OSAC 2022-S-0004 Standard Classification for Ignitable Liquids Encountered in Fire Debris Analysis

Ignitable Liquids, Explosives, and Gunshot Residue Subcommittee
Chemistry: Trace Evidence Scientific Area Committee
Organization of Scientific Area Committees (OSAC) for Forensic Science

Draft OSAC Proposed Standard

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Ignitable Liquids, Explosives, and Gunshot Residue Subcommittee
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Standard Classification for Ignitable Liquids Encountered in Fire Debris Analysis

This standard is issued under the fixed designation E1618; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard covers the classification of ignitable liquids encountered in forensic fire debris analysis and includes classification of petroleum and non-petroleum based ignitable liquids.

1.2 This standard is intended for use in conjunction with approved extraction practices and instrumental test methods used to isolate and classify ignitable liquids (E1386, E1388, E1412, E1413, E2154, E2881, E3189, EXXX Interpretation).

1.3 This standard does not address classification complications arising from matrix contributions, microbial degradation, or weathering effects.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standard:* [1]

E620 Standard Practice for Reporting Opinions of Scientific or Technical Experts

E1386 Practice for Separation of Ignitable Liquid Residues from Fire Debris Samples by Solvent Extraction

E1388 Practice for Sampling of Headspace Vapors from Fire Debris Samples

E1412 Practice for Separation of Ignitable Liquid Residues from Fire Debris Samples by Passive Headspace Concentration with Activated Charcoal

E1413 Practice for Separation of Ignitable Liquid Residues from Fire Debris Samples by Dynamic Headspace Concentration onto an adsorbent tube

E2154 Practice for Separation and Concentration of Ignitable Liquid Residues from Fire Debris Samples by Passive Headspace Concentration with Solid Phase Microextraction (SPME)

E2451 Practice for Preserving Ignitable Liquids and Ignitable Liquid Residue Extracts from Fire Debris Samples

E2881 Standard Test Method for Extraction and Derivatization of Vegetable Oils and Fats from Fire Debris and Liquid Samples with Analysis by Gas Chromatography-Mass

[1] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Spectrometry

E2917 Standard Practice for Forensic Science Practitioner Training, Continuing Education, and Professional Development Programs

E2997 Standard Test Method for Analysis of Biodiesel Products by Gas Chromatography-Mass Spectrometry

E3189 Standard Practice for Separation of Ignitable Liquid Residues from Fire Debris Samples by Static Headspace Concentration onto an Adsorbent Tube

E3197 Terminology Relating to Examination of Fire Debris

E3245 Guide for Systematic Approach to the Extraction, Analysis, and Classification of Ignitable liquids and Ignitable Liquid Residues in Fire Debris Samples

WK73482 Standard Practice for Reporting Results and Opinions of Ignitable Liquids Analysis

WKxxxx Standard Test Method for Interpretation of Gas Chromatography-Electron Ionization Mass Spectrometry Data for the Identification of Ignitable Liquid Classes in Forensic Fire Debris Analysis

EXXXX Standard Practice for Gas Chromatography Electron Ionization Mass Spectrometry Analysis of Ignitable Liquids

3. Terminology

3.1 Definition of Terms Specific to This Standard:

3.1.1 *carbon range, n.*—*n*-alkane range, defined by the boiling points of a homologous series of *n*-alkanes (within *n*-C_4-*n*-C_{20+}), at which other compounds boil.

3.1.2 *component, n.*—a compound found in an ignitable liquid.

3.1.3 *major component(s), n.*—component(s) present at the highest concentration(s).

3.1.4 *minor component, n.*—a compound present with a relative concentration of less than 5% of the major component(s).

3.1.5 *not present, adj.*—does not necessarily signify total absence of the compound or class of chemical compounds in a petroleum product. The petroleum processes used to remove or enhance specific compound classes are not always efficient and trace indications of "not present" compounds are not uncommon.

3.1.6 *Oil and fat, n.*—any oil or fat derived from plants or animals.

3.2 Abbreviations Specific to This Standard

3.2.1 Abbreviations for specific chemicals are located in Appendix A.

3.2.2 *C#* – number of carbons associated with the normal alkane or alkyl fragment for example, "C_8" would refer to *n*-octane or octyl fragment.

3.2.3 *EIP* – extracted ion profile

3.2.4 *FAME* – fatty acid methyl ester

3.2.5 *HAP* – heavy aromatic product

3.2.6 *HIP* – heavy isoparaffinic product

3.2.7 *HPD* – heavy petroleum distillate

3.2.8 *KDF* – key diagnostic features

3.2.9 *LAP* – light aromatic product

3.2.10 *LIP* – light isoparaffinic product

3.2.11 *LPD* – light petroleum distillate

3.2.12 *MAP* – medium aromatic product

3.2.13 *MIP* – medium isoparaffinic product

3.2.14 *MPD* – medium petroleum distillate

3.2.15 *PNA* – polynuclear aromatic

3.2.16 *TIC* – total ion chromatogram

4. Summary of Classification Method

4.1 The classification scheme contains petroleum and non-petroleum-based products resulting in nine classes. Additional guidance is provided for products which do not fall into a single class. For the purposes of this standard, discussion of classification includes assignment to one of these classes.

4.1.1 Petroleum based ignitable liquids are classified based upon their composition resulting from common refinery processes.

4.1.2 Non-petroleum based ignitable liquids are classified based upon their chemical composition.

4.2 Examples of commercial products are provided in Table 1; however, the list is not exhaustive. Distinguishing between examples within any class could sometimes be possible, but such further characterization is not within the scope of this standard.

5. Significance and Use

5.1 The classification of ignitable liquids is based upon the chemical composition and the carbon ranges of known ignitable liquids which may be encountered in forensic fire debris analysis.

5.2 The ignitable liquids described herein are common to the classifications, however each ignitable liquid class contains a range of compositions. It is impractical to provide criteria for every manufactured ignitable liquid.

5.3 Data analysis is based upon the analytical processes used. This standard is intended to be used in conjunction with applicable standards for the analysis (GCMS), interpretation (Interpretation), and reporting of ignitable liquids (E2881, E2997, WK73482).

5.4 Mixtures of ignitable liquids can be marketed as a single commercial product. This standard

cannot differentiate between ignitable liquids that are mixed by a manufacturer for sale or ignitable liquids mixed at the point of use.

TABLE 1 Ignitable Liquid Classification Scheme with Examples of Known Products [1, A, B, C]

Class	Light (C_4-C_9)	Medium (C_8-C_{13})	Heavy (C_9-C_{20+})
Gasoline, including E85		Fresh gasoline is typically in the range C_4-C_{12}	
Petroleum Distillates	Petroleum ether Cigarette lighter fluids Camping fuels	Charcoal starters [B] Paint thinners Dry cleaning solvents Mineral spirits Automotive parts cleaners Spray lubricants Lamp oils Deck sealers Varnishes Kerosene Insecticides	Kerosene Diesel fuels Charcoal starters Aviation fuels Insecticides Fuel additives Lamp oils Automotive parts cleaners
Isoparaffinic Products	Aviation gasoline Lighter fluids Charcoal starters	Charcoal starters Paint thinners Copier toners Mineral spirits Solvent cleaners Kerosene Lamp oils Gun oils	Spot cleaners Penetrating oils Insecticides
Naphthenic- Paraffinic Products		Charcoal starters Insecticide vehicles Lamp oils Automotive part cleaners Mineral spirits	Insecticides Lamp oils
Aromatic Products	Paint and Varnish removers Automotive parts cleaners Degreasing solvents Adhesives and adhesive removers	Automotive parts cleaners Degreasing solvents Specialty Cleaning solvents Insecticide vehicles Brush cleaners	Insecticides Adhesives
Normal-Alkane Products		Lamp oils Copier toners Wax cleaners	Lamp oils Carbonless paper forms Copier toners
Oxygenated Products	Solvents (for example, Alcohols, Ketones) Denatured alcohols or spirits		
Petroleum Products	Adhesive removers Lacquer thinners Enamel reducers	Paint thinners Mineral spirits Automotive parts cleaners Surface preparation materials	Automotive parts cleaners Fuel additives Specialty solvents Insecticides Paint thinners
Oil and Fat-based Products		Flooring Treatments Charcoal starter fluids Torch fuels	Olive oil, bacon grease, linseed oil, sunflower oil, canola oil, massage oils B100 Biodiesel
Single Compounds	Acetone, Ethanol, Hexane	Limonene, 2-butoxyethanol	
Mixtures	Enamel reducer Paint vehicles Lacquer thinners	Adhesive removers Roof sealants Mineral spirits	Lamp oils Insecticides

	Aviation gasoline	Fuel additives	"Citrus" cleaners
	Racing gasoline	Spray lubricants	Automotive parts cleaners
		Brush cleaners	Fuel additives
		Paint thinners	Danish oil
		"Citrus" cleaners	B20 Biodiesel
		Charcoal starter fluids	
Other Products		Turpentine	

A The products listed in the various classes of Table 1 are examples of known commercial uses of these ignitable liquids. These examples are not intended to be all-inclusive. Reference literature materials can be used to provide more specific examples of each classification.

B Many of the examples can be prefaced by the word "some," as in "some charcoal starters." It is not unusual for similarly labeled products to have examples in more than one class, as product labeling can be based upon chemical performance or property, and not necessarily on chemical composition.

C The active ingredient(s) in consumer products categorized here as "insecticides" are typically not inherently flammable, but the solvents and propellants used in some consumer products can be categorized as ignitable liquids.

6. Data Analysis

6.1. The purpose of data analysis is to locate compounds that can be indicative of an ignitable liquid class, matrix contribution or both. Evaluate the TIC and extracted ion profiles for each sample. It is important to consider the general chemical composition (e.g. by mass spectral data evaluation or through a library search report).

6.2. *Evaluation of the Total Ion Chromatogram:*

6.2.1. Evaluate the TIC for peaks to ensure appropriate instrument operation has occurred and data have been collected (refer to GCMS document).

6.2.2. Evaluate the TIC to determine the general types of compounds present and the potential identity of the major peaks using mass spectral interpretation or a commercial or validated mass spectral library.

6.2.3. Evaluate the TIC for the presence or absence of KDF associated with ignitable liquids. **(Warning** – the presence of these compounds is not solely indicative of an ignitable liquid. The relative ratios of the compounds within the groups are also evaluated.)

6.2.3.1. KDF include, but are not limited to (2):

(1) A Gaussian-like distribution of peaks.

(2) Patterns within a distinct boiling point range.

(3) A homologous series of *n*-alkanes or other hydrocarbons.

(4) A series of diagnostic aromatic patterns.

(5) Abundant isolated compounds.

6.2.4. Record this evaluation in the case record.

6.3. *Evaluation of Extracted Ion Profiles:*

6.3.1. EIP is valuable for the classification of ignitable liquids because it can enhance the signal-to-noise ratio and highlight features of interest.

6.3.1.1. Summed ion chromatograms for two or more characteristic ions of the same chemical class can enhance the signal-to-noise ratio and decrease interference by extraneous compounds that contain only one of the ions. Additionally, summed profiles characteristic of specific classes of hydrocarbons can be created (3).

6.3.1.2. Single ion extracted ion profiling can highlight a chromatographic feature of interest.

Note 1: Evaluating only a single ion of a compound type will not clearly present an overview of the selected chemical class distribution throughout the entire chromatogram.

6.3.2. There are five major hydrocarbon types associated with petroleum EIP: alkane (normal or branched), cycloalkane, alkylbenzene (also known as mononuclear aromatic), indane, and polynuclear aromatic (PNA, also known as alkylnaphthalene and condensed ring aromatic) (4, 5, 6). Other classes of compounds may be present.

6.3.2.1. Compounds of each type of hydrocarbon produce characteristic major ion fragments. These ions are listed in Table 2.

6.3.2.2. EIPs may be produced for other chemical classes such as ketones, alcohols and FAMEs. These compounds require full mass spectral comparison and retention time comparison to an appropriate standard for identification.

6.3.2.3. EIPs display all peaks which contain the ions of interest. As a result, extracted ions for chemical classes can be present in a variety of EIPs. For example, the cycloalkane EIP will contain contributions from cycloalkanes, normal alkanes and isoalkanes.

6.3.3. Generate EIPs for each hydrocarbon type listed in 6.3.2.

6.3.4. Other ions and ion combinations, besides those listed in table 2, can be beneficial for evaluating matrix contributions.

TABLE 2 Major Ions of Interest for Ignitable Liquids (4, 5, 6, 9)

Compound Type	m/z
Normal/Branched Alkane	43, 57, 71, 85, 99
Cycloalkane[A]	55, 69, 83, 97
Alkylbenzene	91, 105, 119, 92, 106, 120, 133
Indane	117, 118, 131, 132
PNA	128, 142, 156, 170
Ketone	*43, 58, 72, 86*
Alcohol	*31, 45*
Fatty Acid Methyl Esters[B]	*67, 74, 79*
Trans-deaclin	*138*

[A] Alkenes share these ions, are not common in ignitable liquids, but are common in matrices

[B] FAMEs should be screened for in products containing HPDs and other potential mixtures

7. Basis for the Classification of Ignitable Liquids (KDF) (2, 7, 10)

7.1. Ignitable liquids are separated into classes based upon chemical composition. These classes are gasoline, petroleum distillates, isoparaffinic products, naphthenic-paraffinic products, aromatic products, normal alkane products, oxygenated products, petroleum products, and oil and fat-based products. Single components, mixtures, and non-classifiable products are described and classified according to their chemical composition.

7.2. Guidance is provided for those ignitable liquids that do not fall into one of the definable ignitable liquid classes or which fall into multiple classes. Refer to Sections 15, 17, and 18 for further information.

7.3. The KDFs listed in the following sections are based on neat liquids and are meant to highlight indicative features for the ignitable liquid classes. They are not meant to be an exclusive list.

7.4. Products within classes can contain petroleum based and non-petroleum based components. The products within each ignitable liquid class have relatively consistent compositions based on refining, manufacturing, or both processes.

7.5. With the exception of gasoline, each ignitable liquid class is further subdivided into three subclasses based on carbon ranges.

7.5.1. *Light Product Range*—*n*-C_4-*n*-C_9; major peaks have boiling points in the range *n*-C_4-*n*-C_9; no peaks associated with a boiling point above *n*-C_{11}.

7.5.2. *Medium Product Range*—*n*-C_8-*n*-C_{13}; narrow range products; majority of the peaks have boiling points in the range of *n*-C_8-*n*-C_{13}; no major peaks associated with the ignitable liquid exist with a boiling point below *n*-C_7 or above *n*-C_{14}.

7.5.3. *Heavy Product Range*—*n*-C_9-*n*-C_{20+}; broad range or higher carbon range products; majority of the peaks have boiling points in the range *n*-C_9–*n*-C_{23}. When there are fewer than five n-alkanes in a product, the most volatile compounds have boiling points greater than or equal to *n*-C_{11}.

7.5.4. A product can be characterized as "light to medium" or "medium to heavy" when the carbon number range does not fit into a subclass.

7.6. The individual EIPs will be consistent among all ignitable liquids in comparable boiling point ranges within a classification. The inter-profile and intra-profile ratios may change depending on the product of origin; however, generally the peaks displayed in each of the profiles are consistent.

7.7. The appendix contains images of various classifications labeled with their corresponding KDFs; tables which contain the legend for the image labels are also included.

8. Key Diagnostic Features of Gasoline

8.1. This classification covers all brands and grades of gasoline, including E85. It is a blend of refinery stream products that results in distinctive chemical characteristics that allow for classification as a specified commercial product. The carbon range is dependent upon several factors including legal restrictions and environmental market. In general, the predominant features of the petroleum base of unevaporated gasoline spans within the carbon range of *n*-C4-*n*-C12 and is characterized by alkylbenzene compounds extending from toluene to C5-alkylbenzenes. More volatile additives, including oxygenated compounds, may be present. Gasoline can also contain aliphatic compounds that can dominate the pattern in the lightest boiling point range. When present, aliphatic compounds will have a lesser relative abundance compared to the alkylbenzene compounds following toluene.

8.1.1. Octane enhancers—Depending upon evaporation, octane enhancers should be present as oxygenated compounds (for example, ethanol), alkylates, or combinations of both.

8.1.1.1. Alkylates are narrow carbon range refinery products which are comprised mostly of isoalkanes (11).

8.2. *TIC*—The chromatographic patterns for gasoline, including E85, are characterized by abundant alkylbenzenes in consistent diagnostic peaks and peak patterns (refer to appendix X1.1). Gasoline contains compounds that extend from the light range through the heavy range for ignitable liquids.

8.2.1. Highly evaporated gasoline (over approximately 90 % evaporated) may not contain some of the early eluting KDF.

8.2.2. Some gasolines may not contain the later eluting compounds.

8.2.3. Except for E85, the TIC of gasoline is dominated by aromatic compounds.

8.2.3.1. E85 gasoline is dominated by abundant ethanol; however other KDF are consistent with non-E85 gasoline

Note 2: while it is classified as gasoline, E85 gasoline is reported as a mixture of ethanol and gasoline (refer to reporting WK73482).

8.2.4. Oxygenated compounds are commonly added to gasoline. Methanol, ethanol, MTBE, or other oxygenated octane enhancers may not be present or observed in samples that are more than approximately 50 % evaporated. Oxygenated compounds are not added to or present in all formulations.

8.2.5. *Key Peaks and Groupings:*

8.2.5.1. Isooctane.

8.2.5.2. Trimethylpentane (2,3,4-trimethylpentane)(11, 18) and Toluene.

8.2.5.3. Three peak group comprised of the C2-alkylbenzenes.

8.2.5.4. Six peak group comprised of five C3-alkylbenzenes with a C_{10}-isoalkane isomer preceding 1,2,4-TMB.

8.2.5.5. 1,2,4-TMB.

8.2.5.6. 1,2,3-TMB.

8.2.5.7. Indane (dihydroindene).

8.2.5.8. Four peak (double doublet) group comprised of C4-alkylbenzenes with comparative peak heights between each doublet (group 1).

8.2.5.9. Three peak group comprised of C4-alkylbenzenes, two of which are typically unresolved, preceding the approximate retention time of *n*-C_{11} with escalating peak heights within the group (group 2).

8.2.5.10. Two peak group comprised of C4-alkylbenzene following the approximate retention time of *n*-C11 with escalating peak heights within the group (group 3).

8.2.5.11. Two peak group (doublet) comprised of C1-indane isomers following the C4-alkylbenzenes with escalating peak heights within the group.

8.2.5.12. Naphthalene; may not be present in all formulations.

8.2.5.13. Two peak group (doublet) comprised of the C1-PNAs 2-methylnaphthalene followed by 1-methylnaphthalene with deescalating peak heights within the group.

NOTE 3 – These compounds may not be present in all formulations.

8.3. *EIP*—With the exception of highly evaporated (>90 %) gasoline, in the medium range, the alkylbenzene profile is more abundant than the alkane, cycloalkane, indane and polynuclear aromatic profiles (refer to appendix X1.1). For highly evaporated gasolines the abundance of the alkylbenzene and alkane profiles may be comparable.

8.3.1. *Alkanes*—The alkane pattern is dependent on the refinery and distribution processes. Patterns observed are typically comparable to a petroleum distillate (refer to Section 9), an

isoparaffinic product (refer to Section 10) or, most commonly, a mixture of the two. Additionally, the following diagnostic alkanes should be present depending on evaporation:

8.3.1.1. Isooctane.

8.3.1.2. Trimethylpentane (11, 18).

8.3.1.3. C_{10}-isoalkane isomer in C3-alkylbenzene region.

8.3.1.4. Decane.

8.3.2. *Cycloalkanes*—Can be present; however, this is not a diagnostic profile for the class.

8.3.3. *Alkylbenzenes*—When these features are present (depending upon evaporation), they are in an overall pattern that encompasses the following diagnostic peaks and peak patterns:

8.3.3.1. Toluene.

NOTE 4—Toluene can be present from matrix contribution.

8.3.3.2. Three peak group comprised of the C2-alkylbenzenes.

NOTE 5—C2-Alkylbenzenes can be present from matrix contribution.

8.3.3.3. Six peak group comprised of five C3-alkylbenzenes preceding 1, 2, 4-TMB with comparative peak heights within the group.

8.3.3.4. 1, 2, 4-TMB—At a higher abundance than the preceding member of the C3-alkylbenzene group.

8.3.3.5. 1, 2, 3-TMB.

8.3.3.6. Four peak (double doublet) group comprised of C4-alkylbenzenes with comparative peak heights between each doublet (group 1).

8.3.3.7. Three peak group comprised of C4-alkylbenzenes, two of which are typically unresolved, preceding the approximate retention time of C_{11} with escalating peak heights within the group (group 2).

8.3.3.8. Two peak group comprised of C4-alkylbenzene following the approximate retention time of C11 with escalating peak heights within the group (group 3).

8.3.3.9. An C5-alkylbenzene pattern straddling the approximate retention time of naphthalene with comparative peak heights within the group.

8.3.4. *Indanes*—The following peaks and peak groupings will be present in gasoline:

8.3.4.1. Indane.

8.3.4.2. Two peak group (doublet) comprised of C_1-indane isomers following the C4-alkylbenzenes with escalating peak heights within the group.

8.3.4.3. A four peak group comprised of C_2-indane isomers where the second and fourth peaks are escalating the first and third peaks.

8.3.5. *PNAs*—Some or all PNAs may not be present in various gasoline formulations, however, when present the KDFs are as follows:

8.3.5.1. Naphthalene.

NOTE 6—Naphthalene can be present from matrix contribution.

8.3.5.2. Two peak group (doublet) comprised of the C_1-PNAs 2-methylnaphthalene followed by 1-methylnaphthalene with deescalating peak heights within the group.

8.3.5.3. Six peak group comprised of C_2-PNA isomers in an approximately Gaussian distribution of peak heights within the group. Visualization may be limited in less evaporated samples.

9. Key Diagnostic Features of Petroleum Distillates (6)

9.1. Petroleum distillates are created by the distillation of crude oil within the distinct boiling point ranges. Some products undergo a refinery process to remove aromatic compounds. Distillates with a carbon range that start above *n*-C_7 tend to have a Gaussian-like distribution of compounds. The homologous series of n-alkanes are the most dominant. Lighter distillates (carbon range starting before *n*-C_7) are in the molecular size range in which fewer aliphatic isomers are possible or present. As such, isoalkane and cycloalkane peaks are comparable to normal alkane peaks. Distillates contain minor contributions to the overall pattern of aromatic compounds (alkylbenzenes, indane and polynuclear) and their presence varies based on the refining process used.

9.2. *Alkanes*—The major peaks present are alkanes (both n-alkanes and isoalkanes). Individual n-alkanes are more dominant than other compounds in medium and heavy distillates. In distillates which have had aromatics removed, the ratio between n-alkanes and isoalkanes (and cycloalkanes) may be smaller. In medium or heavy products, if the major *n*-alkane peak is present at less than 1.5 times the major isoalkane or cycloalkane peak(s) height, the product is classified as a naphthenic-paraffinic product rather than a distillate (12).

9.3. *Cycloalkanes*—Present throughout the carbon range. They are less dominant than *n*-alkanes and comparable to isoalkanes in medium to heavy products. In light distillates, there are single or few cycloalkane peaks, which are generally comparable to *n*-alkane(s).

9.4. *Alkylbenzenes*—Aromatic compounds are present in many distillates; however, some products have had these compounds removed during the refining process.

9.5. *Indanes*—Indane, methyl indanes, and C_2 indanes are present in many distillates if the carbon range of the distillate encompasses that of the compounds, however, some products have had these compounds removed during the refining process.

9.6. *PNAs*—Present in many distillates if the carbon range of the distillate encompasses that of these compounds, however, some products have had these compounds removed during the refining process.

Key Diagnostic Features (KDF) of Light Petroleum Distillates (LPD)

9.7. LPDs contain fewer compounds than heavier distillates and the pattern may not be clearly Gaussian. The pattern contains at least one normal alkane in the range of *n*-C_4-*n*-C_9, in which the normal alkane is more, or similar in abundance, to the isoalkanes and cycloalkane isomers. The pattern has fewer eluting peaks on the lighter end of the range due to the limited number of isoalkanes and cycloalkane isomers of the smaller molecular weight hydrocarbons.

9.7.1. *TIC*—The pattern contains a Gaussian distribution of peaks with a homologous series of spiking normal alkanes or a non-Gaussian pattern containing only one or two *n*-alkanes. Lighter distillates (carbon range starting before *n*-C_7) are in the molecular size range in

which fewer aliphatic isomers are possible or present. As such, isoalkane and cycloalkane peaks are comparable in abundance to normal alkane peaks.

9.7.1.1. A series of isoalkanes and cycloalkane isomers are between the consecutive *n*-alkanes. The chromatographic pattern of these isoalkane and cycloalkane peaks is consistent among all distillates.

(1) Methylcyclohexane is present when *n*-C_7 and *n*-C_8 are present (12).

9.7.1.2. Alkylbenzenes can be present but may not be of sufficient abundance to be visualized on the TIC. The abundances vary among formulations, based on the refining process

9.7.2. *EIP*—The alkane and cycloalkane profiles are more abundant than the alkylbenzene profile (refer to appendix X1.2). Due to the carbon range, indane, and polynuclear compounds are not present.

9.7.2.1. *Alkanes*—The pattern contains a Gaussian distribution of peaks with a homologous series of spiking normal alkanes or a non-Gaussian pattern containing only one or two n-alkanes. Between the consecutive normal alkanes are a series of primarily isoalkane isomers which are present in consistent patterns.

9.7.2.2. *Cycloalkanes*—Between the consecutive normal alkanes are a series of cycloalkane isomers which are present in consistent patterns based on carbon range and may be comparable in abundance to the alkane EIP.

(1) Methylcyclohexane is present when *n*-C_7 and *n*-C_8 are present (12)

9.7.2.3. *Alkylbenzenes*—When present, they are in the diagnostic pattern associated with their carbon range:

(1) Toluene, if range encompasses *n*-C_7-*n*-C_8.

(2) Three peak C_2- alkylbenzenes, if the range encompasses *n*-C_8-*n*-C_9.

Key Diagnostic Features (KDF) of Medium Petroleum Distillates (MPD)

9.8. The bulk of the chromatographic pattern occurs in the range of *n*-C_8 to *n*-C_{13} and encompasses two to four normal alkanes.

9.9. *TIC*—With the exception of minor aromatic contributions, the chromatographic patterns for all MPDs that elute in a given carbon range are consistent.

9.9.1. The pattern is dominated by a Gaussian distribution of peaks with a homologous series of spiking normal alkanes.

9.9.2. A series of isoalkanes and cycloalkane isomers are between the consecutive *n*-alkanes. The chromatographic pattern of these less abundant alkane and cycloalkane peaks is consistent among all distillates (refer to appendix X1.3). Due to the number of isoalkanes and cycloalkane isomers present, these compounds can appear unresolved.

9.9.3. Aromatic compounds (alkylbenzenes, indanes, polynuclear aromatics) can be present but may not be of sufficient abundance to be visualized on the TIC. The abundance varies between formulations.

9.10. *EIP*—The alkane profile is more abundant than alkylbenzene, cycloalkane, indane, and polynuclear aromatic profiles.

9.10.1. *Alkanes*—The pattern in dominated by a Gaussian distribution of peaks with a homologous series of spiking normal alkanes.

9.10.1.1. Between the consecutive normal alkanes are a Gaussian distribution of isoalkane isomers which are present in consistent patterns.

9.10.2. *Cycloalkanes*—A Gaussian distribution of cycloalkane isomers in a generally unresolved pattern.

9.10.2.1. Trans-decalin.

9.10.3. *Alkylbenzenes*—When these compounds are present, they are in the diagnostic pattern associated with their carbon range:

9.10.3.1. Toluene, if range encompasses *n*-C_7-*n*-C_8.

9.10.3.2. Three peak C_2- alkylbenzenes, if the range encompasses *n*-C_8-*n*-C_9.

9.10.3.3. Five peak C_3- alkylbenzene group, if the range encompasses *n*-C_9-*n*-C_{10}.

9.10.3.4. 1,2,4-TMB and 1,2,3-TMB, if the range encompasses *n*-C_9-*n*-C_{10}.

9.10.3.5. C_4- alkylbenzene groups, if the range encompasses *n*-C_{10}-*n*-C_{11}.

9.10.4. *Indanes*—When these compounds are present, indane, the C_1-indane group, and the C_2-indane group are present in the range of *n*-C_{10}-*n*-C_{12}.

9.10.5. *PNAs*—When these compounds are present, naphthalene and the C_1-PNA group are present in the range of *n*-C_{11}-*n*-C_{13}.

Key Diagnostic Features (KDF) of Heavy Petroleum Distillates (HPD)

9.11. *TIC*—With the exception of minor aromatic contributions, the chromatographic patterns for all HPDs that elute in a given boiling point (n-alkane) range are consistent.

9.11.1. The pattern is dominated by a Gaussian distribution of peaks with a homologous series of spiking normal alkanes. These products generally contain a minimum of five consecutive normal alkanes; however, it also includes a subclass of narrow ranged distillates starting above *n*-C_{11} which encompass fewer than five n-alkanes.

9.11.2. A series of isoalkanes and cycloalkane isomers are between the consecutive n-alkanes. The chromatographic pattern of these less abundant alkane and cycloalkane peaks is generally consistent among all distillates (refer to appendix X1.4). Due to the number of isoalkanes and cycloalkane isomers present, these compounds can appear unresolved.

9.11.3. Aromatic compounds (alkylbenzenes, indanes, polynuclear aromatics) can be present but may not be of sufficient abundance to be visualized on the TIC. The abundance varies between formulations.

9.12. *EIP*—The alkane profile is more abundant than alkylbenzene, cycloalkane, indane, and polynuclear aromatic profiles.

9.12.1. *Alkanes*—The pattern is dominated by a Gaussian distribution of peaks with a homologous series of spiking normal alkanes. Between the consecutive normal alkanes is a Gaussian distribution of isoalkane isomers which are present in consistent patterns.

9.12.1.1. Pristane is present following *n*-C_{17}, and phytane is present following *n*-C_{18} if the boiling point range includes *n*-C_{17} or *n*-C_{18}, respectively.

9.12.2. *Cycloalkanes*—A Gaussian distribution of cycloalkanes in a generally unresolved pattern.

9.12.2.1. Trans-decalin, if the range encompasses *n*-C_{10}.

9.12.3. *Alkylbenzenes*—When present, they are in the diagnostic pattern associated with their carbon range:

9.12.3.1. Five peak C_3-alkylbenzene group, in the range of *n*-C_9-*n*C_{10}.

9.12.3.2. 1,2,4-TMB and 1,2,3-TMB, if the range encompasses *n*-C_9-*n*-C_{10}.

9.12.3.3. C_4-alkylbenzene groups, in the range of *n*-C_{10}-*n*-C_{11}.

9.12.4. *Indanes*—Indane, the C_1-indane group, and the C_2-indane group are present in the range of *n*-C_{10}-*n*-C_{12}.

9.12.5. *PNAs*—Naphthalene, C_1- PNA, and C_2- PNA groups are present in the range of *n*-C_{11}-*n*-C_{15}.

10. Key Diagnostic Features of Isoparaffinic Products

10.1. Isoparaffinic products are comprised almost exclusively of branched chain aliphatic compounds (isoalkanes). Isoparaffinic products are the result of refinery processes, including alkylation and isomerization, to isolate or create isoalkanes in targeted carbon ranges. The carbon range is dependent upon the specific formulation. Aromatics (alkylbenzenes, indane, and polynuclear), *n*-alkanes, and cycloalkanes have been removed or transformed to isoalkanes from the crude oil distillate fraction from which the product was derived. As a result, *n*-alkanes, cycloalkanes or aromatic compounds are not present.

10.2. *TIC*—Isoparaffinic products are composed of branched alkanes. The number of isomers increases as the molecular size increases. Generally, this results in patterns composed of fewer compounds in the lower carbon ranges and more complex patterns at higher carbon ranges. Consistent compounds are present throughout the light, medium and heavy ranges of isoparaffinic products (as applicable), but in ratios that are representative of the subclass.

10.2.1. LIPs are not as commercially prevalent as MIPs. The LIPs are generally composed of three to five predominant branched alkanes and additional lower abundant isomers.

10.2.2. In MIPs the TICs are generally composed of more than five predominant branched alkanes with minor abundance branched alkanes. The MIPs are generally encompassing a carbon range of no more than 4 *n*-alkanes.

10.2.3. HIPs are not as commercially prevalent as the MIPs. They are composed of numerous isoparaffinic isomers in a high carbon range which results in patterns of low resolution with few distinct chromatographic features consisting of unidentifiable branched alkanes.

10.3. *EIP:*

10.3.1. *Alkanes*—Most abundant profile; pattern resembles the TIC (refer to appendix X1.5).

10.3.1.1. *LIPs*—The alkane profile may be composed of a few highly volatile compounds or some highly volatile compounds with some less volatile compounds nearing the medium range. The highly volatile compounds may be encountered in liquid samples but are unlikely to be encountered in debris samples exposed to fire or other environmental conditions.

10.3.1.2. *MIPs*—The alkane profile shows distinct patterns of interest. C_{10}, C_{11}, and C_{12}

isomers are prevalent. The relative ratios of these to each other change vary depending on the formulation as related to the carbon range of the product.

10.3.1.3. *HIPs*—The alkane profile generally shows a pattern of low resolution with few distinct chromatographic features. The alkane profile is the most abundant profile.

10.3.2. *Cycloalkanes*—The mass spectra for isoalkanes contain ions which comprise the cycloalkane profile. As a result, cycloalkane profile will generally resemble the alkanes profile in a lower abundance.

10.3.3. *Alkylbenzene*—Not present.

10.3.4. *Indanes*—Not present.

10.3.5. *PNAs*—Not present.

11. Key Diagnostic Features of Naphthenic-Paraffinic Products

11.1. Naphthenic-paraffinic products are derived from distillates in which the aromatic compounds, and to an extent *n*-alkane compounds, are removed. As a result, the aromatic compounds including alkylbenzenes, indane, PNAs, or a combination thereof, are not present and the *n*-alkane compounds have been removed or reduced. The carbon range and pattern are dependent on the specific formulation. Light naphthenic-paraffinic products are uncommon.

11.2. *TIC*—Pattern comprised mostly of cycloalkanes (naphthenic) and isoalkanes (isoparaffinic). n-alkanes, when present, are in reduced amounts compared to that in a distillate.

11.3. *EIP*—Alkane and Cycloalkane profiles are the most abundant (refer to appendix X1.6). Alkylbenzene, Indane, and PNA profiles are not present.

11.3.1. *Alkanes*—Pattern consists almost exclusively of branched alkanes. Isoalkane peaks are present and their abundance is comparable to cycloalkane peaks. In medium or heavy products, if the major *n*-alkane peak is present at greater than 1.5 times the major isoalkane or cycloalkane peak(s) with comparable carbon range, then the product is classified as a distillate rather than a naphthenic-paraffinic product (12).

11.3.2. *Cycloalkanes*—Pattern consists of groups of cycloalkane or isoalkane compounds in between the spiking *n*-alkanes. Cycloalkanes are comparable in abundance to isoalkanes. Spiking n-cycloalkanes are more obvious in summed EIP of heavy naphthenic-paraffinic products and in single ion (83) EIP. Pattern comparable to known naphthenic-paraffinic products.

11.3.3. *Alkylbenzenes*—Not present.

11.3.4. *Indanes*—Not present.

11.3.5. *PNAs*—Not present.

12. Key Diagnostic Features of Aromatic Products

12.1. Aromatic products are comprised almost exclusively of alkylbenzene compounds, indanes, polynuclear aromatic compounds, or a combination thereof; alkanes and cycloalkanes are not present. The boiling point range and pattern are dependent on the specific formulation. Aromatic products are the result of refinery processes, including reforming, to isolate or create aromatic compounds in targeted carbon ranges. Unlike gasoline, aromatic products generally are narrow range products, but a few may contain a larger range.

12.2. *TIC:*

12.2.1. LAPs typically consist of toluene, C_2-alkylbenzenes, or both.

12.2.2. MAPs usually consist of C_3-, C_4-alkylbenzenes, C_1-, C_2-indanes but the composition depends on the formulation. The TIC will resemble that of gasoline within the product range.

12.2.3. HAPs consist mostly of polynuclear aromatics.

12.3. *EIP*—Aromatic ion profiles (either alkylbenzene or polynuclear aromatic) are the most abundant profiles and resembles the TIC (refer to appendix X1.7 through X1.9).

12.3.1. *Alkanes*—Not present.

12.3.2. *Cycloalkanes*—Not present.

12.3.3. *Alkylbenzenes*—Most abundant profile in LAPs and MAPs. Pattern depends on formulation; however, it will resemble the TIC.

12.3.4. *Indanes*—C_1-, C_2-indanes are present in aromatic products that encompass n-C_{11}-n-C_{12}.

12.3.5. *PNAs*—Most abundant profile in HAPs. Naphthalene as well as C_1- and C_2-PNAs may be present in HAPs if the pattern encompasses *n*-C_{11}-*n*-C_{15}. PNA pattern depends on formulation.

13. Key Diagnostic Features of Normal Alkane Products

13.1. Normal alkane products are produced by physical separation (molecular sieve) from petroleum feedstocks. They typically have very narrow boiling point ranges and consist of three to seven *n*-alkanes. Isoalkanes, cycloalkanes, or aromatics (alkylbenzenes, indanes, polynuclear) are not present in these products.

13.2. *TIC*—Comprised almost exclusively of *n*-alkanes in a homologous series (refer to appendix X1.10).

13.2.1. The carbon range and pattern are dependent on the specific formulation.

13.3. *EIP*—The only diagnostic profile is the alkane profile. Cycloalkane, alkylbenzene, indane and PNAs compounds are not present.

13.3.1. *Alkanes*—A narrow carbon range of homologous *n*-alkanes are present. Isoalkanes are not present.

14. Key Diagnostic Features of Oxygenated Solvents

14.1. Oxygenated ignitable liquids are most commonly comprised of very low boiling compounds. The most common examples are alcohols (ethanol, isopropyl alcohol), esters, and ketones (methyl ethyl ketone, methyl isobutyl ketone).

14.2. *TIC*—Products comprised exclusively of oxygenated peaks (refer to appendix X1.11).

14.2.1. The mere presence of oxygenated compounds, such as alcohols or acetone, does not indicate that a foreign ignitable liquid is present in the sample. A large excess of the compound (at least one order of magnitude above the matrix peaks in the chromatogram) should be present before classifying an oxygenated compound.

14.2.2. This class does not include oil and fat-based products.

14.3. *EIP*—Alkanes, cycloalkanes, alkylbenzenes, indanes, and PNAs are not present.

15. Key Diagnostic Features of Petroleum Products

15.1. This class describes products that have a singular distinct carbon range and are primarily consistent with one of the previously mentioned classifications; however, they do not meet the criteria for a single classification or a mixture (refer to appendix X1.12), such as:

15.1.1. Enhanced aromatics in a distillate.

15.1.2. Distillate present in a primarily aromatic pattern.

15.1.3. HPD which includes *n*-C_{17} and *n*-C_{18} but does not contain pristane or phytane.

15.2. *TIC*—The chromatographic patterns for petroleum products will vary and will meet requirements from more than one class.

15.2.1. Petroleum products will have characteristics of more than one class but will not have sufficient characteristics to identify two or more separate classes within the same carbon range.

NOTE 7—If the TIC and EIPs contain the requirements to classify more than one pattern, then classify each pattern separately. Refer to Section 17 for additional guidance.

15.2.2. The carbon range and pattern are dependent on the specific formulation.

15.3. *EIP*—The profiles will be dependent on the observed pattern(s).

15.3.1. *Alkanes*—Pattern dependent.

15.3.2. *Cycloalkanes*—Pattern dependent.

15.3.3. *Alkylbenzenes*—Pattern dependent.

15.3.4. *Indanes*—Pattern dependent.

15.3.5. *PNAs*—Pattern dependent.

16. Key Diagnostic Features of Oil and Fat-Based Products (13, 14, 15, 16)

16.1. Oil and fat-based products cover those composed of fatty acids, FAMEs (fatty acid methyl esters), and biofuels. They are refined from plant or animal sources and include pure oils which have the potential for spontaneous ignition and products made from the transesterification of fatty acids.

16.1.1. Fatty acids and FAMEs are identified based on their carbon length and the position of the double bond location. It is not necessary to identify the specific isomer(s) present.

16.1.2. Pure oil and fat products are typically derivatized FAMEs for analysis (refer to E2881). Products containing FAMEs do not need to be derivatized prior to GC-MS analysis.

16.1.2.1. In pure oil and fat products, hydrocarbons, including alkanes, isoalkanes, cycloalkanes, and aromatics (alkylbenzenes, indanes, and PNAs), are absent.

16.1.3. Some wood finishes, treatments, sealants, environmentally friendly lighter fluids, and firelog fuels are mixtures of fatty acids with other ignitable liquid classifications. These are usually found in proprietary formulations (for example, wood finishes) and can include the following ignitable liquid classifications:

16.1.3.1. Petroleum distillates.

16.1.3.2. Naphthenic-paraffinic products.

16.1.3.3. Aromatic products.

16.1.3.4. Transesterified oil and fat-based products (FAMEs).

16.1.4. Consider evaluating samples containing other ignitable liquid classifications as well as negative samples for the presence of fatty acids, FAMEs, or a combination of both.

16.1.4.1. Caution—The presence of fatty acids does not necessarily indicate that a foreign oil or fat-based product is present in the sample. Take caution when identifying fatty acids when only saturated fatty acids are present.

Key Diagnostic Features of Oil and Fat-based

16.2. *General*—This class includes underivatized fatty acids from animal and vegetable sources, some which have the potential for spontaneous ignition. They typically contain high levels of polyunsaturated fatty acids and include corn, cottonseed, fish, linseed, perilla, rapeseed, soybean and tung oils (10). These are typically transesterified during analysis and analyzed as FAMEs.

16.3. *TIC*—The TIC will be comprised of saturated and unsaturated transesterified fatty acids (refer to appendix X1.13).

16.4. *EIP*—Alkanes, cycloalkanes, alkylbenzenes, indanes and PNAs are not present.

16.4.1. Additional extracted ions can be used to assess the sample's unsaturation level.

16.4.1.1. *n*-C16:0 – ion 270.

16.4.1.2. *n*-C16:1 – ion 268.

16.4.1.3. *n*-C18:0 – ion 298.

16.4.1.4. *n*-C18:1 – ion 296.

16.4.1.5. *n*-C18:2 – ion 294.

16.4.1.6. *n*-C18:3 – ion 292.

Key Diagnostic Features of FAME-Based Products

16.5. *General*—FAME-based products are transesterified prior to commercial distribution and are comprised of FAMEs. While not always marketed as such, they can be present in combination with underivitized oils and fats, petroleum products or light oxygenated solvents. When present in combination with underivatized oils and fats or other ignitable liquid classifications, refer to Section 17 for additional guidance.

16.6. *TIC*—The sample will be comprised exclusively of FAMEs derived from vegetable and animal sources or present as a mixture of FAMEs and different classes.

16.7. *EIP*—FAMEs present vary based on formulation.

16.7.1. Ion 74 can be used to screen for the presence of FAMEs.

Key Diagnostic Features of Biofuels

16.8. *General*— "Biodiesel" refers to engine fuels which are comprised of FAMEs or mixtures of HPDs and FAMEs (Refer to E2997 and appendix X1.14).

16.9. *TIC* and *EIP*—The sample will be comprised exclusively of FAMEs (for example, B100), or a mixture of FAMEs and distillates (for example, B20).

16.9.1. Ions 74 and 294 can be used to screen for the presence of biofuels.

16.9.1.1. Mixtures of HPDs and FAMEs may be further sub-classified as "biodiesel."

16.9.1.2. Refer to Section 17 for further guidance on mixtures.

17. Key Diagnostic Features of Single Components

17.1. Single components are characterized by their retention time and mass spectrum. Refer to EXXX (Interpretation) for the requirements for identification of single components**.**

18. Key Diagnostic Features of Mixtures

18.1. More than one ignitable liquid class or subclass may be present in a single sample (refer to appendix X1.15).

18.1.1. When two or more classes or subclasses are present, the requirements for each class are met.

NOTE 8—Mixtures of ignitable liquid classifications can be the result of a single commercial product or a mixture of products. This standard cannot differentiate between ignitable liquids that are mixed by a manufacturer for sale or ignitable liquids mixed at the point of use.

19. Other Ignitable Liquid Products

19.1. No classification system is likely to describe all possible ignitable liquids. Numerous commercial and industrial products are ignitable and do not fall into any of the above classifications. Many of these are synthetic mixtures consisting of only a few compounds, rather than distillation fractions, such as terpenes. For such products, describe the composition instead of classifying it as a "miscellaneous" or other product.

20. Keywords

20.1. FAME, fire debris; forensic sciences; ignitable liquid

Appendix

(Nonmandatory Information)

X1 Classification Examples, Labeled with KDFs

X1.1 Table X1.1 displays the key for groupings labeled in images located in the appendix along with the sections within the standard which reference the groups.

X1.2 Table X1.2 displays the key for chemicals labeled in images located in the appendix along with the sections within the standard which reference the chemicals

TABLE X1.1 Table of Groupings

Designation	Group Name	Cited Sections
A	C2-alkylbenzenes	8.2.5.3, 8.3.3.2, 9.7.2.3, 9.10.3.2, 12.2.1

B	C3-alkylbenzenes	8.2.5.4, 8.3.3.3, 9.10.3.3, 12.2.2
C	C4-alkylbenzenes, group 1	8.2.5.8, 8.3.3.6, 9.10.3.5, 9.12.3.3, 12.2.2
D	C4-alkylbenzenes, group 2	8.2.5.9, 8.3.3.7, 9.10.3.5, 9.12.3.3, 12.2.2
E	C4-alkylbenzenes, group 3	8.2.5.10, 8.3.3.8, 9.10.3.5, 9.12.3.3, 12.2.2
F	C1-indanes	8.2.5.11, 8.3.4.2, 9.5, 9.10.4, 9.12.4, 12.2.2, 12.3.4
G	C2-indanes	8.3.4.3, 9.5, 9.10.4, 9.12.4, 12.2.2, 12.3.4
H	C1-PNAs	8.2.5.13, 8.3.5.2, 9.10.5, 9.12.5, 12.3.5
I	C2-PNAs	8.3.5.3, 9.12.5, 12.3.5
J	Area of medium isoparaffinic contribution, if present	8.3.1
K	C5-alkylbenzenes	8.1, 8.3.3.9
L	Isoalkane and cycloalkane isomers	9.1, 9.2, 9.7, 9.7.1, 9.7.1.1, 9.7.2.1, 9.9.2, 9.10.1.1, 9.10.2, 9.11.2, 9.12.1, 11.3.1, 11.3.2

TABLE X1.2 Table of Chemicals

Designation	Common Name	IUPAC Name	Cited Sections
1	Isooctane	2,2,4-trimethylpentane	8.2.5.1, 8.3.1.1
2	Trimethylpentane	2,3,4-trimethylpentane	8.2.5.2, 8.3.1.2
3	Methylcyclohexane	methylcyclohexane	9.7.1.1, 9.7.2.1.(1)
4	Toluene	methylbenzene	8.1, 8.2.5.2, 8.3.3.1, 9.7.2.3, 9.10.3.1, 12.2.1
5	Ethylbenzene	ethylbenzene	
6	n-propylbenzene	propylbenzene	
7	C_{10} alkane isomer		8.2.5.4, 8.3.1.3
8	1,2,4-TMB	1,2,4-trimethylbenzene	8.2.5.4, 8.2.5.5, 8.3.3.3, 8.3.3.4, 9.10.3.4, 9.12.3.2
9	Decane	Decane	8.3.1.4
10	1,2,3-TMB	1,2,3-trimethylbenzene	8.2.5.6, 8.3.3.5, 9.10.3.4, 9.12.3.2
11	Indane	2,3-dihydro-1H-indene	8.2.5.7, 8.3.4.1, 9.5, 9.10.4, 9.12.4
12	trans-decalin	trans-Decahydronaphthalene	9.10.2.1, 9.12.2.1
13	Naphthalene	bicyclo[4,4,0]deca-1,3,5,7,9-pentane	8.2.5.12, 8.3.3.9, 8.3.5.1, 9.10.5, 9.12.5, 12.3.5
14	Pristane	2,6,10,14-tetramethylpentadecane	9.12.1.1, 15.1.3
15	Phytane	2,6,10,14-tetramethylhexadecane	9.12.1.1, 15.1.3
16	Ethanol	ethyl alcohol	8.1.1, 8.2.3.1, 8.2.4, 14.1
17	MTBE	2-methoxy-2-methylpropane	8.2.4

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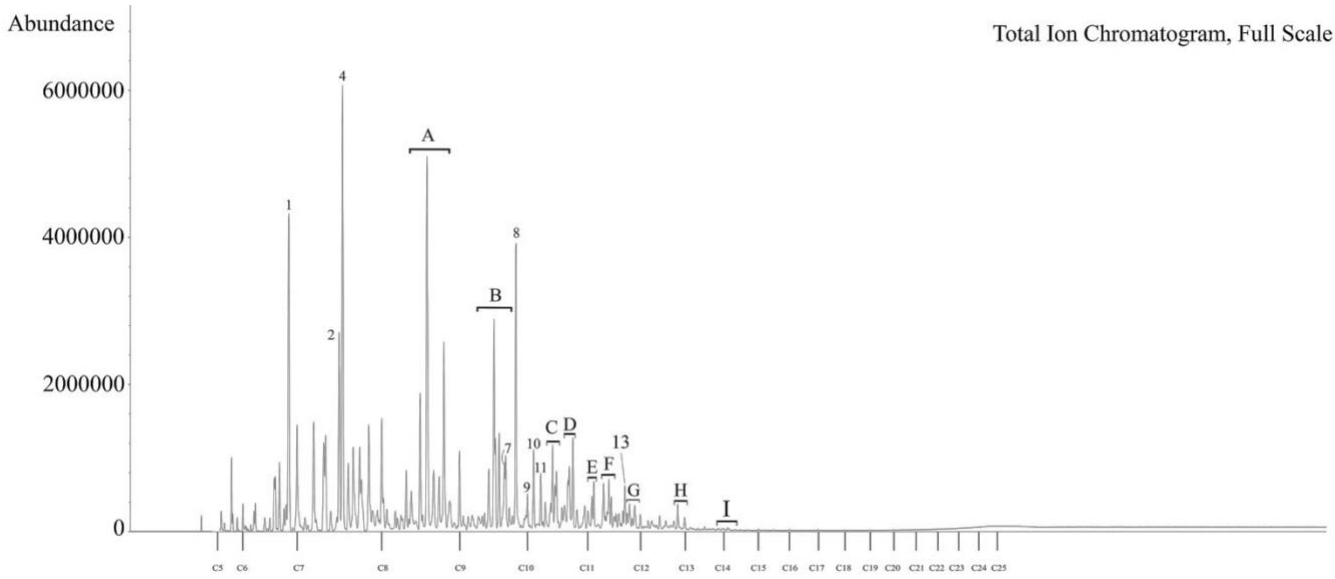
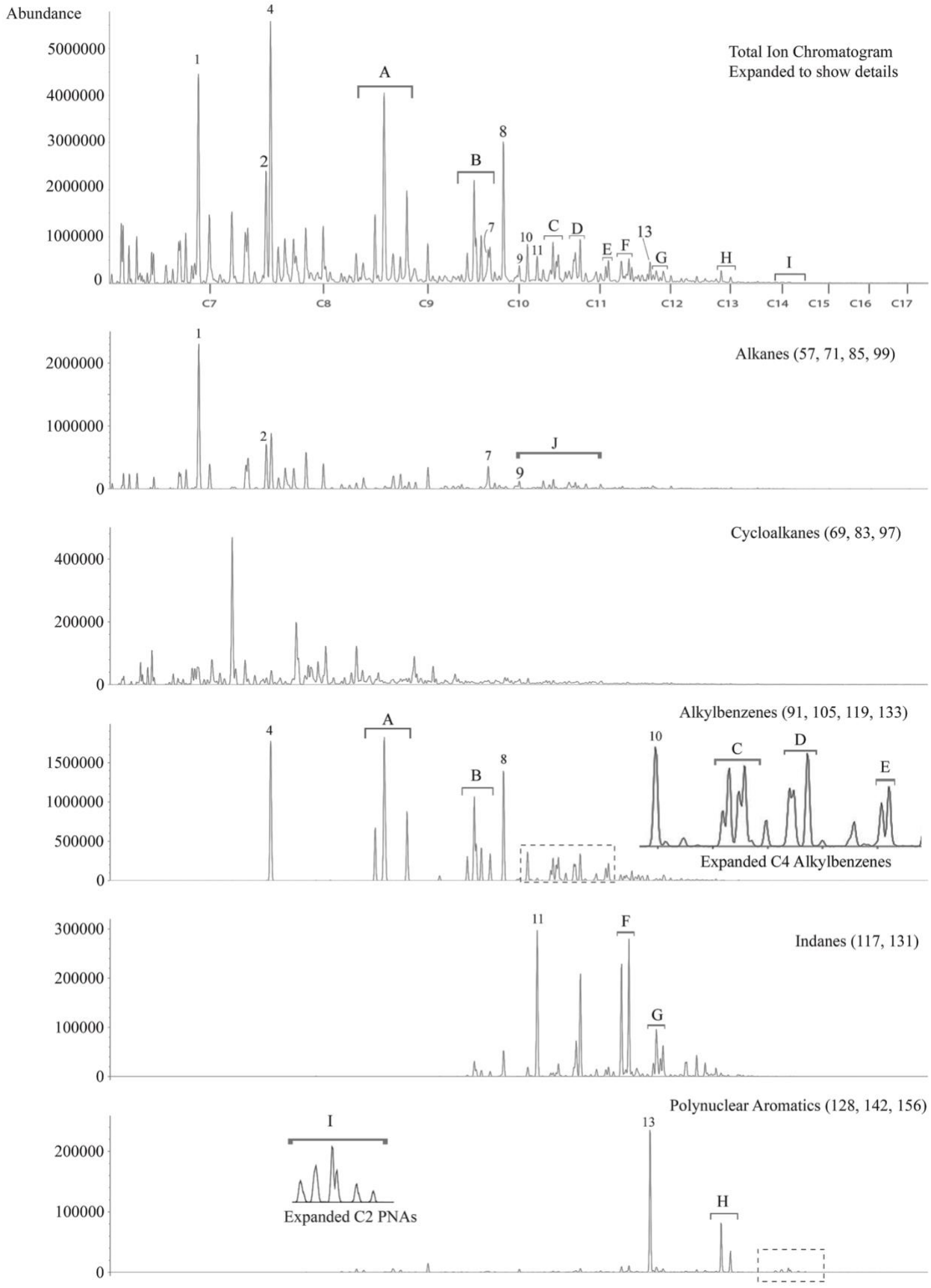
647 **Fig. X1.1 Gasoline**



648


Abundance
Total Ion Chromatogram
Expanded to show details
Alkanes (57, 71, 85, 99)
Cycloalkanes (69, 83, 97)
Alkylbenzenes (91, 105, 119, 133)
Expanded C4 Alkylbenzenes
Indanes (117, 131)
Polynuclear Aromatics (128, 142, 156)
Expanded C2 PNAs
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17

649

Fig. X1.2 LPD

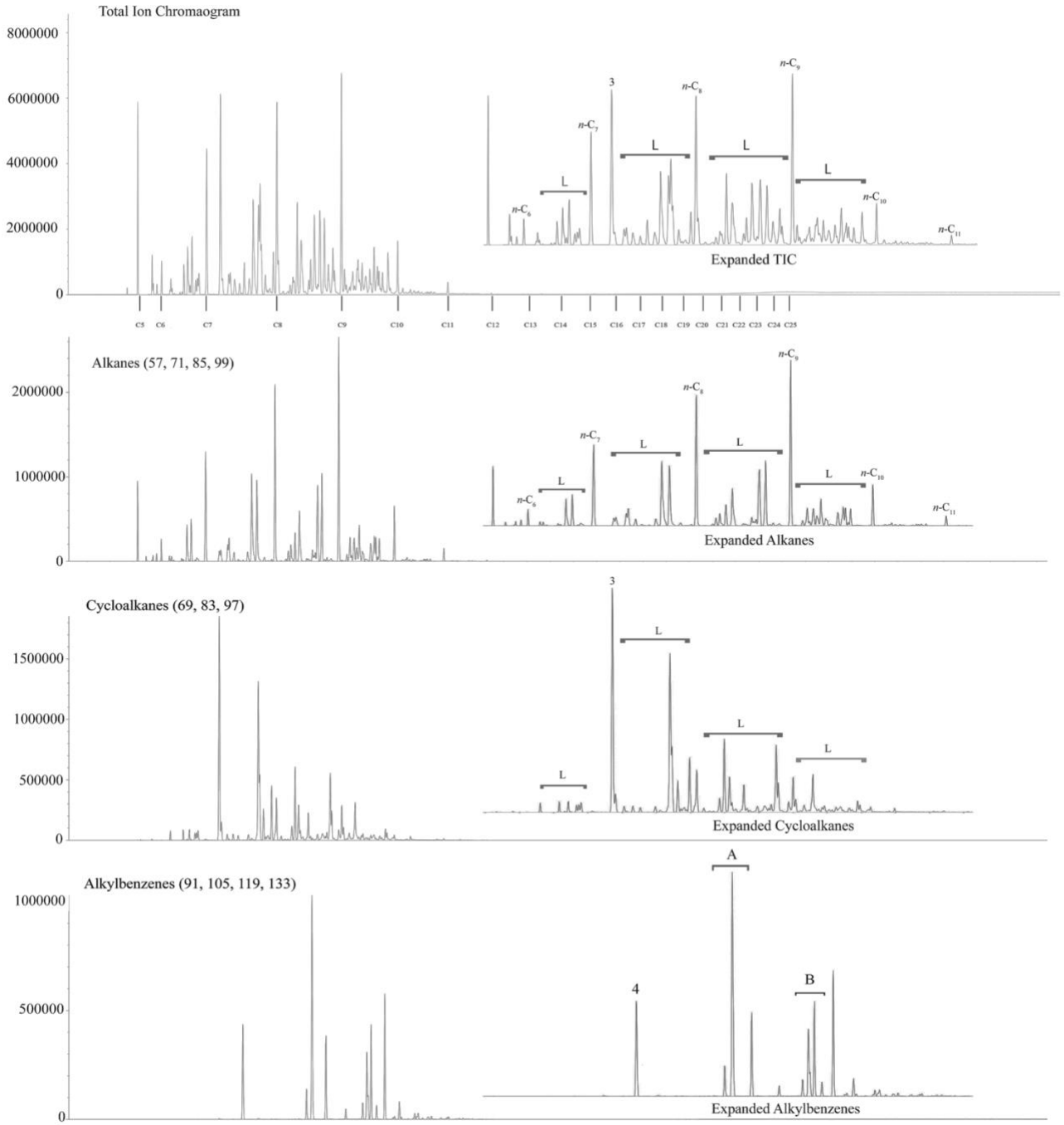
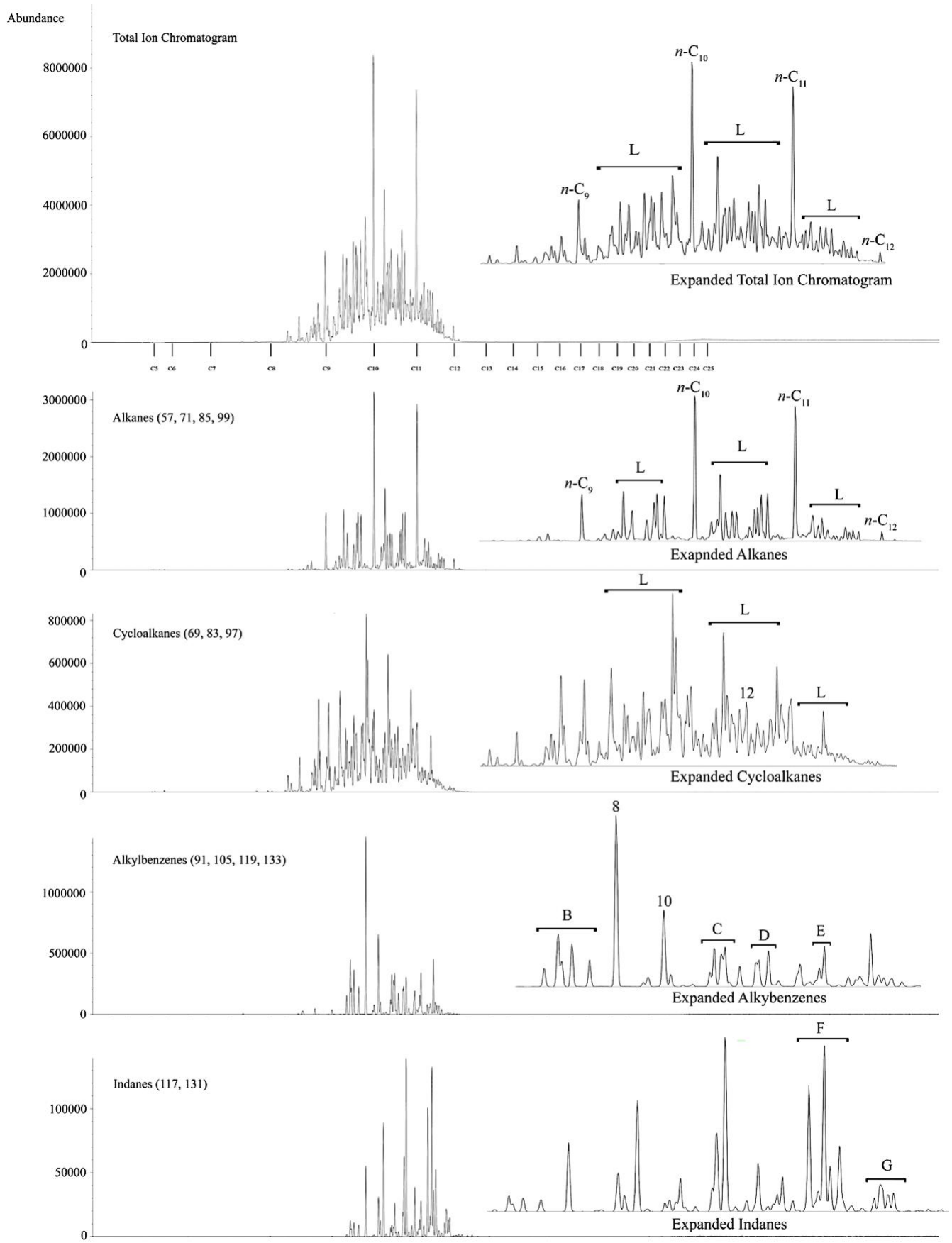


Fig. X1.3 MPD


Abundance
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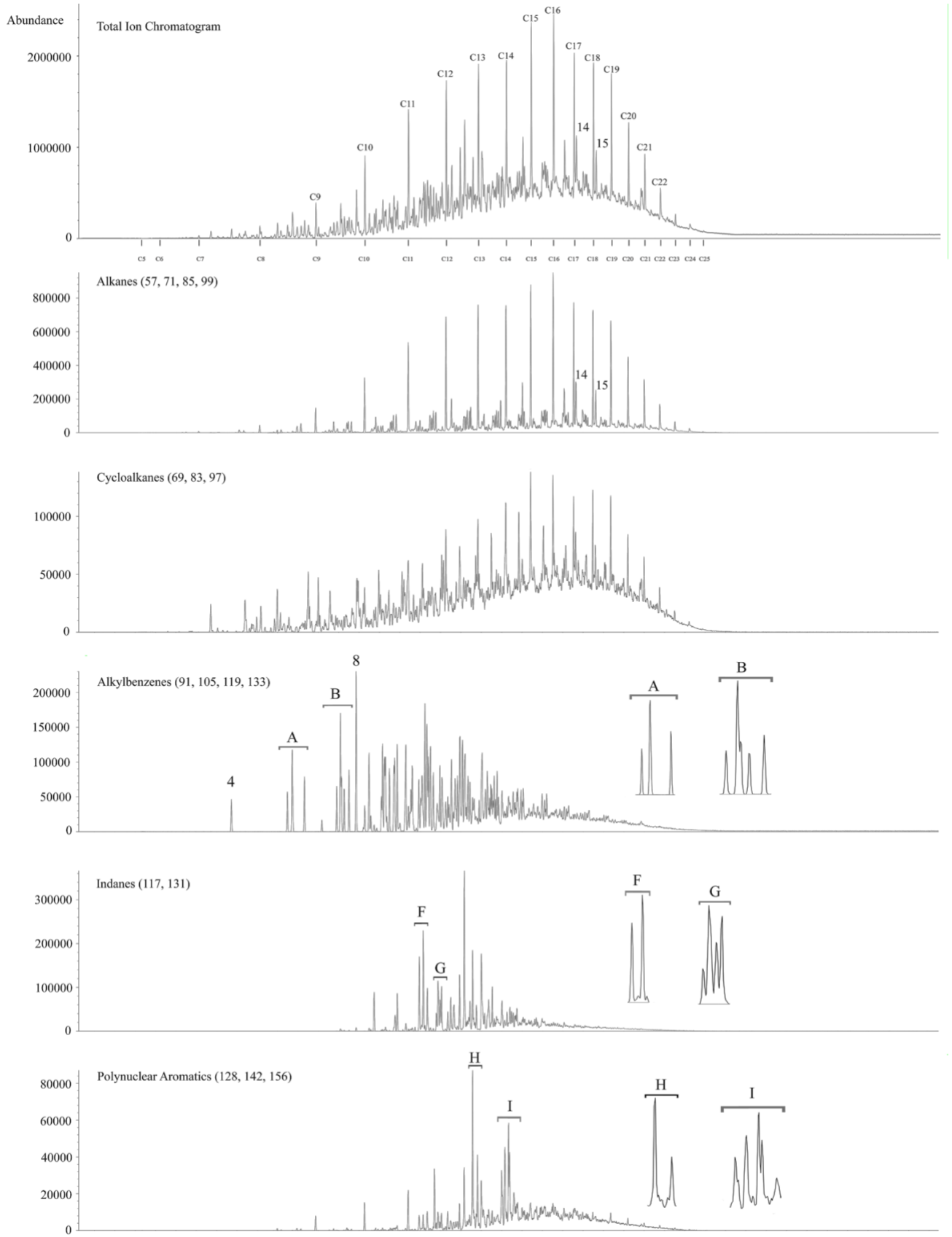
6000000
4000000
2000000
0
C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23 C24 C25
n-C10
n-C11
L
L
L
n-C9
n-C12
Expanded Total Ion Chromatogram
3000000
2000000
1000000
0
Alkanes (57, 71, 85, 99)
n-C10
n-C11
L
L
L
n-C9
n-C12
Exapnded Alkanes
800000
600000
400000
200000
0
Cycloalkanes (69, 83, 97)
L
L
12
L
Expanded Cycloalkanes
1000000
500000
0
Alkylbenzenes (91, 105, 119, 133)
8
10
B
C
D
E
Expanded Alkybenzenes
100000
50000
0
Indanes (117, 131)
F
G
Expanded Indanes

654

Fig. X1.4 HPD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Total Ion Chromatogram
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1000000
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C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
14
15
Alkanes (57, 71, 85, 99)
800000
600000
400000
200000
0
14
15
Cycloalkanes (69, 83, 97)
100000
50000
0
Alkylbenzenes (91, 105, 119, 133)
200000
150000
100000
50000
0
4
A
B
8
A
B
Indanes (117, 131)
300000
200000
100000
0
F
G
F
G
Polynuclear Aromatics (128, 142, 156)
80000
60000
40000
20000
0
H
I
H
I

Fig. X1.5 Isoparaffinic Product

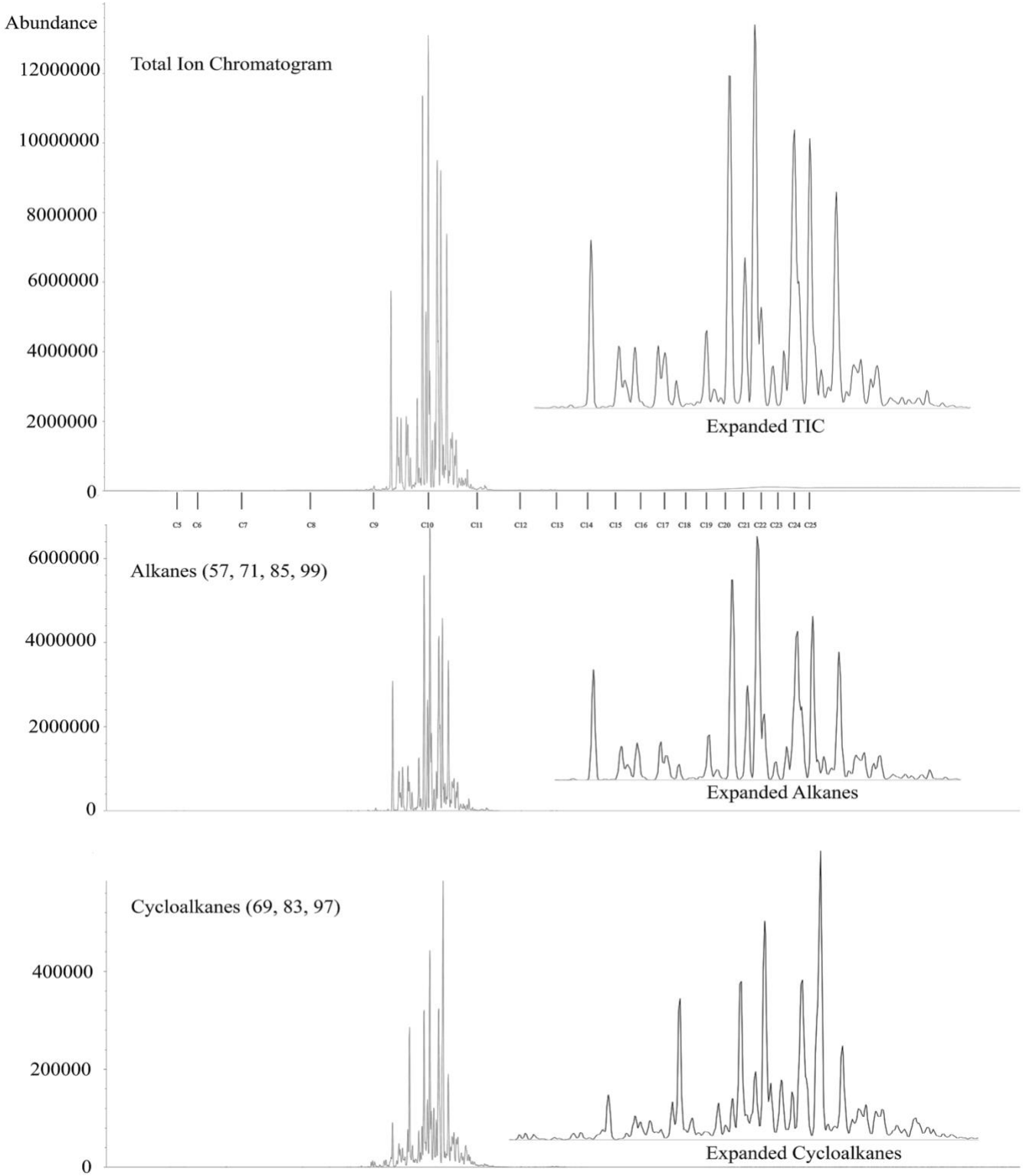


Fig. X1.6 Naphthenic-Paraffinic Product

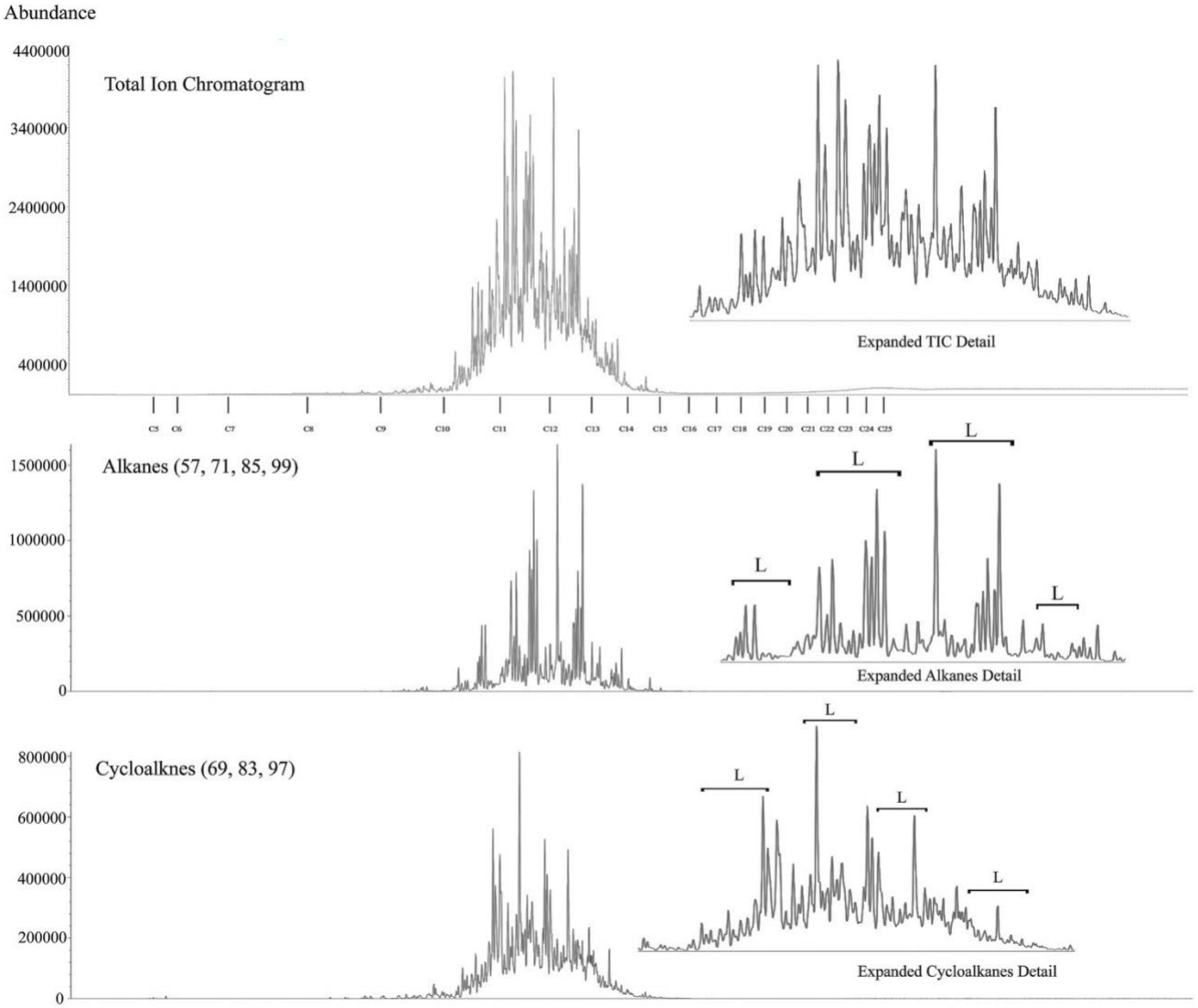

Abundance
Total Ion Chromatogram
Expanded TIC Detail
Alkanes (57, 71, 85, 99)
Expanded Alkanes Detail
Cycloalknes (69, 83, 97)
Expanded Cycloalkanes Detail

Fig. X1.7 LAP

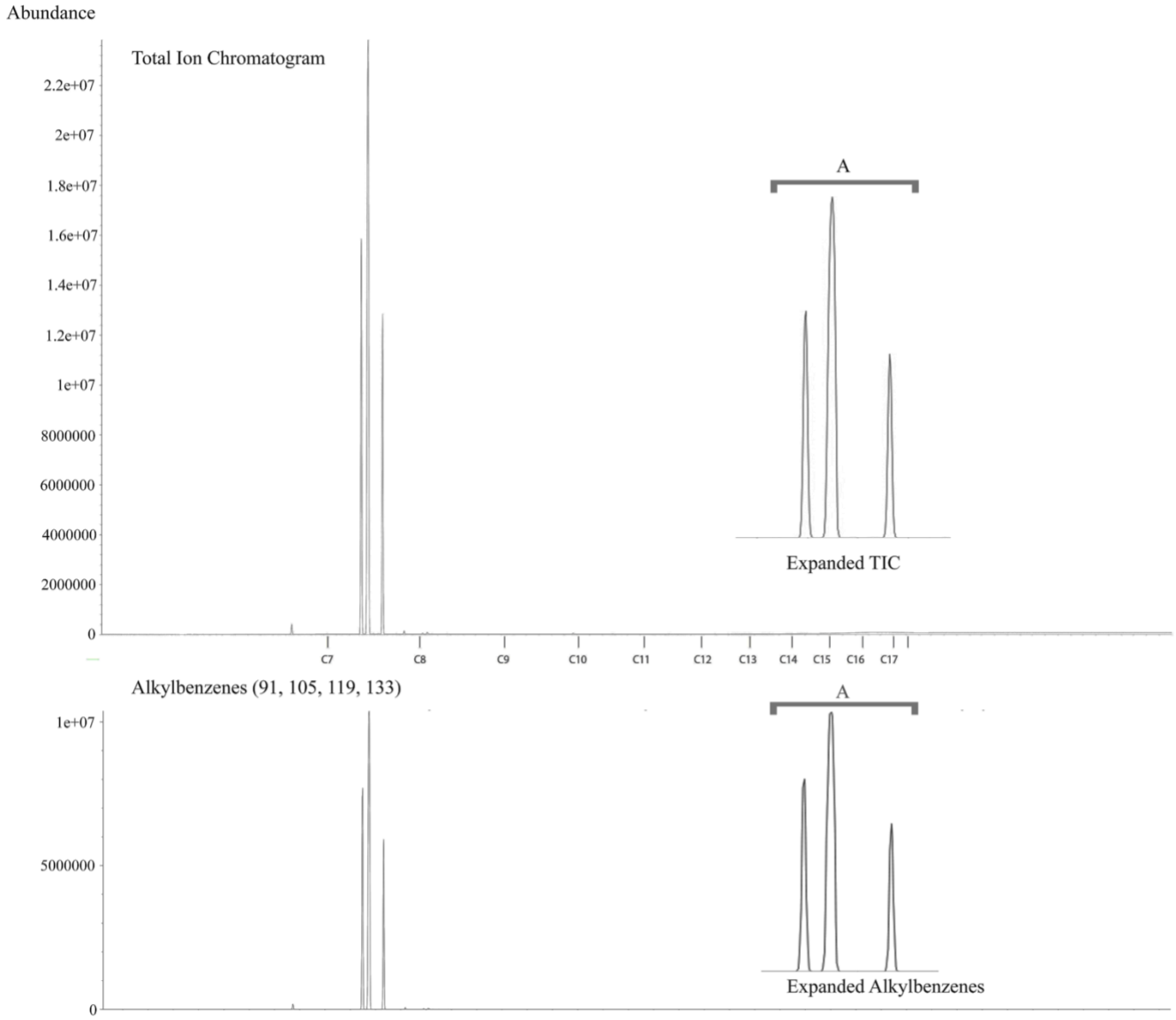
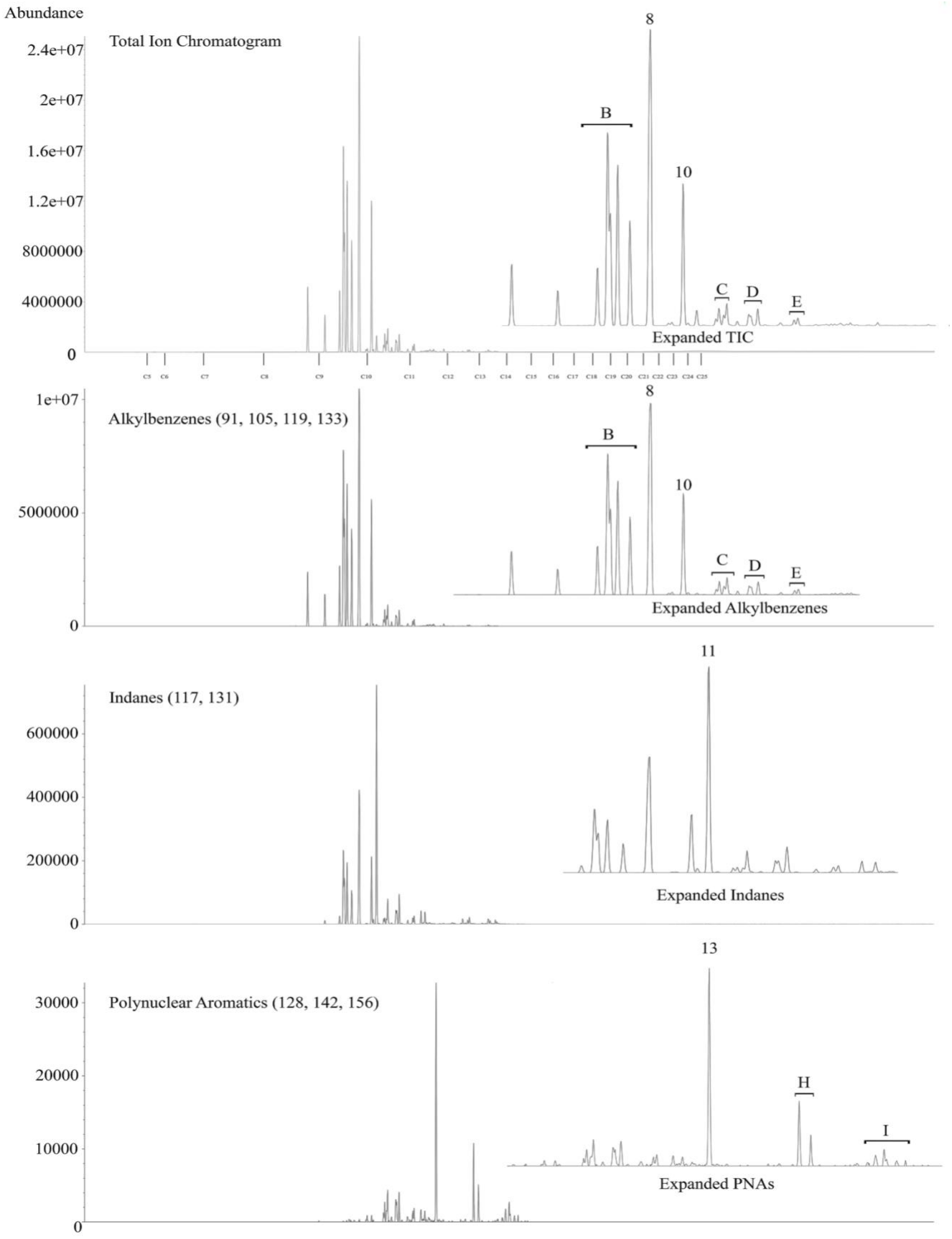
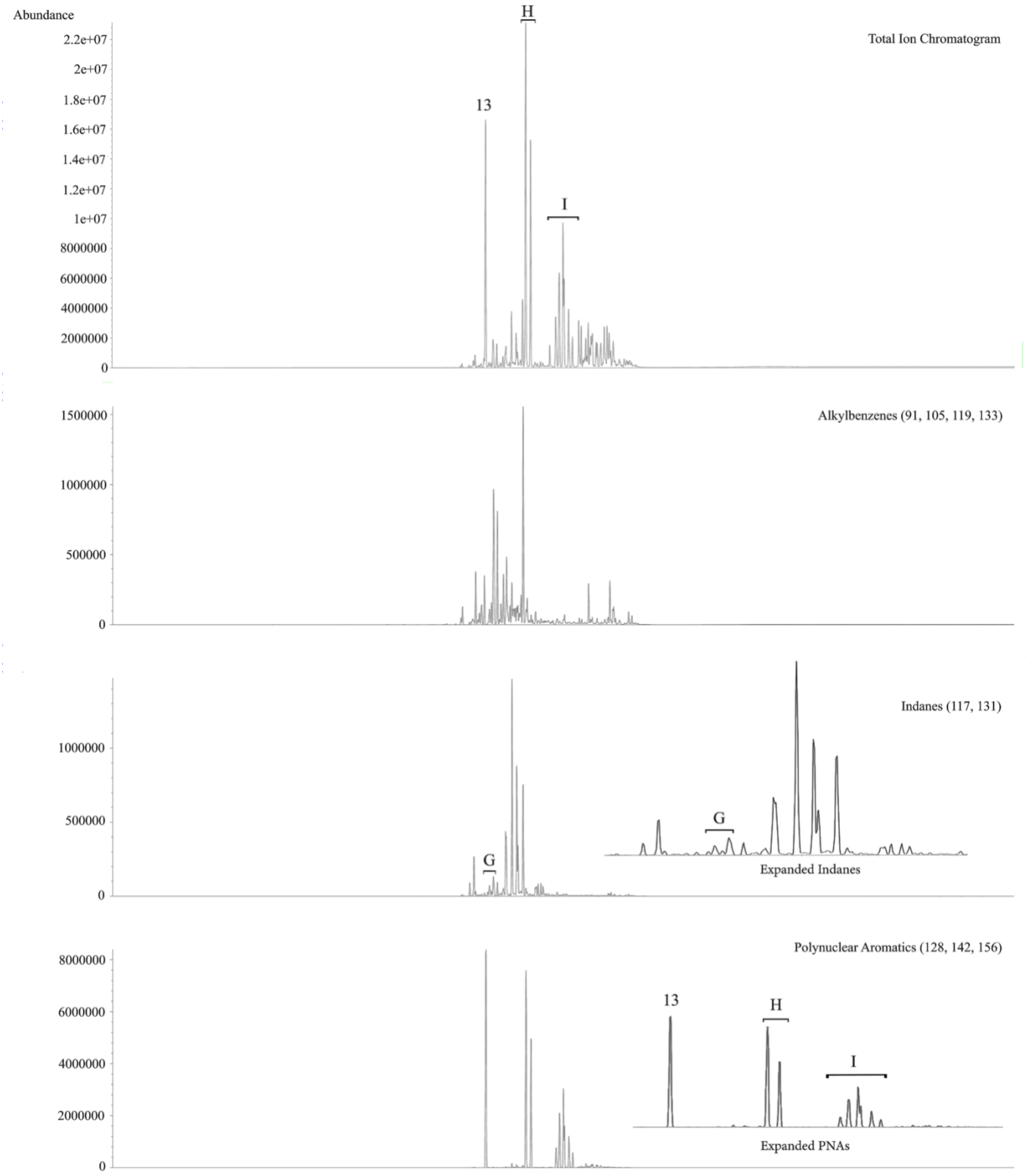

Abundance
Total Ion Chromatogram
2.2e+07
2e+07
1.8e+07
1.6e+07
1.4e+07
1.2e+07
1e+07
8000000
6000000
4000000
2000000
0
A
Expanded TIC
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
Alkylbenzenes (91, 105, 119, 133)
1e+07
5000000
0
A
Expanded Alkylbenzenes

Fig. X1.8 MAP


Abundance
Total Ion Chromatogram
2.4e+07
2e+07
1.6e+07
1.2e+07
8000000
4000000
0
8
B
10
C
D
E
Expanded TIC
C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23 C24 C25
1e+07
Alkylbenzenes (91, 105, 119, 133)
5000000
0
8
B
10
C
D
E
Expanded Alkylbenzenes
11
Indanes (117, 131)
600000
400000
200000
0
Expanded Indanes
13
Polynuclear Aromatics (128, 142, 156)
30000
20000
10000
0
H
I
Expanded PNAs

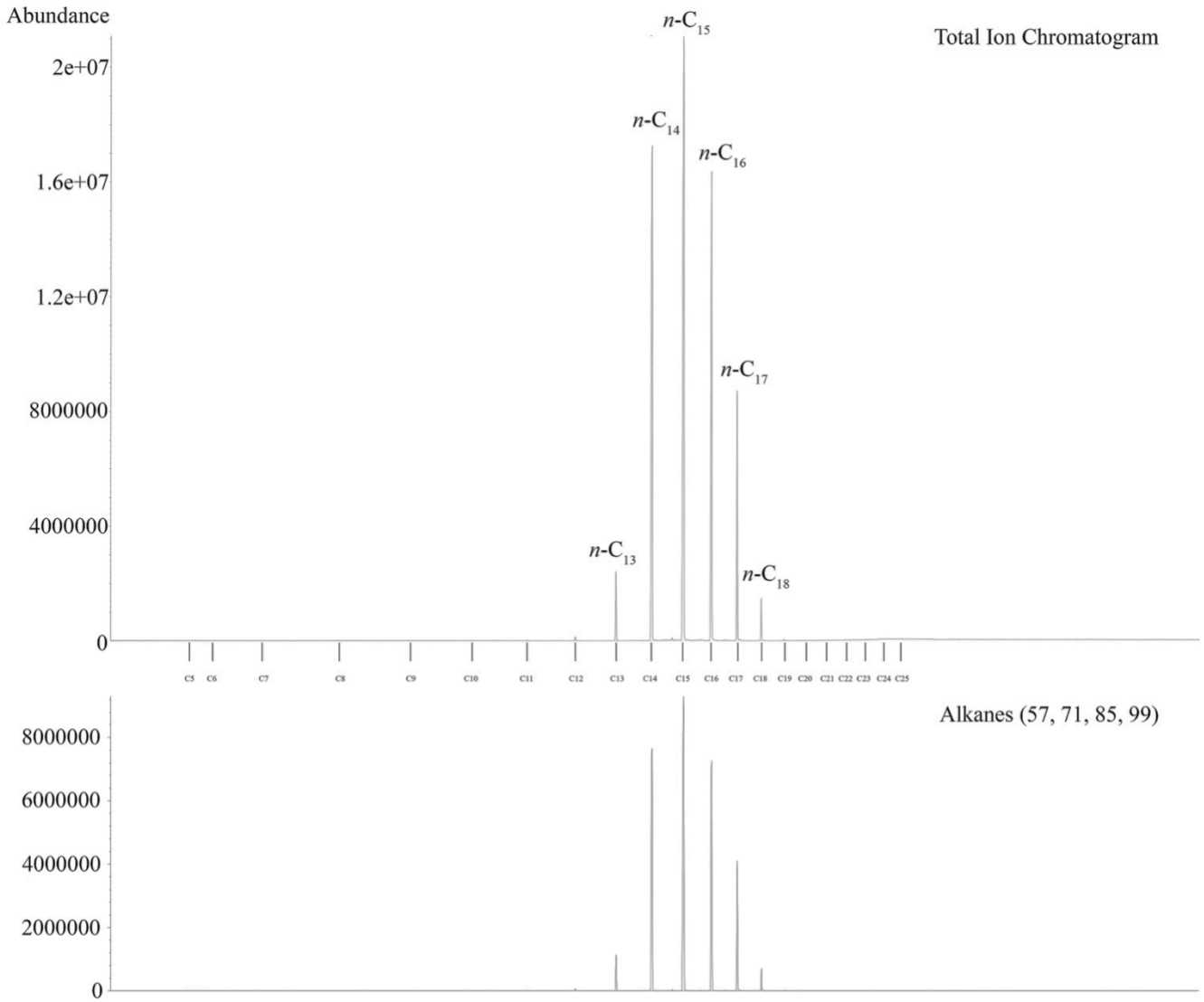
664

665 **Fig. X1.9 HAP**

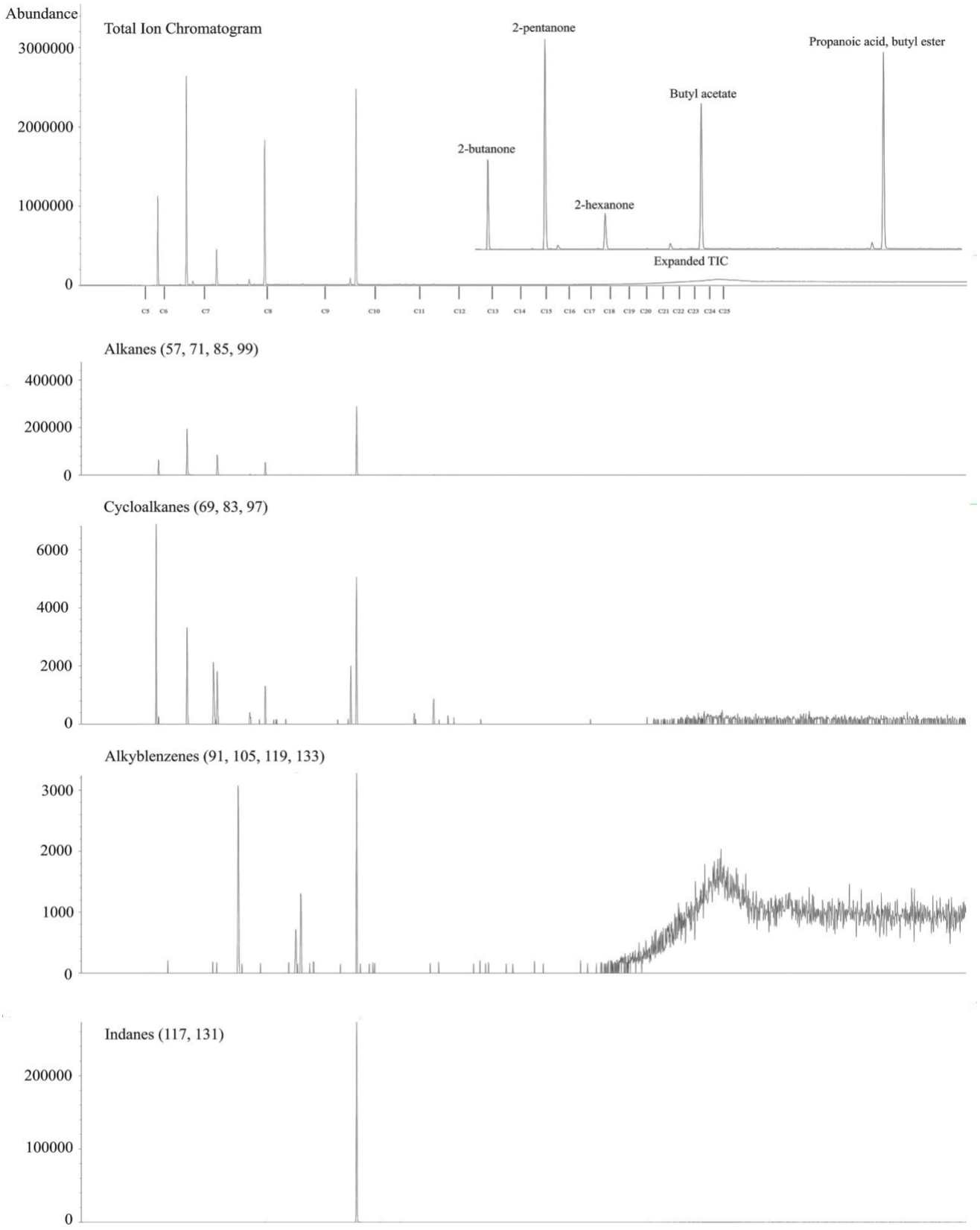


666

667 **Fig. X1.10 Normal Alkanes Product**


Abundance
Total Ion Chromatogram
2e+07
1.6e+07
1.2e+07
8000000
4000000
0
n-C13
n-C14
n-C15
n-C16
n-C17
n-C18
C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23 C24 C25
Alkanes (57, 71, 85, 99)
8000000
6000000
4000000
2000000
0

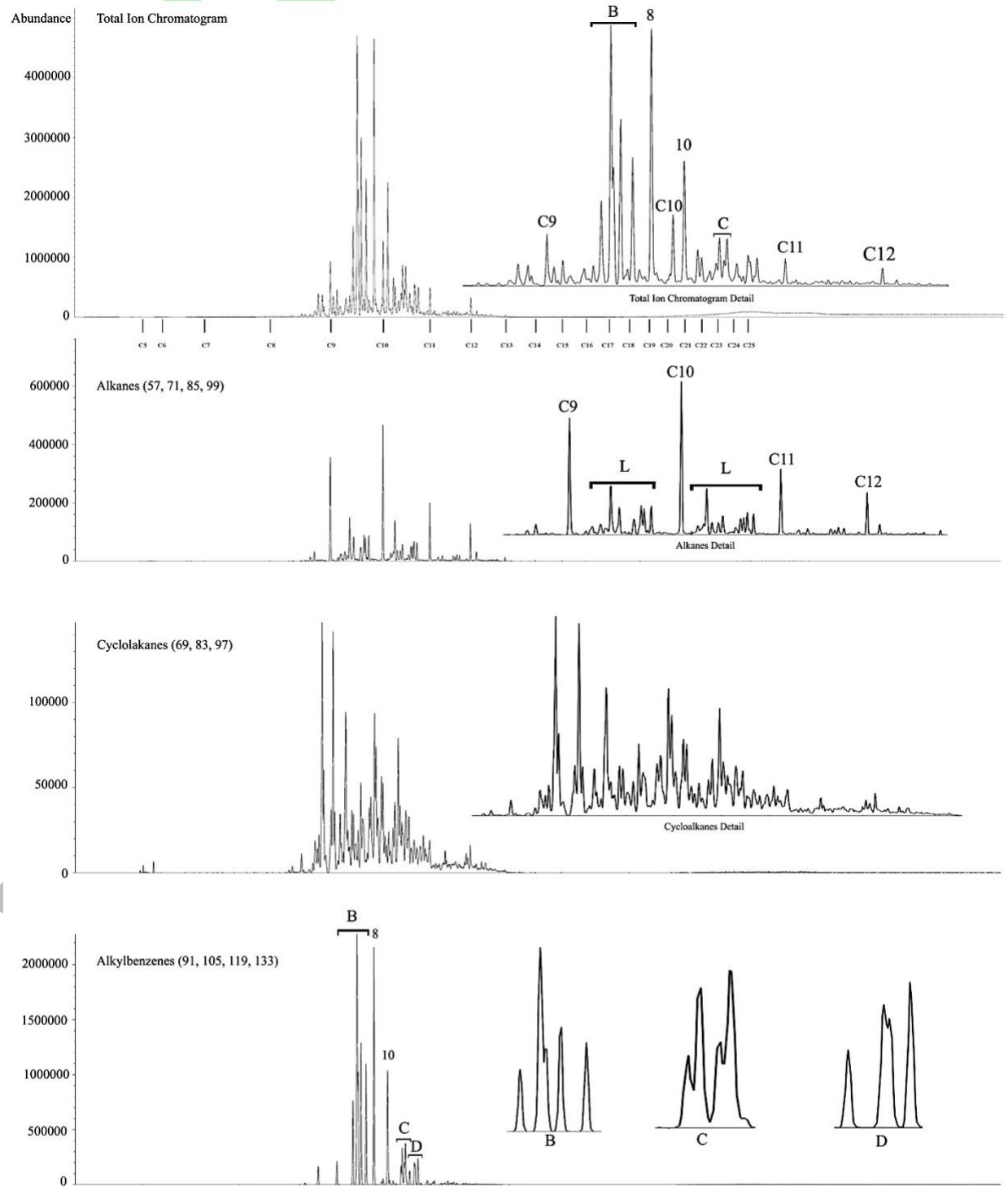
681 **Fig. X1.11 Oxygenated Product**



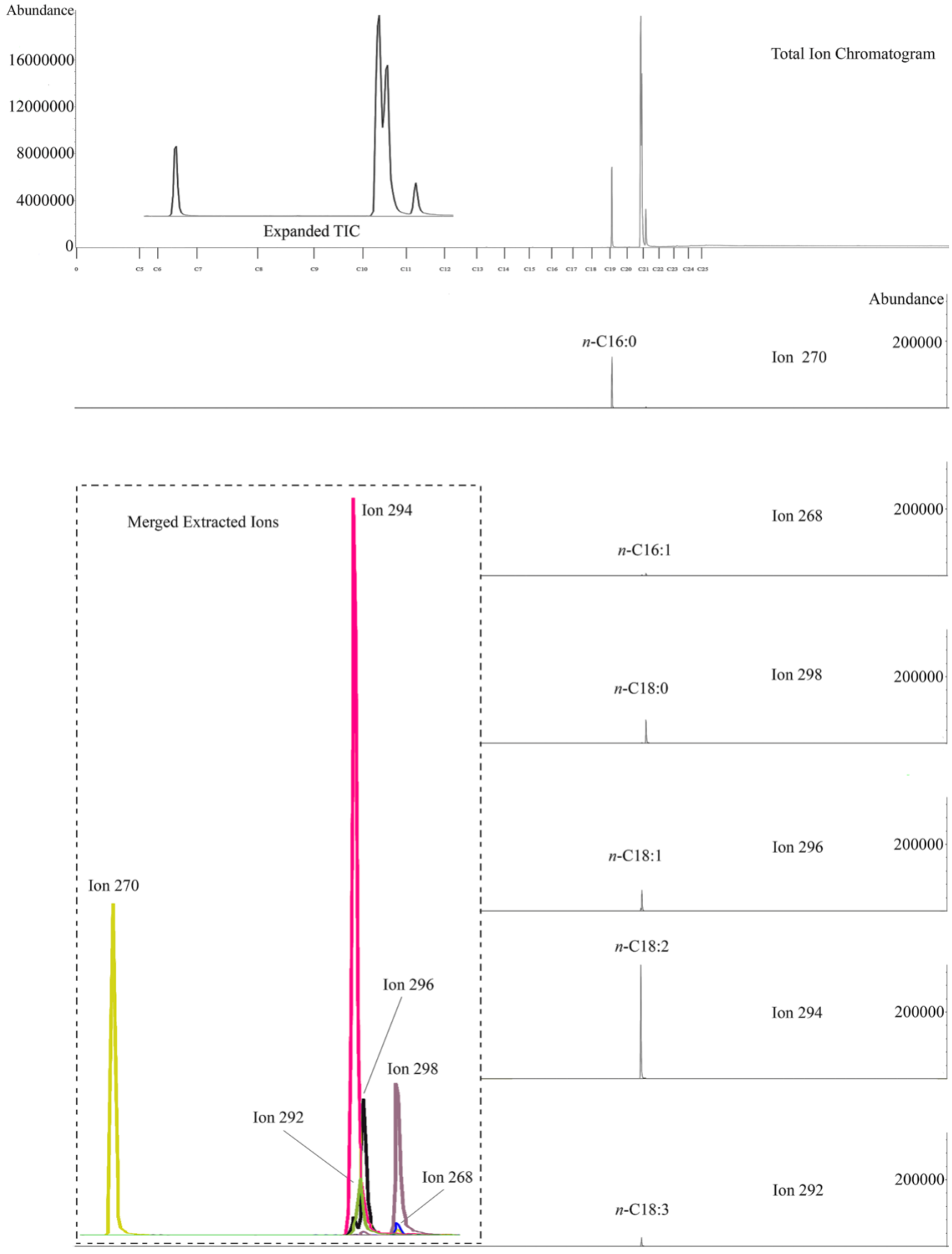
682

Fig. X1.12 Petroleum Product

This product shows elevated aromatics in an overlapping pattern with an MPD and is classified as a medium petroleum product.



687 **Fig. X1.13 Oil and Fat-based Product**



688

Fig. X1.14 Biodiesel

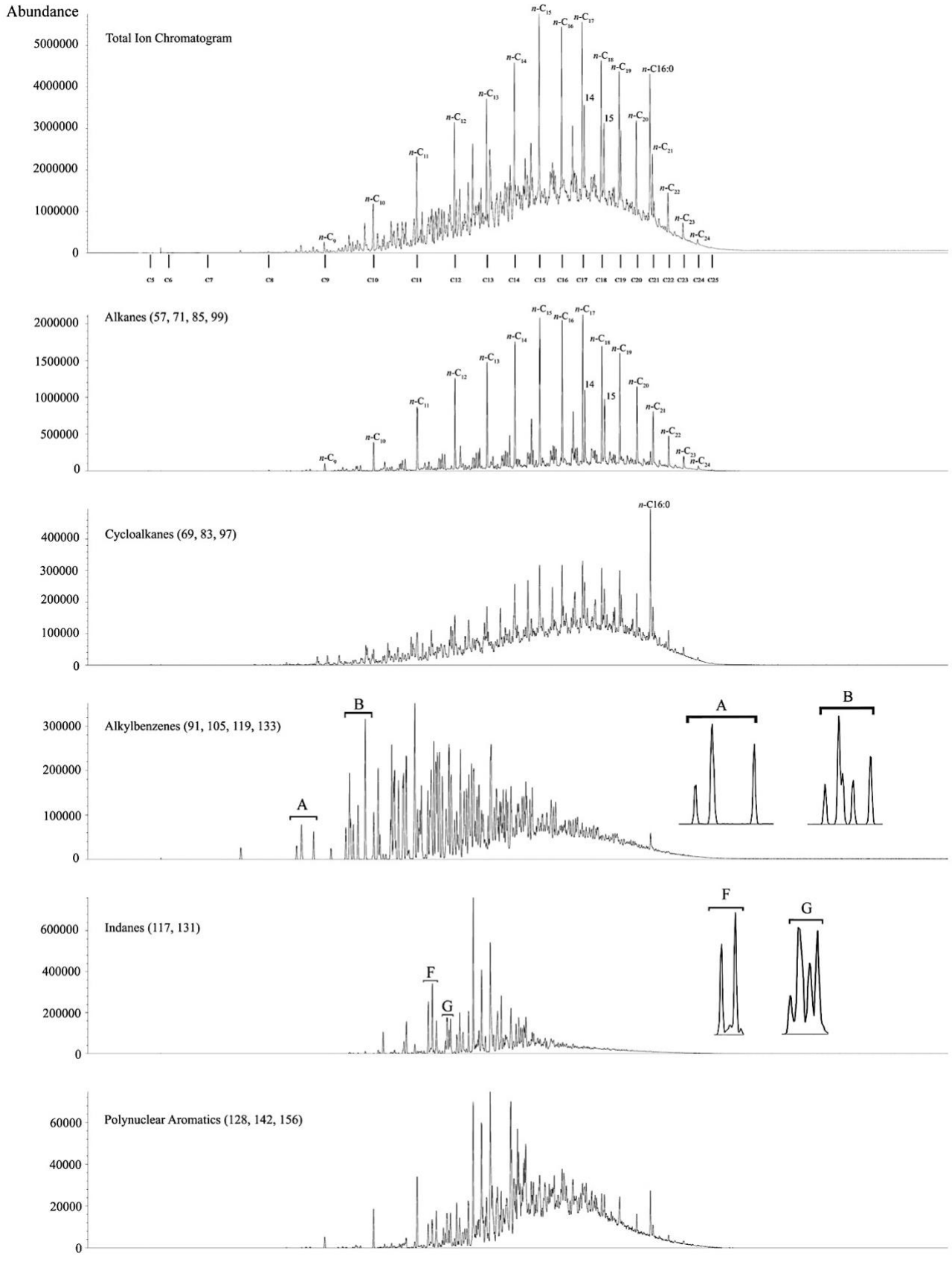
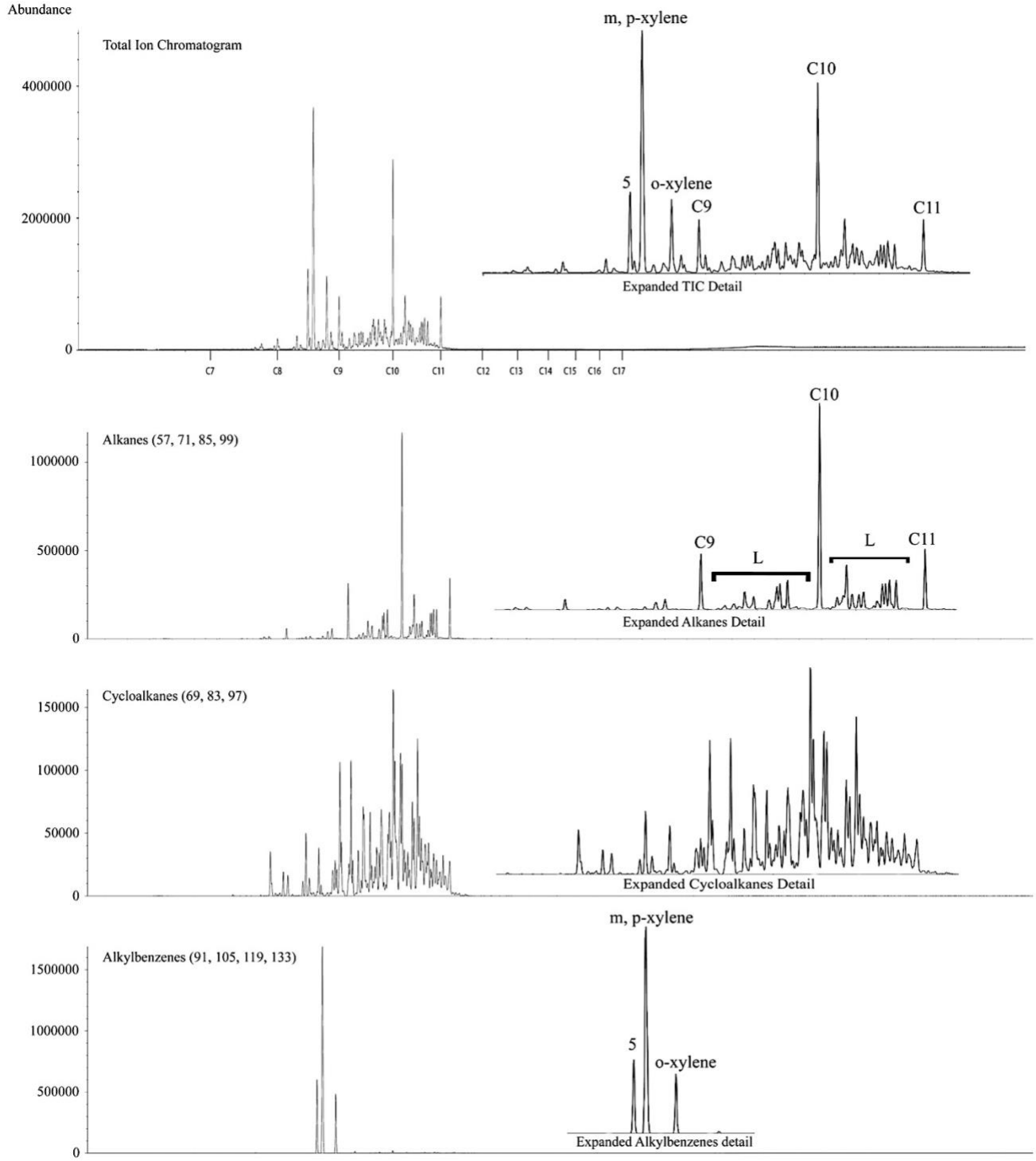


Fig. XI.15 Mixture of an MPD and Aromatic Product

This data shows an aromatic product whose pattern is separated from the majority of the chemicals in the MPD and is classified as a mixture of a light aromatic and a medium petroleum distillate.



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