marketing Terminal		LNAPL Type:	Literature assumptions based on California Crude		
Site Location (City, ST):	Seattle WA			Geology Type:	Medium grained sand - based on grain size analysis		

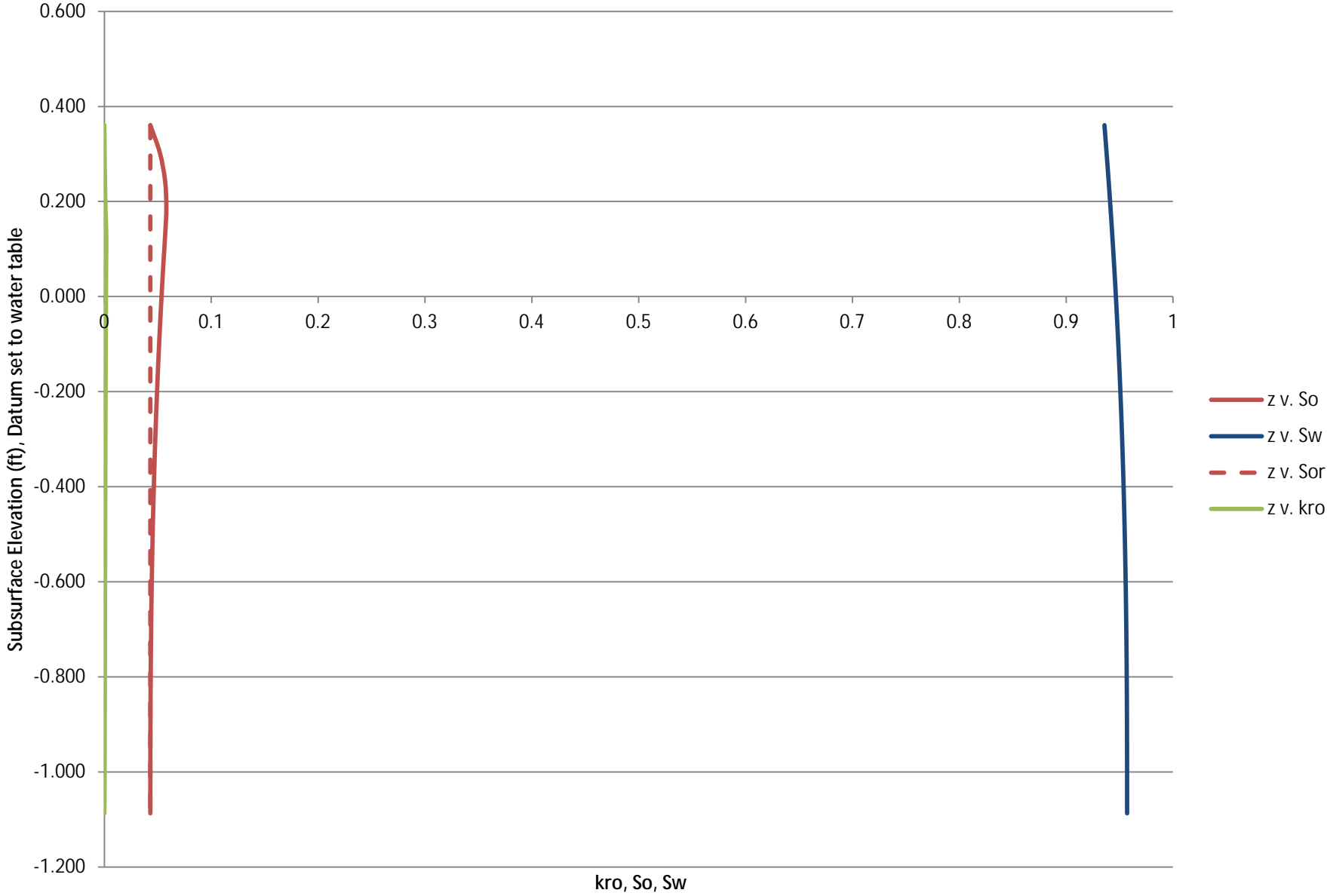
PROFILE CALCULATIONS

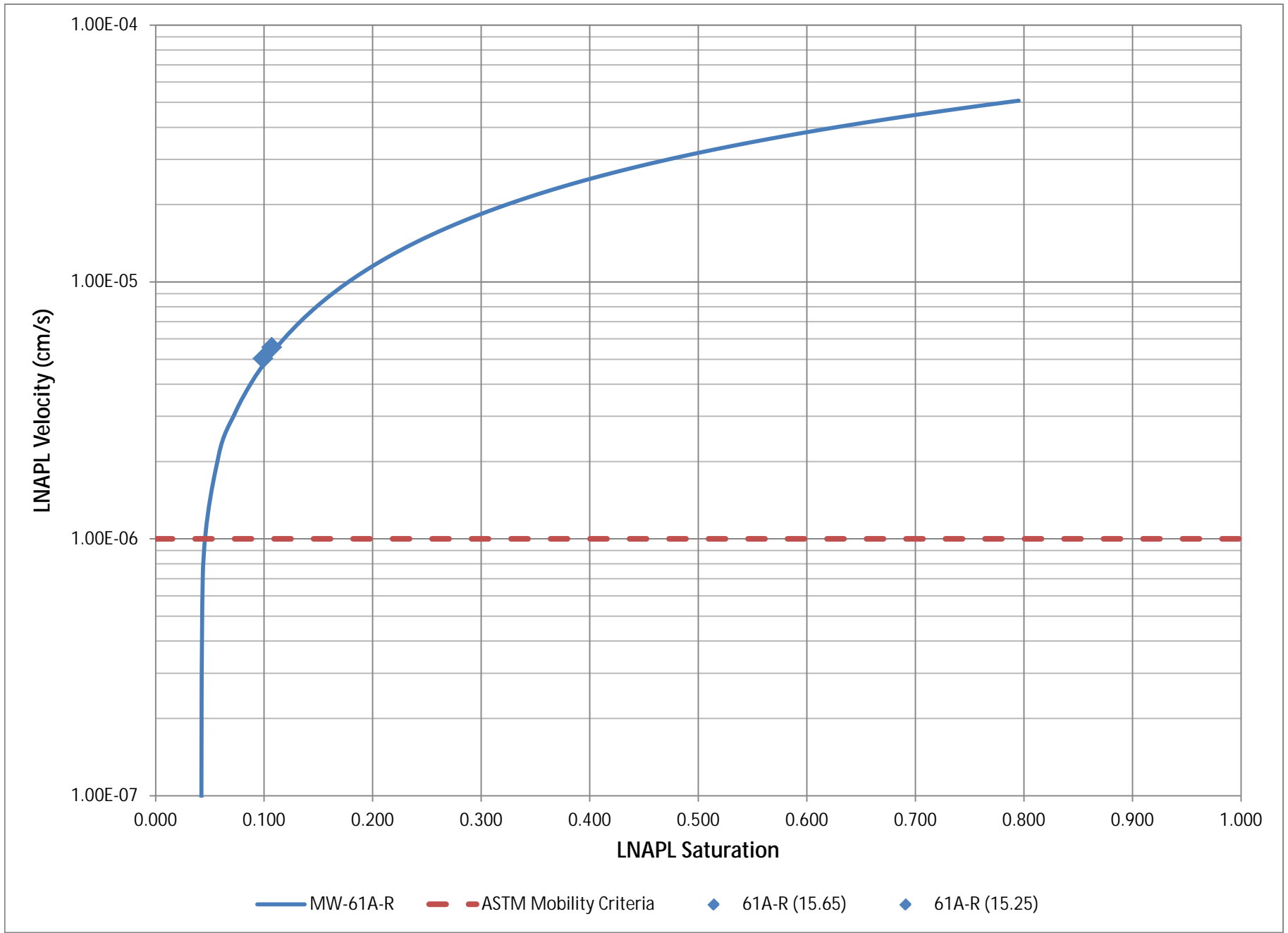
Scale	z	$S_{e(w)}(z)$	$S_w(z)$	$S_{e(l)}(z)$	$S_o(z)$	S_{or}	$k_{ro}(S_w, S_o)$	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for $T_o(b_o)$ (cm ² /s)	Step Calc for $D_o(b_o)$ (cm ³ /cm ²)	Step Calc for R_o (cm ³ /cm ²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.361	0.971850314	0.935803287	0.971850314	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
1	0.303	0.97449014	0.937791075	0.986313906	0.051903296	0.043	2.08E-04	2.56E-07	1.76	3.81E-07	0.028	4.87E-03
2	0.245	0.976995665	0.939677736	0.995248465	0.056744358	0.043	5.62E-04	6.32E-07	1.76	1.03E-06	0.031	7.52E-03
3	0.187	0.97936502	0.94146186	0.999275812	0.057992827	0.043	1.02E-03	1.13E-06	1.76	1.87E-06	0.032	8.20E-03
4	0.129	0.981596809	0.943142397	1	0.056857603	0.043	1.80E-03	2.02E-06	1.76	3.30E-06	0.031	7.58E-03
5	0.071	0.983690139	0.944718675	1	0.055281325	0.043	1.66E-03	1.92E-06	1.76	3.04E-06	0.030	6.72E-03
6	0.013	0.985644635	0.94619041	1	0.05380959	0.043	1.53E-03	1.81E-06	1.76	2.80E-06	0.029	5.91E-03
7	-0.045	0.987460452	0.94755772	1	0.05244228	0.043	1.41E-03	1.71E-06	1.76	2.58E-06	0.029	5.17E-03
8	-0.103	0.989138292	0.948821134	1	0.051178866	0.043	1.30E-03	1.62E-06	1.76	2.38E-06	0.028	4.47E-03
9	-0.161	0.990679411	0.949981596	1	0.050018404	0.043	1.20E-03	1.53E-06	1.76	2.19E-06	0.027	3.84E-03
10	-0.218	0.992085623	0.951040474	1	0.048959526	0.043	1.11E-03	1.44E-06	1.76	2.03E-06	0.027	3.26E-03
11	-0.276	0.993359307	0.951999558	1	0.048000442	0.043	1.02E-03	1.36E-06	1.76	1.87E-06	0.026	2.74E-03
12	-0.334	0.994503406	0.952861065	1	0.047138935	0.043	9.45E-04	1.28E-06	1.76	1.73E-06	0.026	2.26E-03
13	-0.392	0.995521432	0.953627638	1	0.046372362	0.043	8.73E-04	1.20E-06	1.76	1.60E-06	0.025	1.85E-03
14	-0.450	0.99641746	0.954302348	1	0.045697652	0.043	8.06E-04	1.13E-06	1.76	1.47E-06	0.025	1.48E-03
15	-0.508	0.997196135	0.95488869	1	0.04511131	0.043	7.43E-04	1.05E-06	1.76	1.36E-06	0.025	1.16E-03
16	-0.566	0.997862671	0.955390591	1	0.044609409	0.043	6.83E-04	9.77E-07	1.76	1.25E-06	0.024	8.81E-04
17	-0.624	0.998422864	0.955812417	1	0.044187583	0.043	6.25E-04	9.03E-07	1.76	1.14E-06	0.024	6.50E-04
18	-0.682	0.998883105	0.956158978	1	0.043841022	0.043	5.68E-04	8.28E-07	1.76	1.04E-06	0.024	4.60E-04
19	-0.740	0.99925041	0.956435559	1	0.043564441	0.043	5.12E-04	7.51E-07	1.76	9.38E-07	0.024	3.09E-04
20	-0.797	0.999532473	0.956647952	1	0.043352048	0.043	4.56E-04	6.71E-07	1.76	8.34E-07	0.024	1.93E-04
21	-0.855	0.999737746	0.956802523	1	0.043197477	0.043	3.96E-04	5.86E-07	1.76	7.25E-07	0.024	1.08E-04
22	-0.913	0.999875586	0.956906316	1	0.043093684	0.043	3.33E-04	4.93E-07	1.76	6.09E-07	0.024	5.13E-05
23	-0.971	0.999956519	0.956967259	1	0.043032741	0.043	2.61E-04	3.87E-07	1.76	4.77E-07	0.024	1.79E-05
24	-1.029	0.999992795	0.956994574	1	0.043005426	0.043	1.73E-04	2.56E-07	1.76	3.16E-07	0.024	2.97E-06
25	-1.087	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	1.76	0.00E+00	0.024	0.00E+00

SUMMARY CALCULATIONS (common units)

							Average S_o	Maximum LNAPL velocity (cm/s)	$T_o(b_o)$ (ft ² /day)	U_{nx} (ft ² /yr)	$D_o(b_o)$ (gal/ft ²)	R_o (gal/ft ²)
							Equation:		3.31	3.32	2.40	2.41
							0.047899716	2.02E-06	3.44E-03	2.39E-02	0.161	1.71E-02

Relative Permeability and Saturation against Subsurface Elevation





	S _o	S _w	S _a	S _{e(t)}	S _{e(w)}	K _{ro} (S _w , S _o) Burdine (sand)	Permeability to NAPL (in the presence of water)	LNAPL Velocity
Scale	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(unitless)	(cm ²)	(cm/s)
0	0.043	0.957		1	1.000	0.000	5.55E-14	1.17E-09
1%>Sor	0.043	0.957		1	0.999	0.000	3.36E-11	7.03E-07
1	0.058	0.942		1	0.980	0.002	1.34E-10	2.11E-06
2	0.073	0.927		1	0.960	0.004	2.48E-10	3.08E-06
3	0.088	0.912		1	0.940	0.006	3.93E-10	4.05E-06
4	0.103	0.897		1	0.920	0.008	5.70E-10	5.02E-06
5	0.118	0.882		1	0.900	0.011	7.82E-10	6.01E-06
6	0.133	0.867		1	0.880	0.015	1.03E-09	7.01E-06
7	0.148	0.852		1	0.860	0.019	1.31E-09	8.02E-06
8	0.163	0.837		1	0.840	0.023	1.62E-09	9.04E-06
9	0.179	0.821		1	0.820	0.028	1.98E-09	1.01E-05
10	0.194	0.806		1	0.800	0.034	2.36E-09	1.11E-05
11	0.209	0.791		1	0.780	0.040	2.78E-09	1.21E-05
12	0.224	0.776		1	0.760	0.046	3.24E-09	1.32E-05
13	0.239	0.761		1	0.740	0.053	3.73E-09	1.42E-05
14	0.254	0.746		1	0.720	0.061	4.25E-09	1.52E-05
15	0.269	0.731		1	0.700	0.069	4.81E-09	1.63E-05
16	0.284	0.716		1	0.680	0.077	5.40E-09	1.73E-05
17	0.299	0.701		1	0.660	0.086	6.03E-09	1.83E-05
18	0.314	0.686		1	0.640	0.095	6.69E-09	1.94E-05
19	0.329	0.671		1	0.620	0.105	7.38E-09	2.04E-05
20	0.344	0.656		1	0.600	0.115	8.10E-09	2.14E-05
21	0.359	0.641		1	0.580	0.126	8.86E-09	2.24E-05
22	0.374	0.626		1	0.560	0.137	9.65E-09	2.34E-05
23	0.389	0.611		1	0.540	0.149	1.05E-08	2.45E-05
24	0.404	0.596		1	0.520	0.161	1.13E-08	2.55E-05
25	0.420	0.581		1	0.500	0.174	1.22E-08	2.65E-05
26	0.435	0.565		1	0.480	0.187	1.31E-08	2.75E-05
27	0.450	0.550		1	0.460	0.201	1.41E-08	2.85E-05
28	0.465	0.535		1	0.440	0.215	1.51E-08	2.95E-05
29	0.480	0.520		1	0.420	0.229	1.61E-08	3.05E-05
30	0.495	0.505		1	0.400	0.244	1.71E-08	3.15E-05
31	0.510	0.490		1	0.380	0.259	1.82E-08	3.24E-05
32	0.525	0.475		1	0.360	0.275	1.93E-08	3.34E-05
33	0.540	0.460		1	0.340	0.291	2.04E-08	3.44E-05
34	0.555	0.445		1	0.320	0.308	2.16E-08	3.54E-05
35	0.570	0.430		1	0.300	0.325	2.28E-08	3.63E-05
36	0.585	0.415		1	0.280	0.342	2.40E-08	3.73E-05
37	0.600	0.400		1	0.260	0.360	2.53E-08	3.83E-05
38	0.615	0.385		1	0.240	0.378	2.66E-08	3.93E-05
39	0.630	0.370		1	0.220	0.397	2.79E-08	4.02E-05
40	0.645	0.355		1	0.200	0.416	2.92E-08	4.12E-05
41	0.660	0.340		1	0.180	0.436	3.06E-08	4.22E-05
42	0.676	0.324		1	0.160	0.456	3.20E-08	4.31E-05
43	0.691	0.309		1	0.140	0.477	3.35E-08	4.41E-05
44	0.706	0.294		1	0.120	0.498	3.50E-08	4.50E-05
45	0.721	0.279		1	0.100	0.519	3.65E-08	4.60E-05
46	0.736	0.264		1	0.080	0.541	3.80E-08	4.70E-05
47	0.751	0.249		1	0.060	0.564	3.96E-08	4.79E-05
48	0.766	0.234		1	0.040	0.587	4.12E-08	4.89E-05
49	0.781	0.219		1	0.020	0.610	4.28E-08	4.98E-05
50	0.795	0.205		1	0.001	0.632	4.44E-08	5.08E-05

$$z_{an} - z_{av} = (1 - \rho_r) b_n \quad (2.19)$$

$$z_{av} - z_{mv} = \rho_r b_n \quad (2.20)$$

The elevation z_{\max} is the maximum elevation of free LNAPL due to capillary rise. Above this elevation, any LNAPL is present at residual saturation and is not mobile.

$$z_{\max} = z_{an} + \frac{(1 - \rho_r)(\sigma_{an}/\sigma_{mv})}{\rho_r - (1 - \rho_r)(\sigma_{an}/\sigma_{mv})} b_n \quad (2.38)$$

$$S_{e[w]}(z) = \left(1 + (\alpha_{mv}(z - z_{mv}))^N\right)^{-M} \quad (2.24)$$

$$\alpha_{mv} = (1 - \rho_r) \frac{\sigma_{av}}{\sigma_{mv}} \alpha \quad (2.25)$$

$$\text{Mualem: } M = 1 - 1/N \quad ; \quad N > 1 \quad (2.6)$$

$$\text{Burdine: } M = 1 - 2/N \quad ; \quad N > 2 \quad (2.5)$$

$$S_w(z) = S_{wr} + (1 - S_{wr} - S_{nr}) S_{e[w]}(z) \quad (2.27)$$

For elevations $z < z_{an}$, the pore space not occupied by water will be filled with LNAPL. Thus for $z < z_{an}$,

$$S_n(z) = 1 - S_w(z) \quad (2.28)$$

$$S_{e[l]}(z) = \left(1 + (\alpha_{an}(z - z_{an}))^N\right)^{-M} \quad (2.30)$$

$$\alpha_{an} = \rho_r \frac{\sigma_{av}}{\sigma_{an}} \alpha \quad (2.31)$$

$$S_n(z) = S_{nr} + (1 - S_{wr} - S_{nr})(S_{e[l]} - S_{e[w]}) \quad (2.33)$$

Similar changes are made to the tortuosity term for the three-phase equations, which become

$$k_{rn}(S_w, S_n) = (S_n)^2 \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right) \quad (3.13)$$

$$k_{rn}(S_w, S_n) = \sqrt{S_n} \times \left(\left(1 - S_{e[w]}^{1/M}\right)^M - \left(1 - S_{e[l]}^{1/M}\right)^M \right)^2 \quad (3.14)$$

$$D_n(b_n) = \int_{z_{nw}}^{z_{max}} n S_n(z) dz \quad (2.40)$$

$$K_{nz} = K_{wz} \frac{\rho_r}{\mu_r} \quad (3.2)$$

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

eqn 3.32 also shows the relationship between water hydraulic gradient and oil hydraulic gradient.

This calculation may be made by defining the LNAPL-layer transmissibility as follows:

$$T_n(b_n) = \frac{\rho_r}{\mu_r} \int_{z_{nw}}^{z_{max}} K_{wz}(z) k_m(S_w, S_n) dz \quad (3.31)$$

In terms of the transmissibility, the lens unit flux (in the x-direction) is calculated from

$$U_{nx} = \int_{z_{nw}}^{z_{max}} q_{nx} dz = T_n(b_n) J_{nx} = \frac{T_n(b_n) J_{wx}}{\rho_r} \quad (3.32)$$

$$q_{nx} = \frac{K_{wz} k_m J_{wx}}{\mu_r} = \frac{k_m q_{wx}}{k_{rw} \mu_r} \quad (3.27)$$

$$R_n(b_n) = \int_{z_{nw}}^{z_{max}} n (S_n(z) - S_w(z)) dz \quad (2.41)$$