

U.S. DEPARTMENT OF INTERIOR
U.S. GEOLOGICAL SURVEY

Composition of crude oil and natural gas produced from 10 wells in the
Lower Silurian "Clinton" sands, Trumbull County, Ohio

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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Introduction

In the northern Appalachian basin the "Clinton" sands, Medina Group sandstones, and equivalent Tuscarora Sandstone of Early Silurian age are the reservoirs for a regional accumulation of natural gas and oil. A continuous-type (basin-centered) part of this regional accumulation containing an estimated 30 trillion cubic feet (TCF) of recoverable gas covers an area of 17,000 sq. mi. in a band that stretches from western New York, through western Pennsylvania and eastern Ohio, to northernmost West Virginia (Ryder and others, 1996). The gas accumulation occurs in rocks of low permeability, 0.1 millidarcies (mD) or less, downdip of more permeable, water-saturated rocks. The rocks updip from the continuous gas accumulation contain accumulations of oil and gas that have characteristics of both continuous-type (unconventional) and discrete (conventional) accumulations (Ryder, 1998).

In the continuous-type part of the accumulation, individual wells ultimately produce on the order of 50 to 250 million cubic feet (MMCF) of natural gas. In addition to gas, many wells produce variable amounts of brine and crude oil. The gas-to-fluid ratio is variable but generally high, on the order of 50,000 to 500,000 standard cubic feet (SCF) of gas per barrel of oil or brine. The amount of oil and brine produced affects the economics of individual wells because of the cost incurred to dispose of brine or the value

added through the sale of oil. In general, the best gas producers are those wells that produce the least oil and brine.

To better understand the origin of the gas within the Clinton/Medina sands in the northern Appalachian basin, we are investigating the geochemistry of the gas and the co-produced oil. This report documents ten oil samples and three gas samples from ten wells producing from "Clinton" sands in Trumbull County, Ohio. Future work will focus on samples from both shallower and greater burial depths, allowing study of the range in geochemical properties of the produced hydrocarbons as a function of depth and thermal history of the reservoir rocks.

Previous workers have published analyses of crude oils and natural gases from Silurian age reservoirs in the northern Appalachian basin (Barker and Pollock, 1984; Cole, Drozd, and others, 1987; Drozd and Cole, 1994; Jenden, Drozan, and Kaplan, 1993; Laughrey and Baldassare, 1998; Powell and others, 1984). Cole, Drozd, and others (1987) suggest that most of the oil in Silurian age reservoirs in Ohio was generated from marine black shale of Devonian age. Most oil in the Lower Silurian "Clinton" sands may have been generated from Middle Ordovician black shale (Drozd and Cole, 1994; Ryder, Burruss and Hatch, 1998). Molecular and isotopic data on natural gas from Silurian reservoirs in western and central Pennsylvania (Laughrey and Baldassare, 1998) are not as diagnostic of the source sediments for that gas as geochemical parameters measured in oil samples. The general conclusion of the work on

gases is that they are derived from thermally mature, marine organic matter, probably in strata older than Silurian.

Sample locations

The wells sampled are all within 10 miles of the southern end of Mosquito Creek Lake, Trumbull County, Ohio as shown on **Figure 1A**. With the exception of two wells sampled for oil in Weathersfield Township, the locations of all samples are within 5 miles of stratigraphic correlation cross section D-D' through the "Clinton" sands interval (Keighin, 1998). The position of the cross section is shown in **Figure 1B**. Selected information on the wells sampled is listed in **Table 1**. Three of the wells in this study were included in a separate report on the potential impact of oil and gas development on water quality in Trumbull County (Barton, Burruss, and Ryder, 1998).

Sampling and Analytical Methods

All oil and gas samples were obtained with the assistance of operating company field personnel from the wellhead or the oil and gas separator of individual wells. Gas was sampled at the pressure gauge port on the production tubing using evacuated stainless steel cylinders supplied by Isotech Laboratories, Inc. Oil was sampled, where possible, at the drain for the fluid level sightglass on the oil and gas separator. The oil is initially saturated with gas at the separator pressure and foams from exsolution of the gas as it

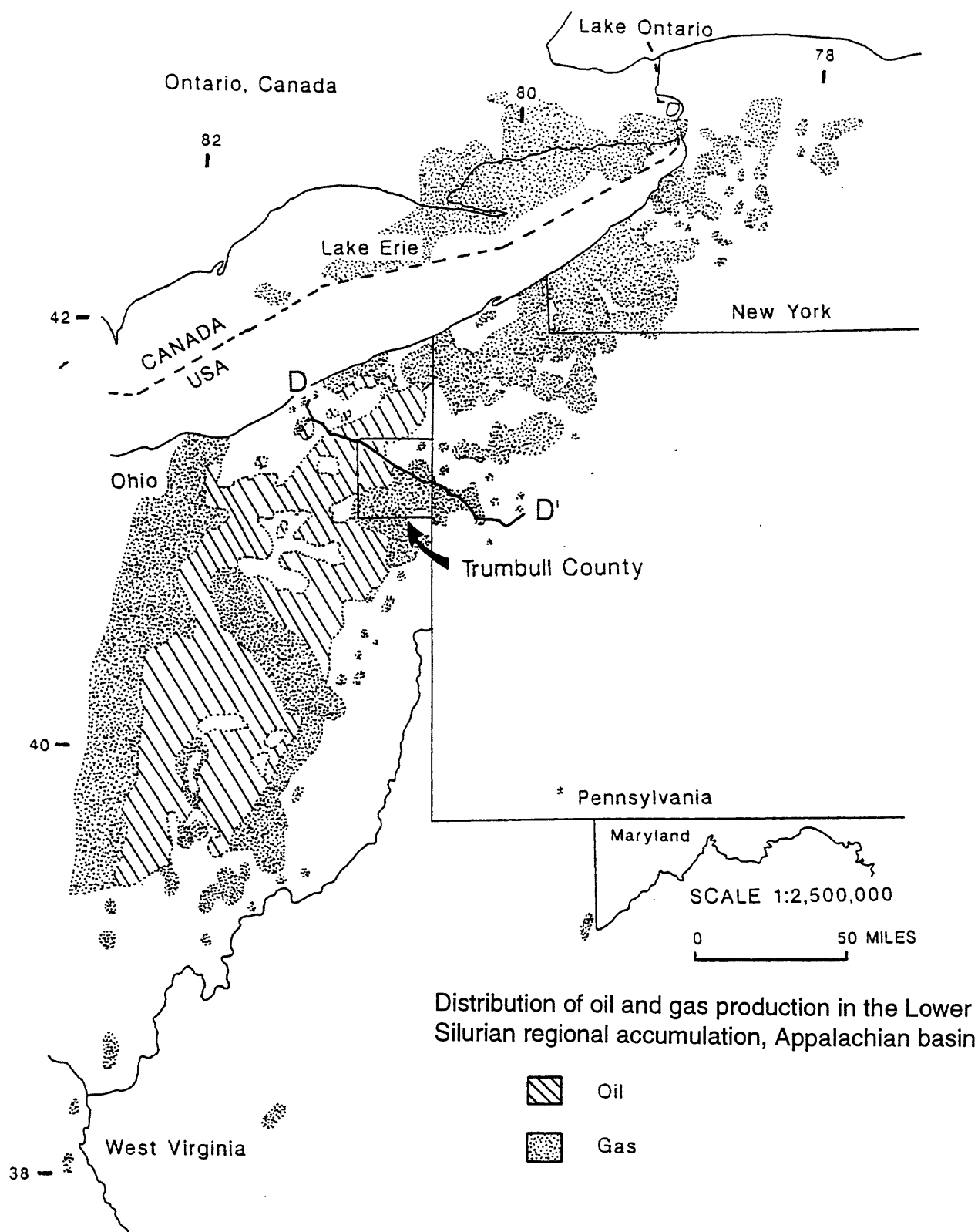


Figure 1A: Map of the regional, continuous-type accumulation of gas and oil in the Lower Silurian "Clinton" sands, showing the location of Trumbull County, Ohio, and the regional cross-section D-D'

Trumbull County, Ohio

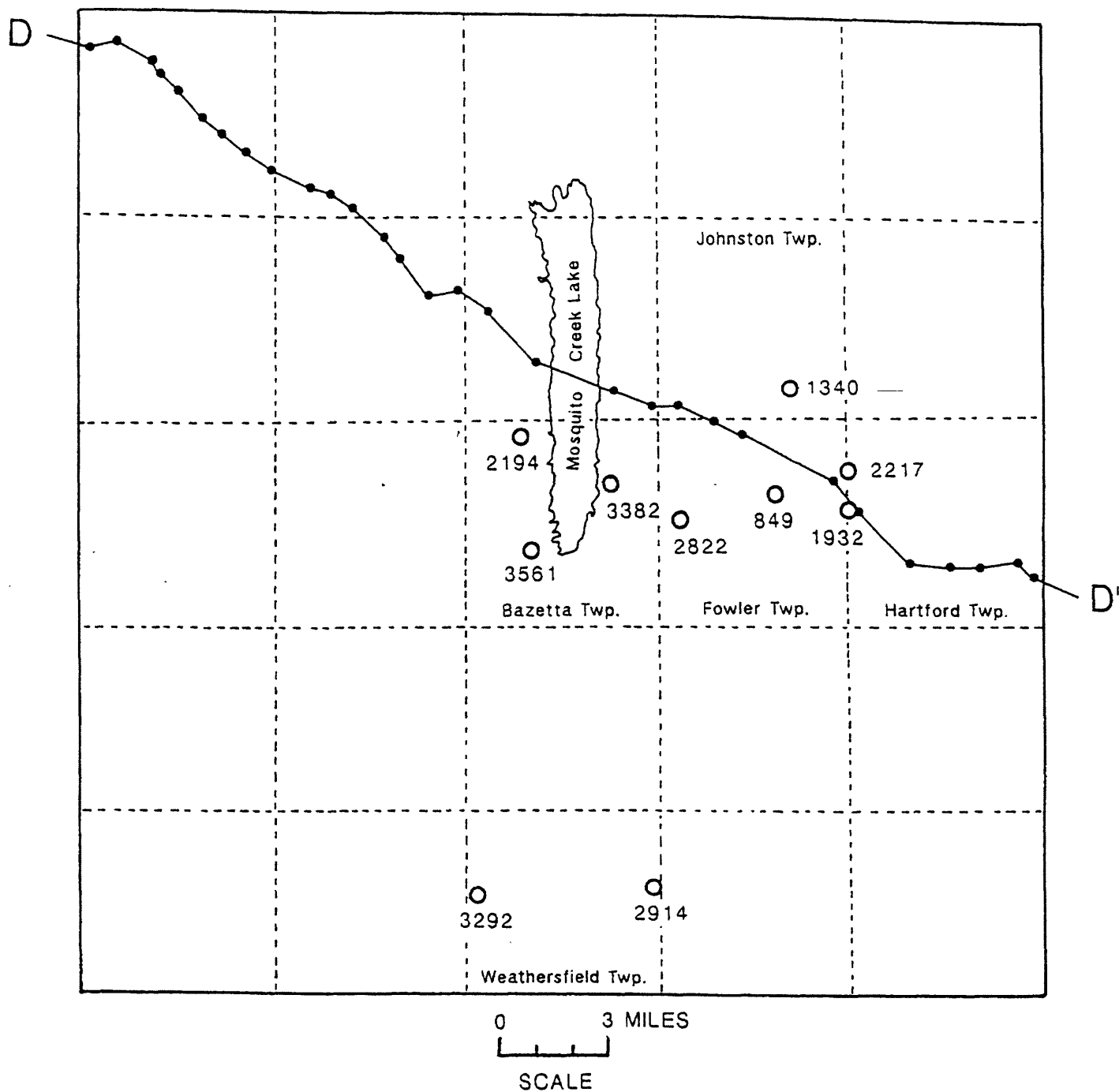


Figure 1B: Map of the well locations in Trumbull County, Ohio. Wells are identified by the last four digits of the API number given in Table 1.

Sample ID	Well name	Operator	API number	Ohio Township	Producing Formation	Perforation Top	Depth, ft. Bottom	Total Depth, ft.	Sample	Oil Sample Point
97MCR3	#1 Governor	Loma Ent.	3415523382	Bazetta	"Clinton" sands	4372	4432	4602	gas, oil	sightglass
97MCR4	#1 Wargo	Loma Ent.	3415522914	Weathersfield	"Clinton" sands	4746	4786	5006	oil	flowline
97MCR5	#1 Baker	Loma Ent.	3415523292	Weathersfield	"Clinton" sands	4612	4686	4825	oil	sightglass
97MCR6	#2 Clemens	Lomak Pet.	3415522194	Bazetta	"Clinton" sands	4252	4318	4472	gas, oil	sightglass
97MCR7	#2 Krantz	Lomak Pet.	3415523561	Bazetta	"Clinton" sands	4356	4397	4600	gas, oil	sightglass
97MCR8	#1 Rhine	Lomak Pet.	3415522822	Fowler	"Clinton" sands	4560	4620	4821	oil	sightglass
97MCR9	#1 Gowdy	Lomak Pet.	3415520849	Fowler	"Clinton" sands	4627	4677	4854	oil	sightglass
97MCR10	#2 Redmond	Lomak Pet.	3415521340	Johnston	"Clinton" sands	4450	4496	4685	oil	sightglass
97MCR11	#7 Consumer	Lomak Pet.	3415522217	Hartford	"Clinton" sands	4545	4599	4767	oil	stocktank
97MCR12	#3 Consumer	Lomak Pet.	3415521932	Hartford	"Clinton" sands	4600	4628	4798	oil	sightglass

Table 1: Wells sampled for gas and oil in Trumbull County, Ohio

exits the sightglass drain. As noted in **Table 1**, two samples could not be obtained this way and the oil was sampled either from the flowline to the stock tank or from the drain valve at the bottom of the stock tank. The latter sample was relatively heavy oil with some brine.

All samples were analyzed by standard analytical methods. Natural gas samples were analyzed at Isotech Laboratories, Inc., Champaign, IL, for molecular composition by gas chromatography and for stable isotopic composition by ratio mass spectrometry. Carbon isotopic composition was determined for methane (C1), ethane (C2), and propane (C3), and hydrogen isotopic composition was determined for methane. Carbon isotope ratios are reported in standard per mil deviation relative to the Pee Dee belemnite standard (PDB), and hydrogen isotope ratios are reported relative to standard mean ocean water (SMOW) for both gases and oils.

Crude oils were analyzed by the U.S. Geological Survey, Denver, CO. API gravity of the oils was determined gravimetrically. Oils were fractionated by dilution in n-heptane to remove asphaltenes. A concentrate of the solution was further fractionated by column chromatography on silica gel by successive elution with heptane, benzene, and benzene-methanol (1:1 v/v) to collect the saturated hydrocarbon, aromatic hydrocarbon, and resin (NSO compounds) fractions, respectively. The carbon stable isotope composition of an aliquot of the saturated and aromatic hydrocarbon fractions was determined on a Micromass Optima isotope ratio mass spectrometry system.

Gas chromatography of the whole oil, and the saturated hydrocarbon, and the aromatic hydrocarbon fractions was performed with a Hewlett/Packard Model 6890 (HP6890) gas chromatograph with a 60 m x 0.32 mm DB-1 fused silica capillary column and a FID detector. The chromatograph was programmed from 50 to 330°C at 4.5 °C/min and held isothermal at 330°C for 15 min with helium carrier gas flow at 35 cm/sec. Gas chromatography-mass spectrometry (GCMS) of the saturated hydrocarbon fraction of one oil was performed with a HP6890-JEOL GCMate system in selective ion monitoring mode.

Results

Natural Gases

The molecular and isotopic composition of natural gas from three wells is presented in **Table 2**. All three gases are rich in methane, about 90 mole %, with low concentrations of hydrocarbons that have more than three carbon atoms. All samples contain a trace of helium and 2.5 to 2.8 mole % nitrogen. These gas compositions are consistent with those reported for the "Clinton" sands in Ohio by the U.S. Bureau of Mines (Moore, 1982).

The carbon isotopic composition of methane, ethane, and propane in all samples is within 1 per mil for all three components. The variation in the hydrogen isotopic composition of methane is only slightly larger at about 3 per mil. In all three samples, the content of carbon dioxide was so low, 0.01

Sample ID:	97RCB7	97RCB3	97RCB6
Well Name:	#2 Krantz	#1 Governor	#2 Clemens
Molecular Analysis, mole %			
Methane	89.34	90.33	90.64
Ethane	5.11	4.64	4.48
Ethylene	nd	nd	nd
Propane	1.65	1.47	1.32
iso-Butane	0.22	0.2	0.18
n-Butane	0.4	0.38	0.31
iso-Pentane	0.11	0.11	0.085
n-Pentane	0.11	0.13	0.096
Hexanes+	0.12	0.14	0.12
Helium	0.091	0.089	0.099
Hydrogen	0.0013	0.0024	nd
Argon	nd	nd	nd
Oxygen	nd	nd	nd
Nitrogen	2.84	2.5	2.67
Carbon Dioxide	0.01	0.01	nd
Isotopic Analysis, per mil			
Methane, $\delta^{13}\text{C}$	-37.49	-37.20	-37.40
δD	-168.5	-166.6	-165.7
Ethane, $\delta^{13}\text{C}$	-35.29	-34.88	-34.67
Propane, $\delta^{13}\text{C}$	-30.94	-30.58	-30.40
Carbon dioxide, $\delta^{13}\text{C}$	na	na	na

Table 2: Molecular and isotopic composition of gas samples.
nd: not detected; na: not analyzed

percent or less, that the isotopic composition of the carbon in the carbon dioxide could not be determined (indicated by, na, in Table 2).

Crude Oils

Bulk parameters and selected molecular parameters of the crude oils are listed in Table 3. The API gravity of 9 of the 10 samples is 40° or greater. The exception, 37° API for the #7 Consumer well, was measured on a sample obtained from the stocktank instead of the separator. The oils are uniformly high (86 to 90 wt. %) in saturated hydrocarbons with 9% or less of aromatic hydrocarbons. Carbon isotopic compositions of the saturated and aromatic hydrocarbon fractions show small ranges of 0.6 per mil and 0.7 per mil, respectively.

Gas chromatograms of the whole oil, saturated hydrocarbon and aromatic hydrocarbon fractions for samples from the 10 wells are shown in Figure 2A, 2B, 2C respectively through Figure 11A, 11B, 11C. The saturated hydrocarbon gas chromatograms have similar characteristics to "Clinton" oils reported by Cole and others (1987). Molecular parameters derived from the gas chromatograms of the saturated hydrocarbon fractions are listed in Table 4. In general, all the gas chromatographic data show that these oil samples are remarkably uniform in composition. The whole oil chromatograms for samples from the #1 Wargo, #1 Rhine, #1Gowdy, and #7 Consumer show depletion in the low carbon number range ($< n-C_{10}$) suggesting evaporative loss of the light ends. The pristane/phytane (pr/ph) ratios listed in Table 4 range from 1.07 to 1.63. The lowest value appears to be an artifact from the

Sample ID	Well name	API	Petroleum Fractions, wt. %				Isotopic Composition, per mil	
		Gravity	Sat HC	Aro HC	NSOs	Asph	Sat HC, $\delta^{13}\text{C}$	Aro HC, $\delta^{13}\text{C}$
97MCR3	#1 Governor	40.9	86.7	8.6	3.2	1.6	-29.80	-28.96
97MCR4	#1 Wargo	40.5	89.2	7.2	2.4	1.3	-29.73	-28.68
97MCR5	#1 Baker	43.9	90.5	6.3	2.2	1.0	-29.76	-28.90
97MCR6	#2 Clemens	43.5	87.3	8.5	3.4	0.8	-29.61	-29.08
97MCR7	#2 Krantz	42.2	89.3	7.6	1.8	1.3	-29.66	-28.86
97MCR8	#1 Rhine	43.1	85.7	9.2	3.8	1.3	-29.50	-28.92
97MCR9	#1 Gowdy	39.7	88.9	7.7	2.7	0.7	-29.71	-29.19
97MCR10	#2 Redmond	44.3	88.8	7.8	2.5	0.9	-30.05	-29.23
97MCR11	#7 Consumer	37.3	90.0	6.8	2.3	0.9	-29.76	-28.55
97MCR12	#3 Consumer	42.6	89.4	7.0	2.4	1.1	-29.59	-28.87

Table 3: Properties of the whole crude oil and crude oil fractions. Sat HC: saturated hydrocarbons; Aro HC: aromatic hydrocarbons; NSOs: Nitrogen, sulfur, oxygen-bearing organics; asph: asphaltenes.

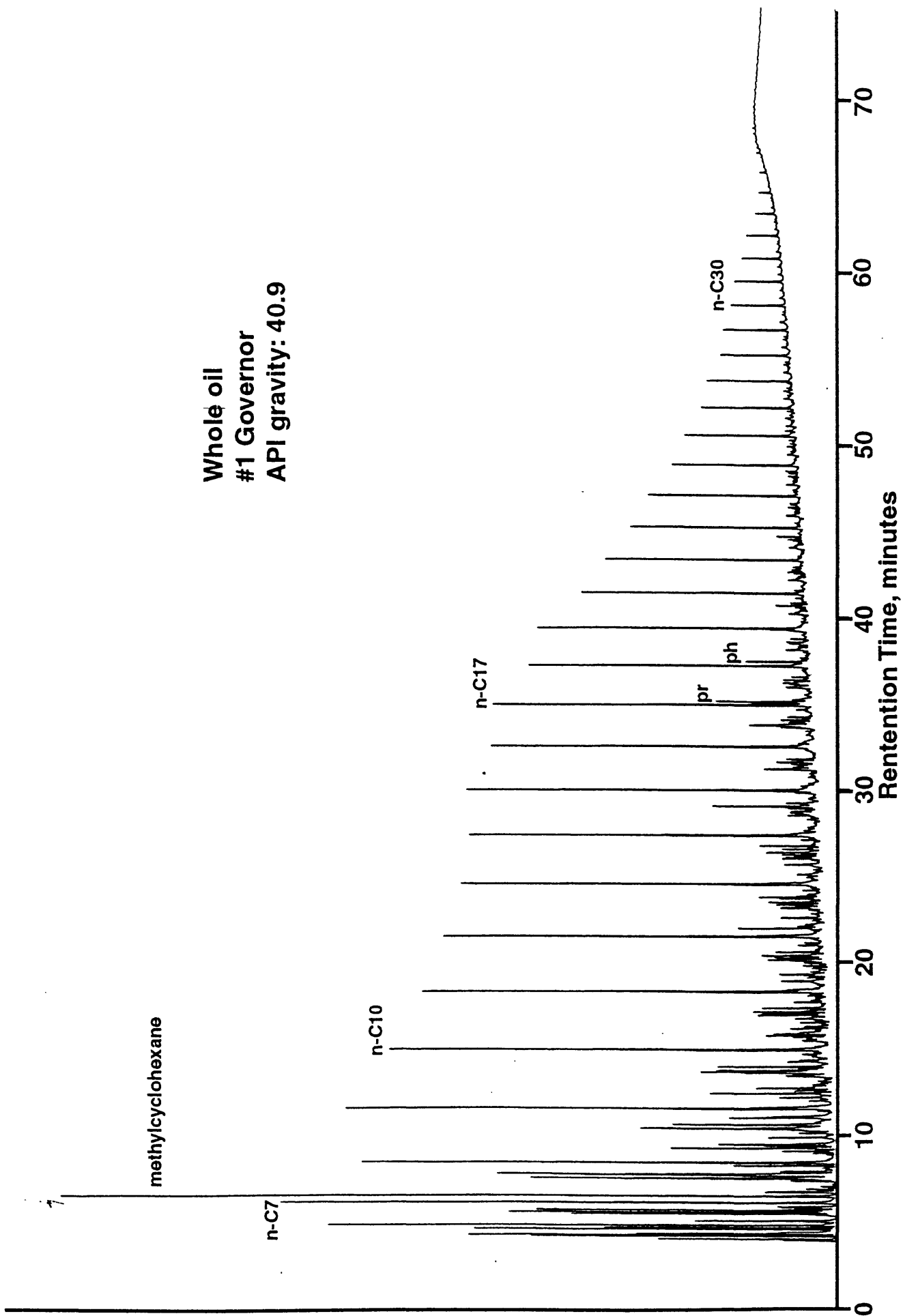


Figure 2A: Whole oil gas chromatogram, sample 97MCR3, #1 Governor. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#1 Governor
API gravity: 40.9

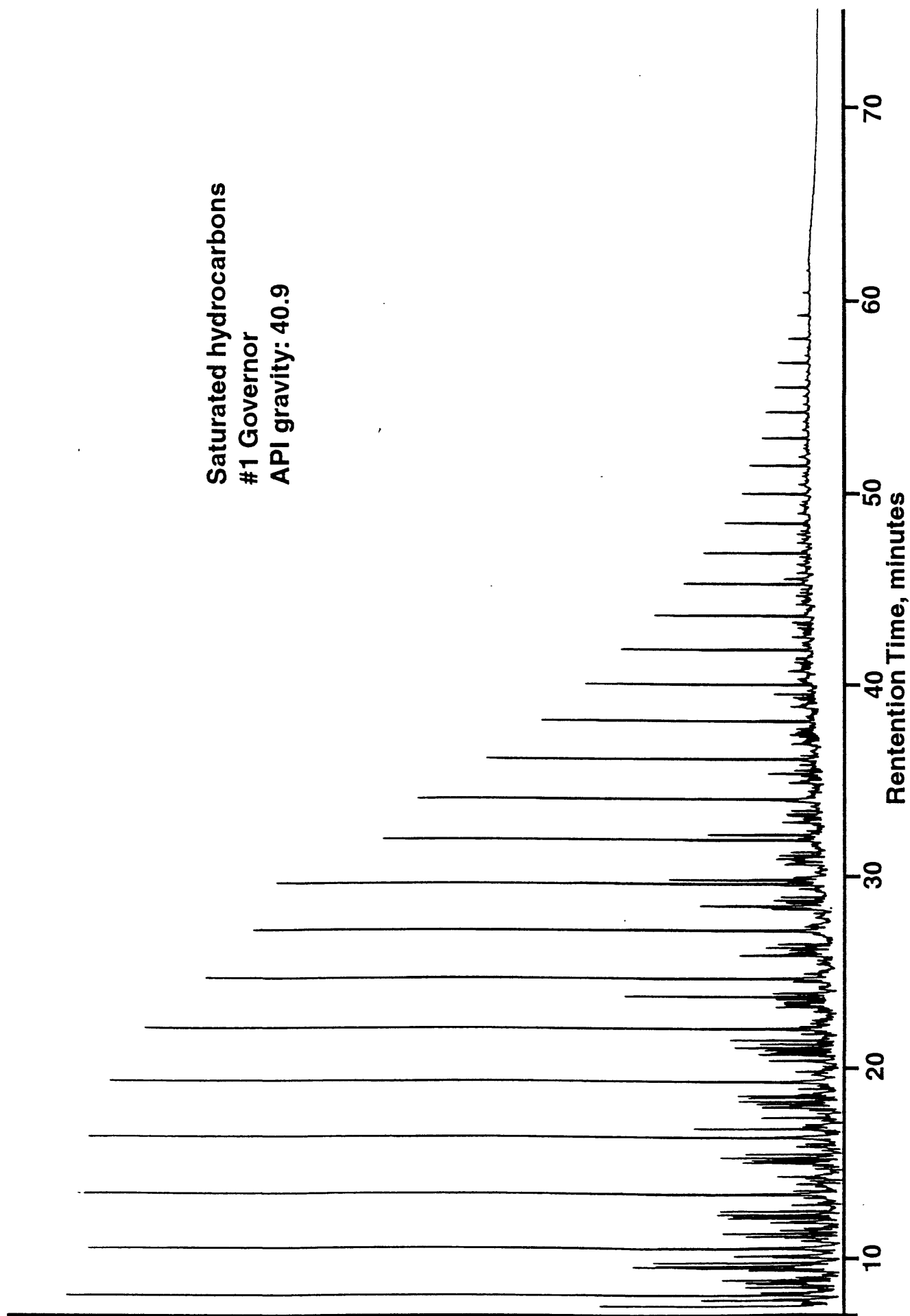


Figure 2B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR3, #1 Governor.

Aromatic hydrocarbons
#1 Governor
API gravity: 40.9

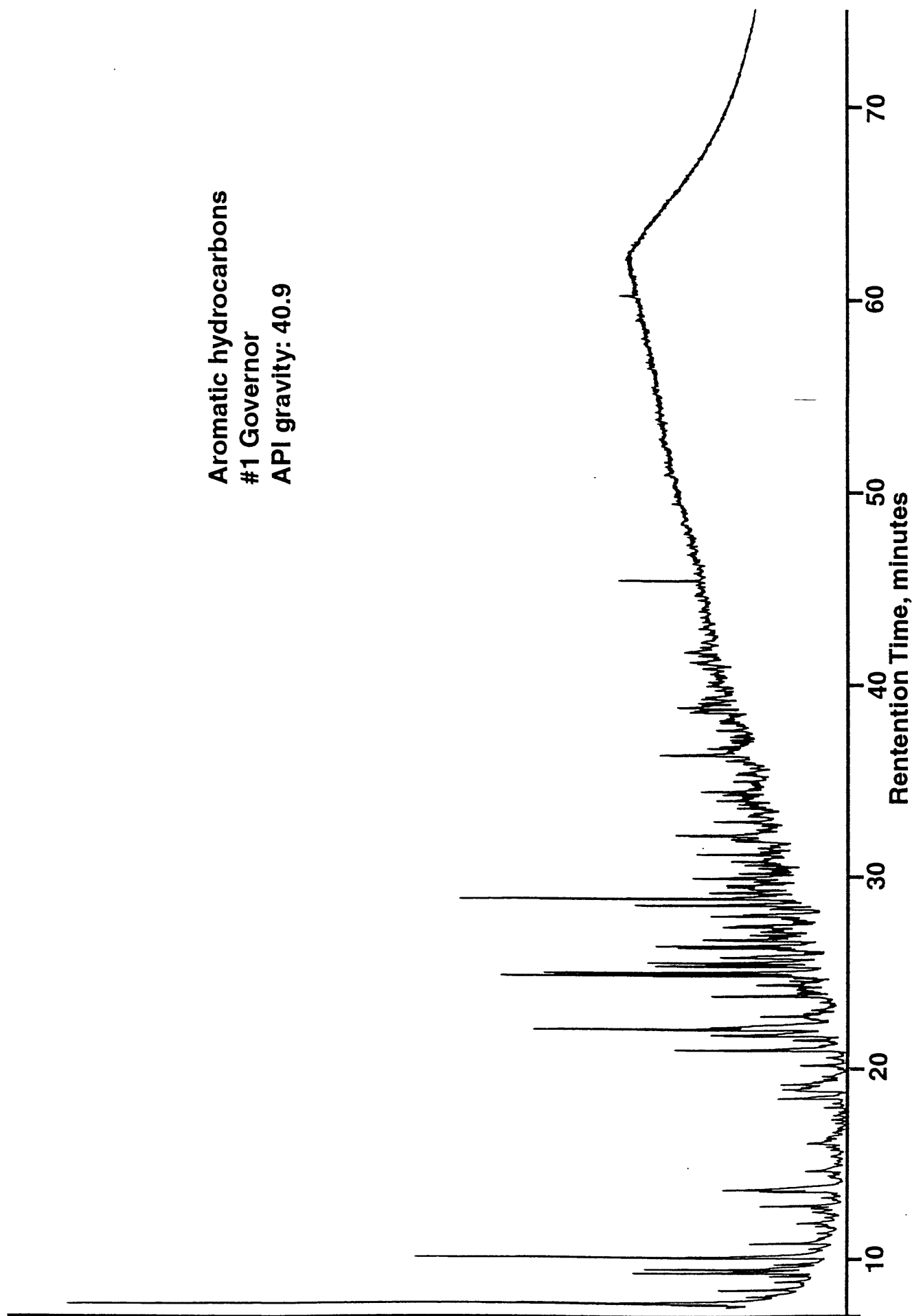


Figure 2C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR3, #1 Governor.

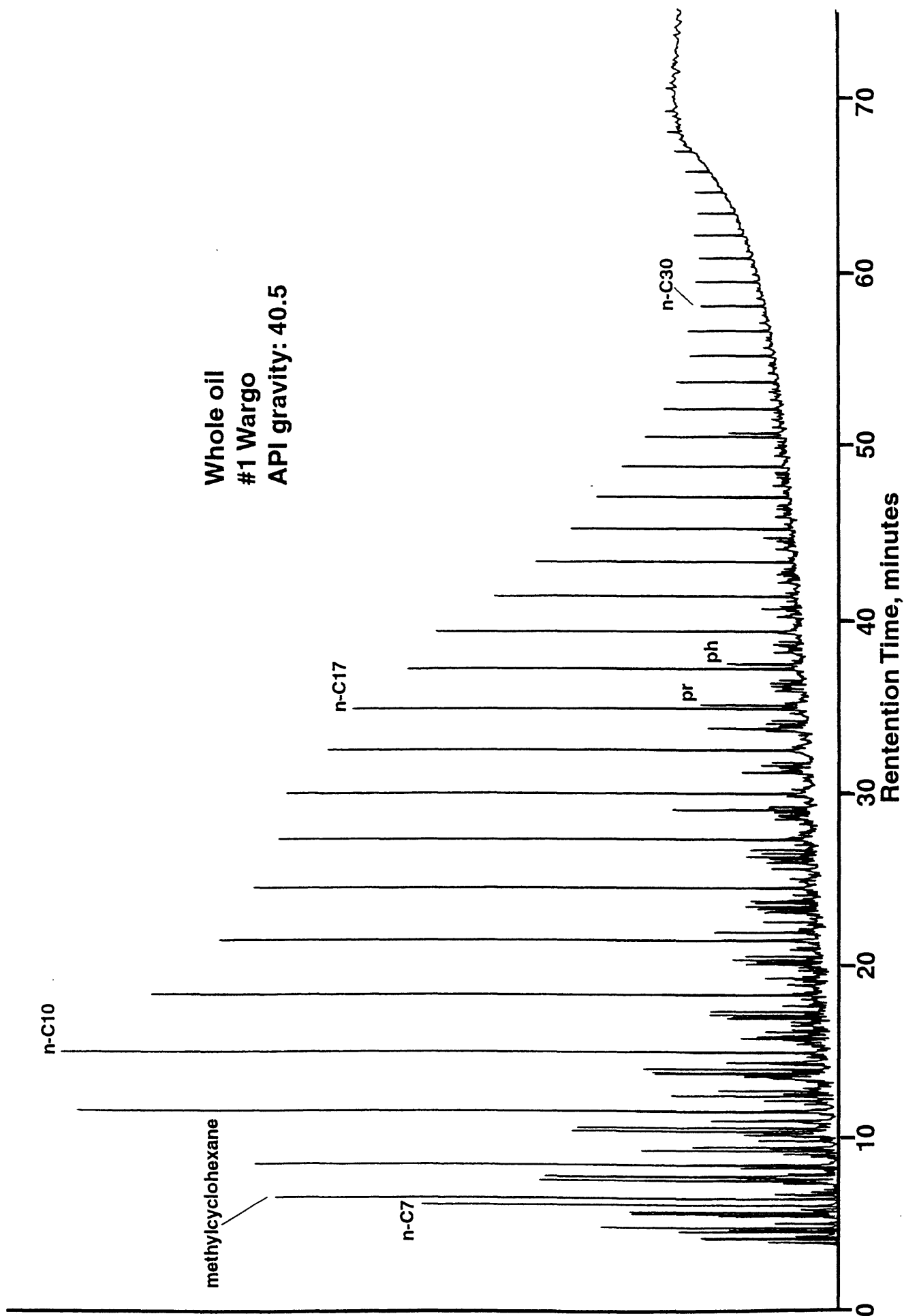


Figure 3A: Whole oil gas chromatogram, sample 97MCR4, #1 Wargo. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#1 Wargo
API gravity: 40.5

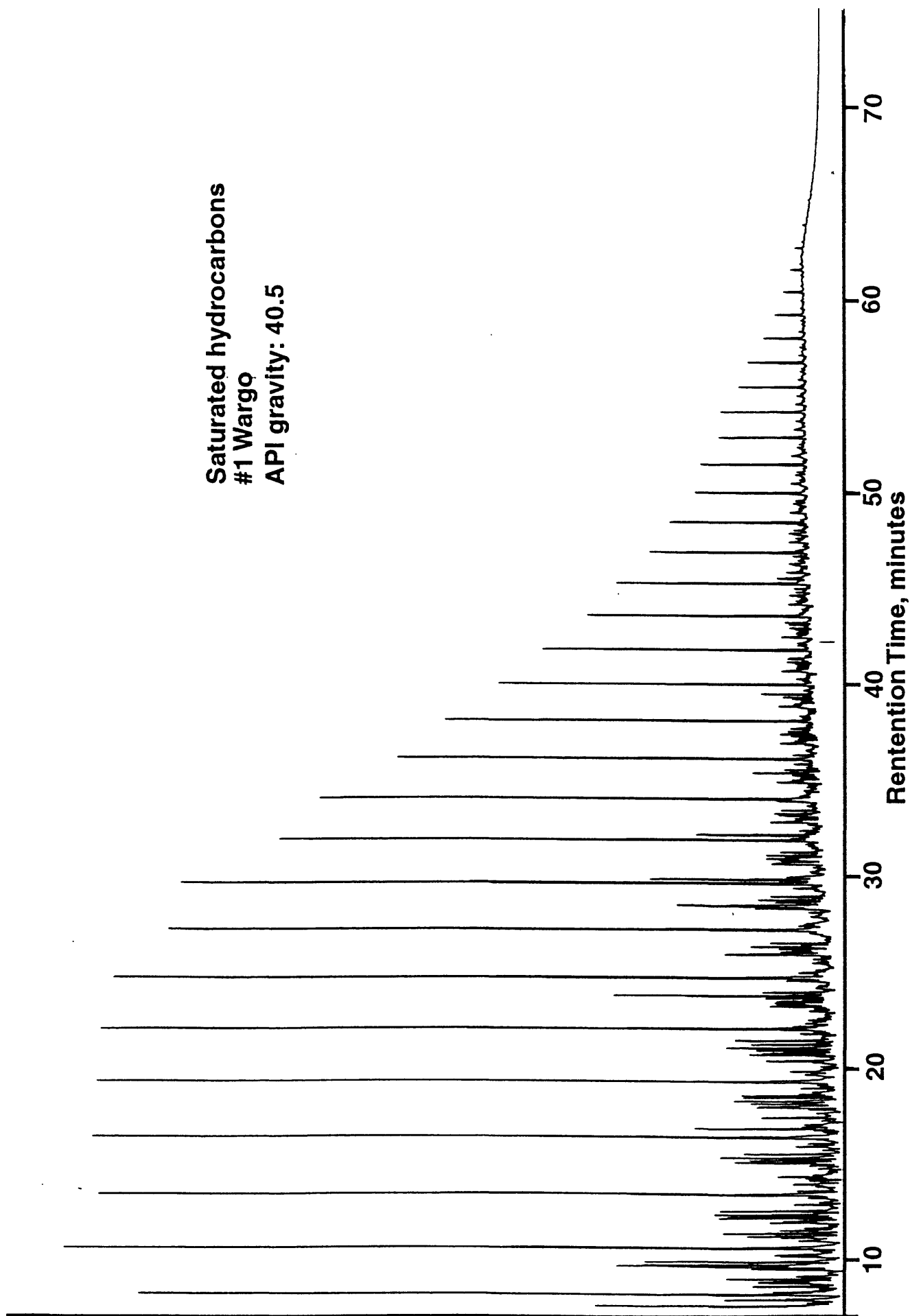


Figure 3B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR4, #1 Wargo.

Aromatic hydrocarbons
#1 Wargo
API gravity: 40.5

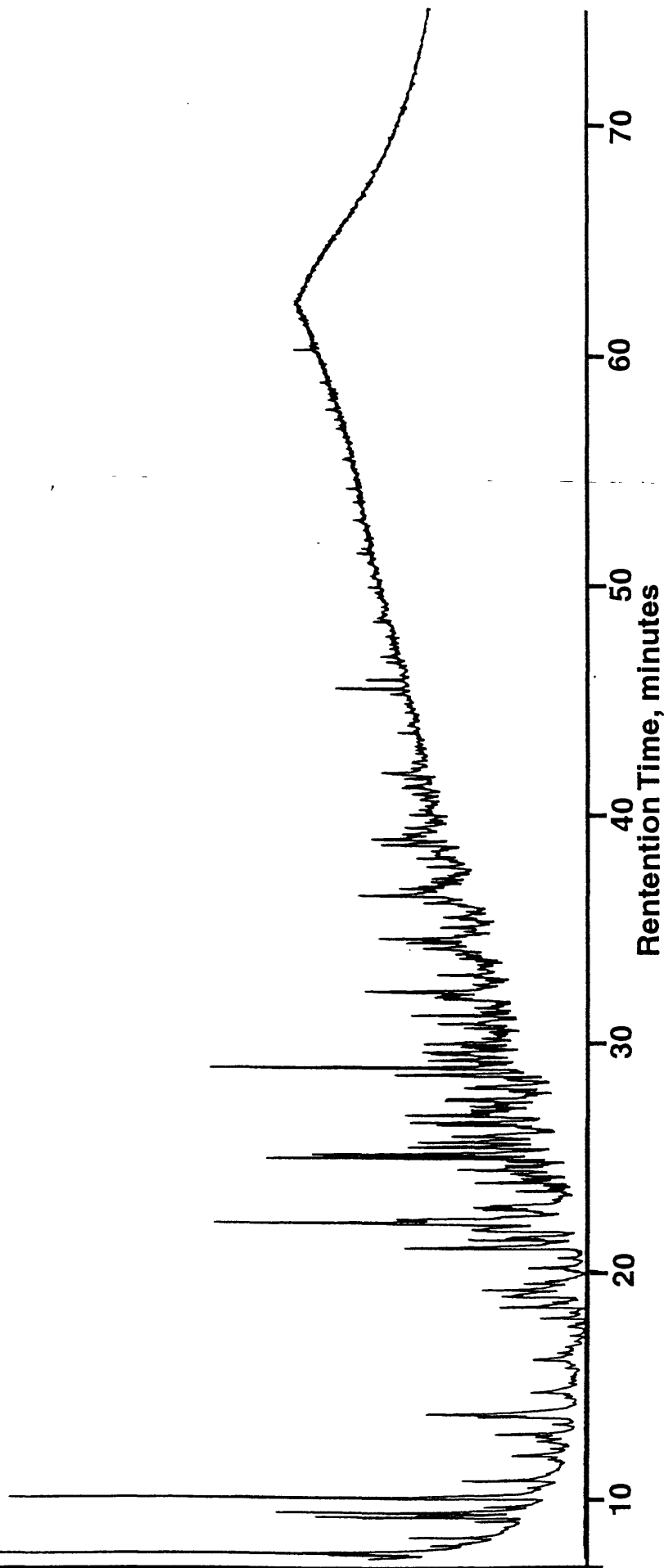


Figure 3C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR4, #1 Wargo.

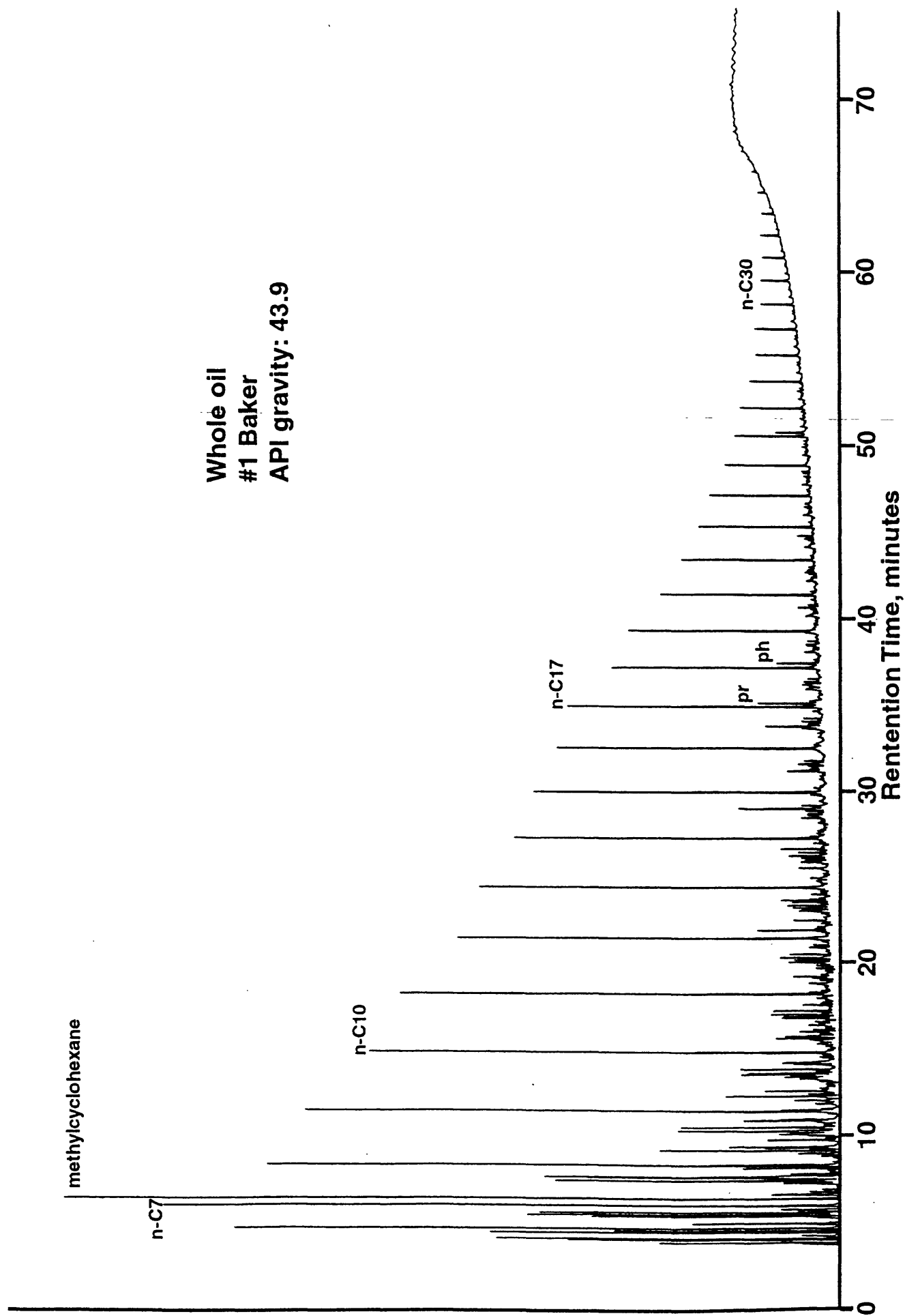


Figure 4A: Whole oil gas chromatogram, sample 97MCR5, #1 Baker. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#1 Baker
API gravity: 43.9

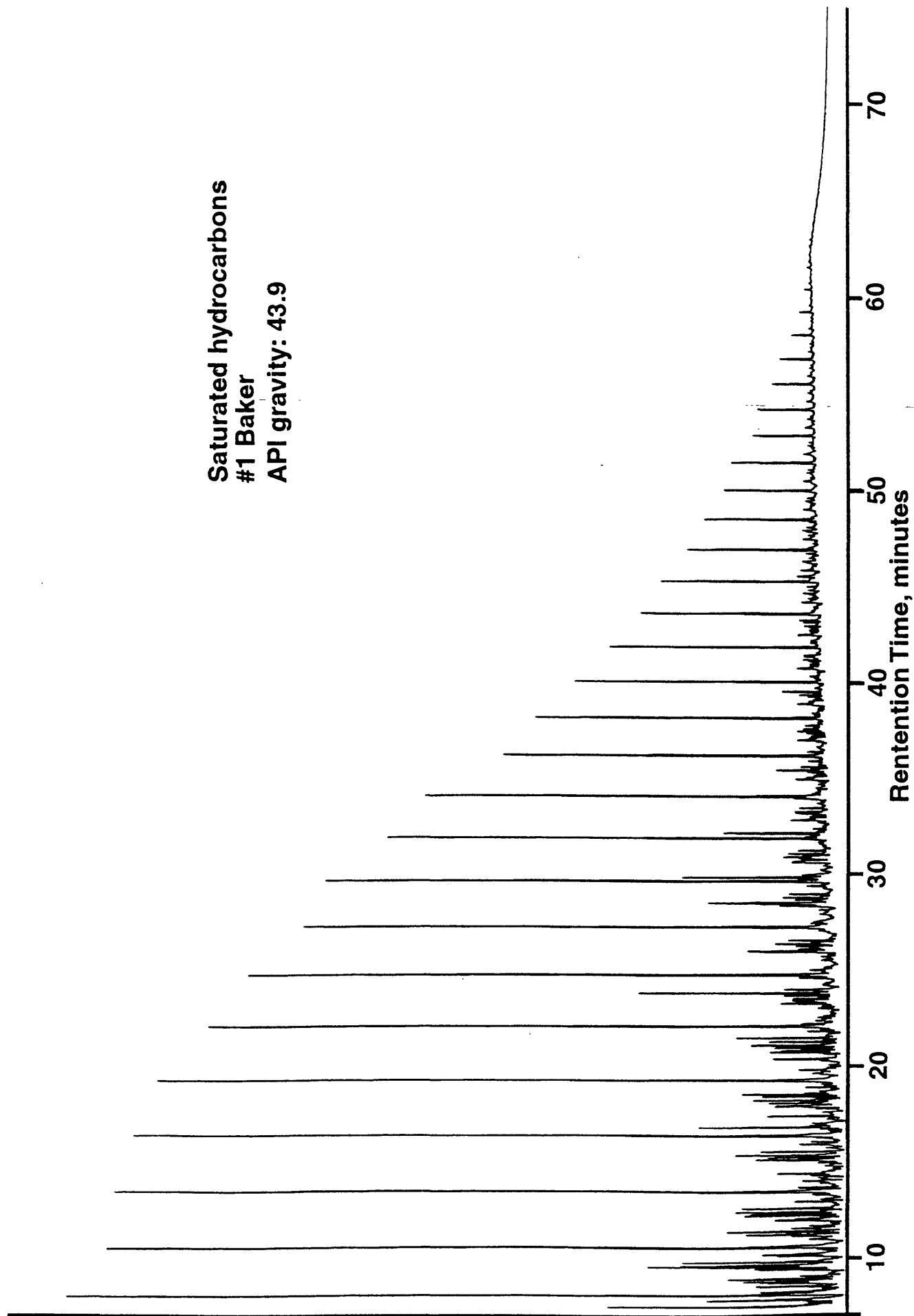


Figure 4B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR5, #1 Baker.

Aromatic hydrocarbons
#1 Baker
API gravity: 43.9

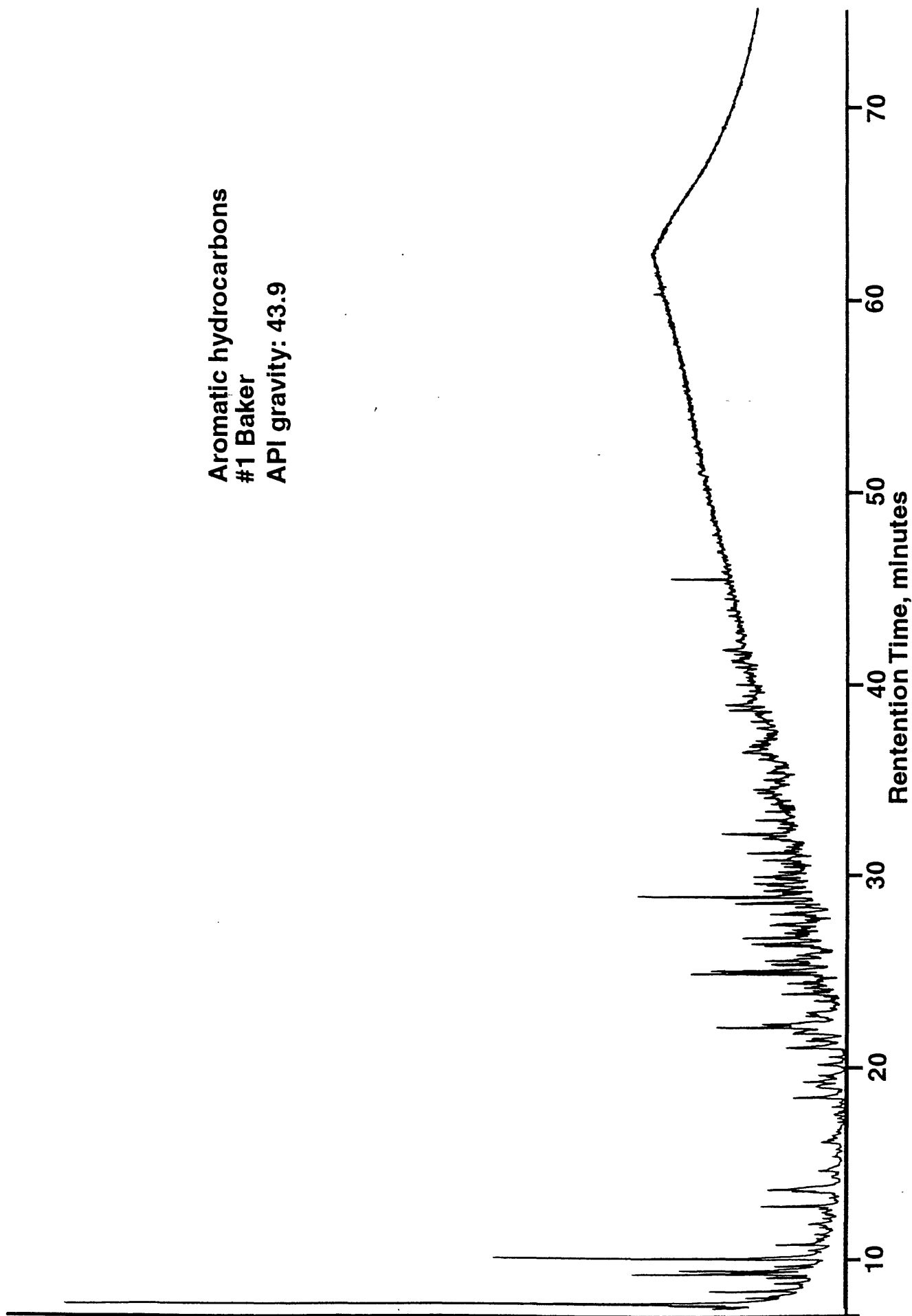


Figure 4C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR5, #1 Baker.

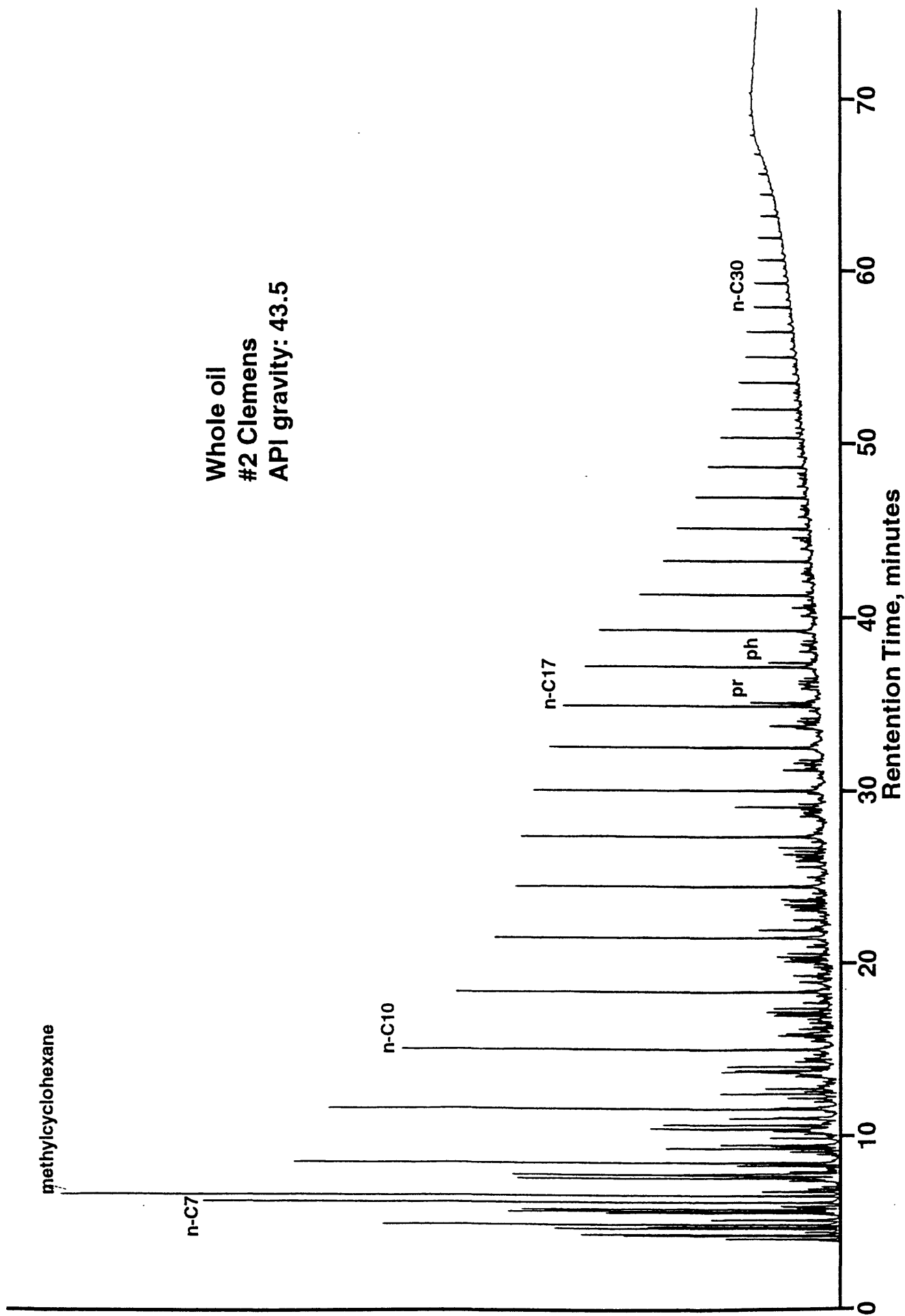


Figure 5A: Whole oil gas chromatogram, sample 97MCR6, #2 Clemens. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#2 Clemens
API gravity: 43.5

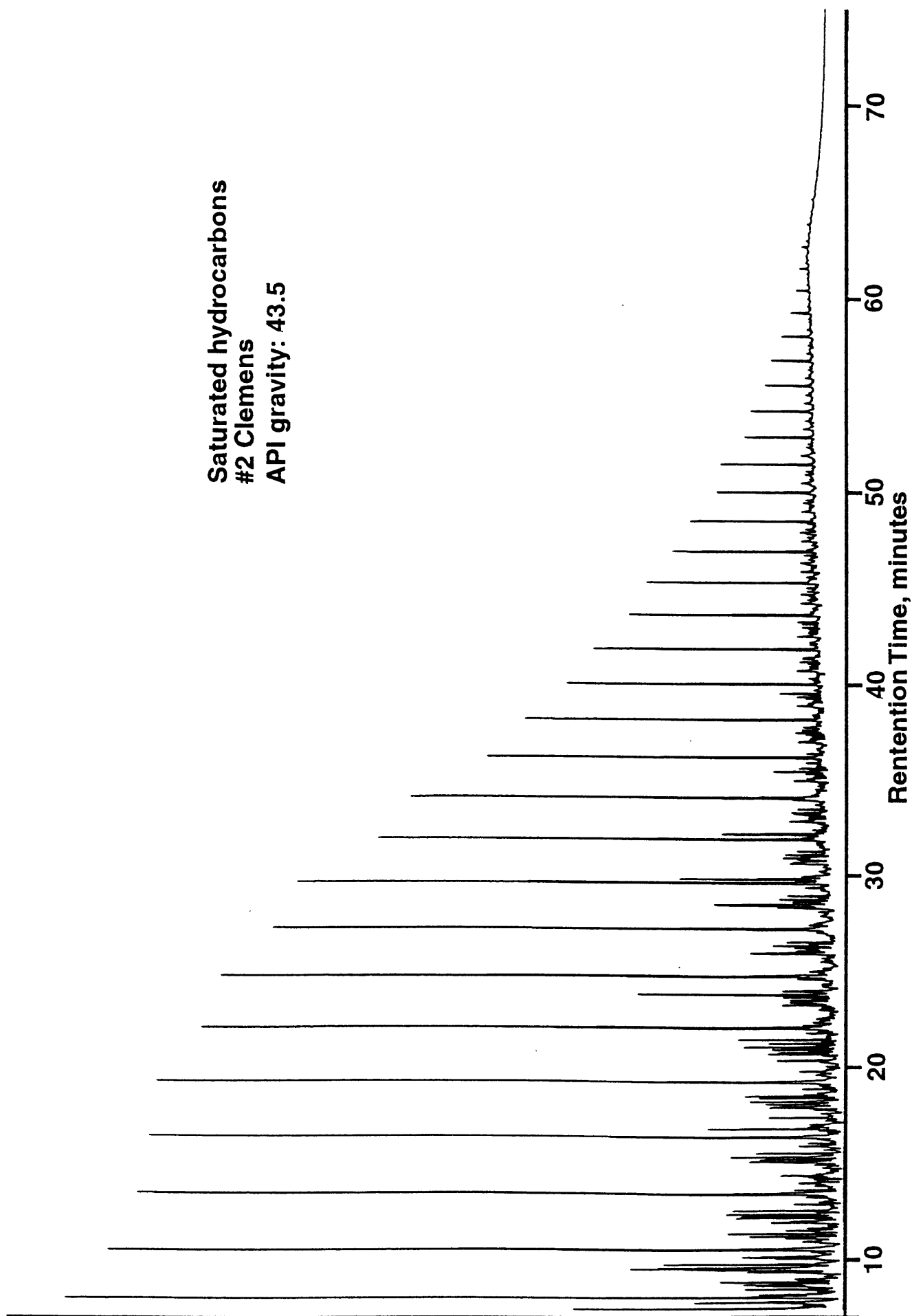


Figure 5B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR6, #2 Clemens.

Aromatic hydrocarbons
#2 Clemens
API gravity: 43.5

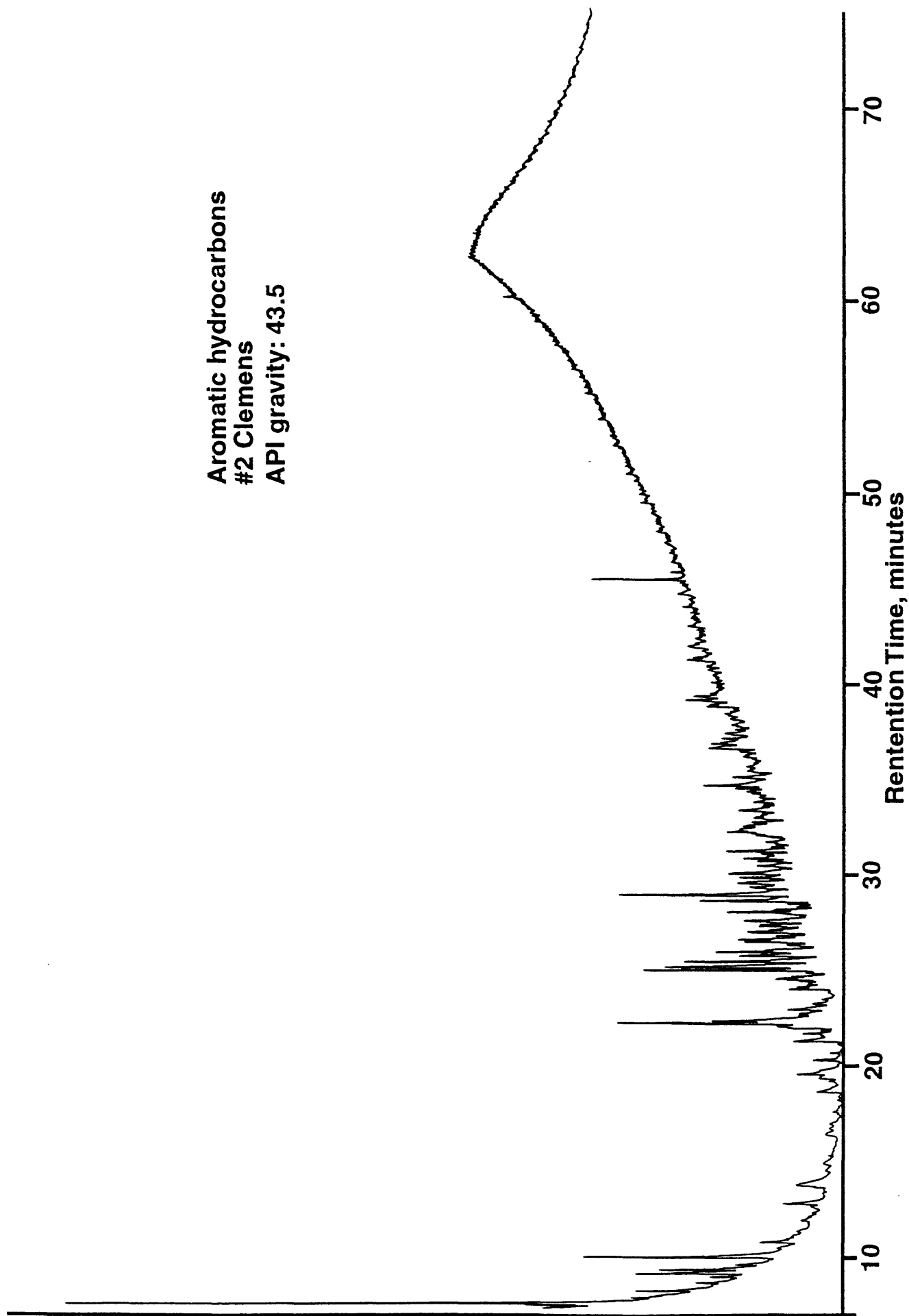


Figure 5C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR6, #2 Clemens.

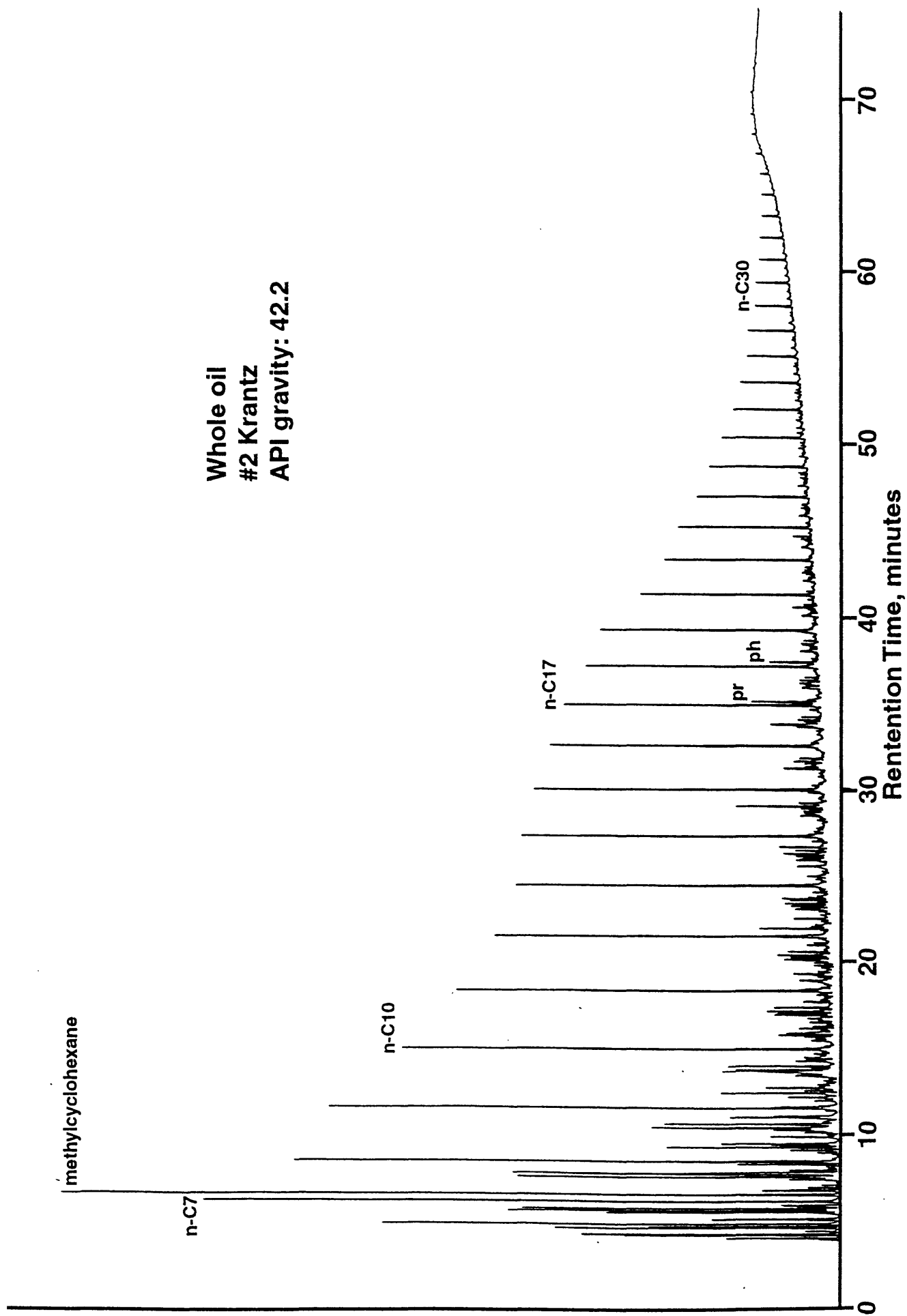


Figure 6A: Whole oil gas chromatogram, sample 97MCR7, #2 Krantz. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#2 Krantz
API gravity: 42.2

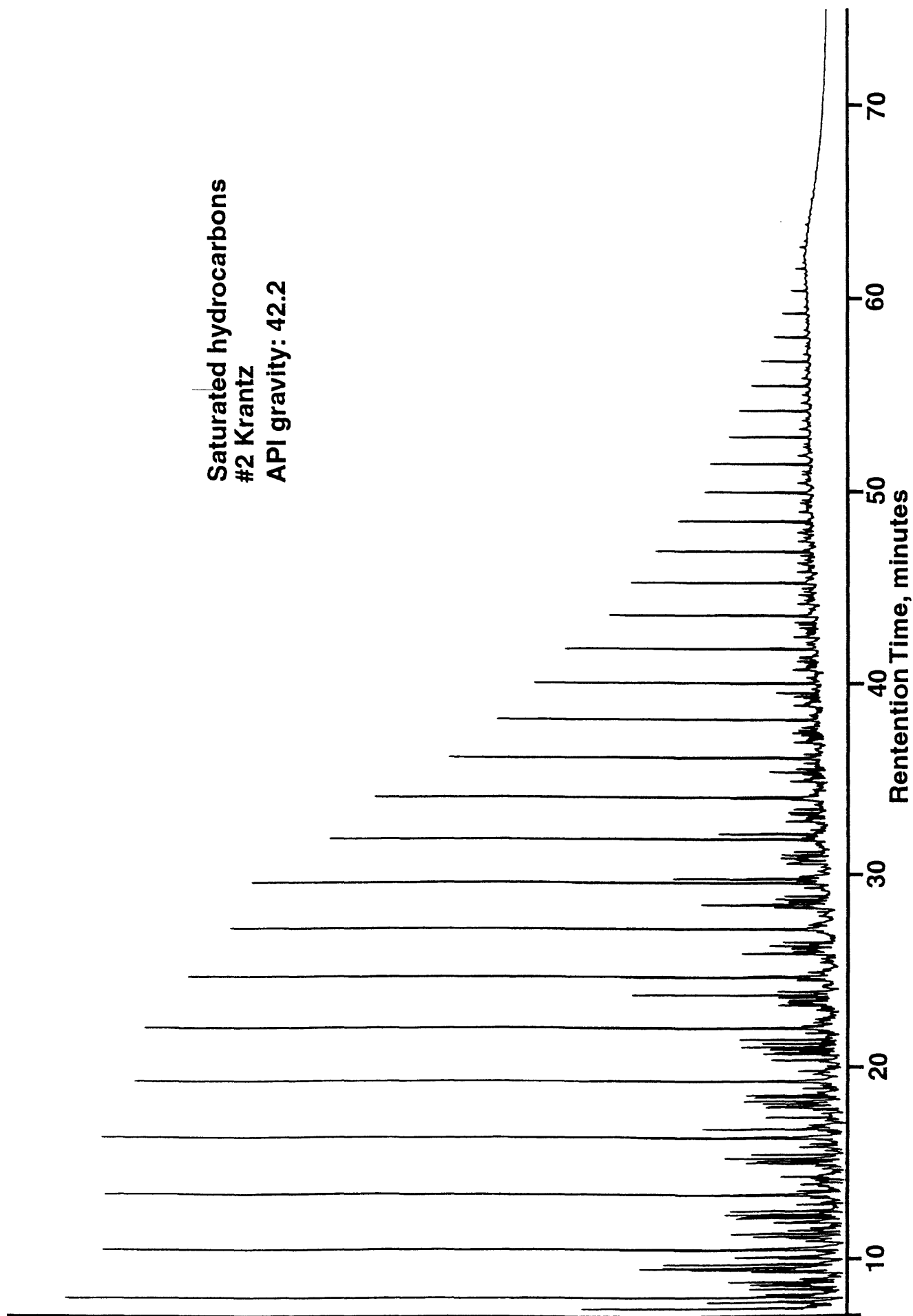


Figure 6B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR7, #2 Krantz.

Aromatic hydrocarbons
#2 Krantz
API gravity: 42.2

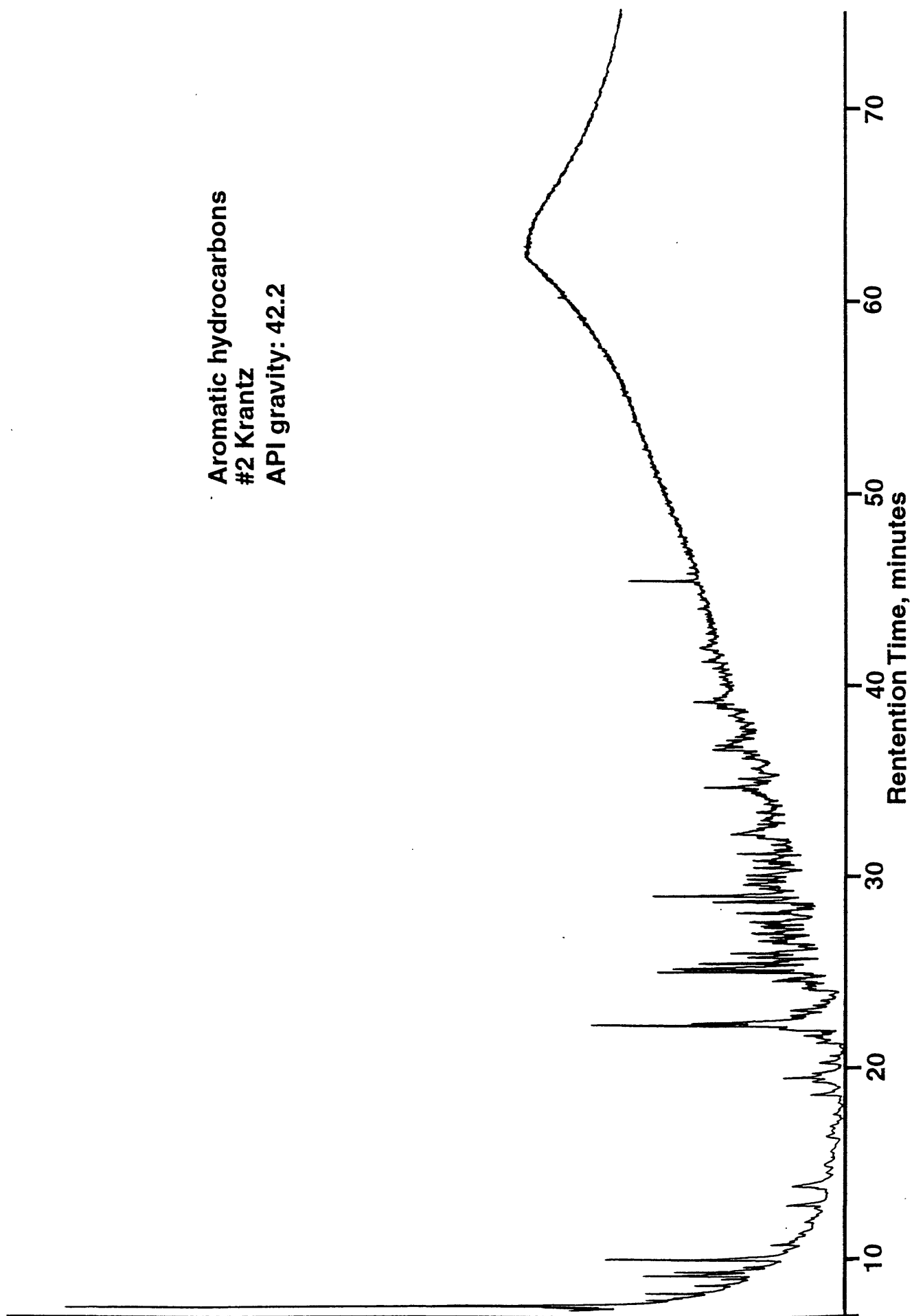


Figure 6C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR7, #2 Krantz.

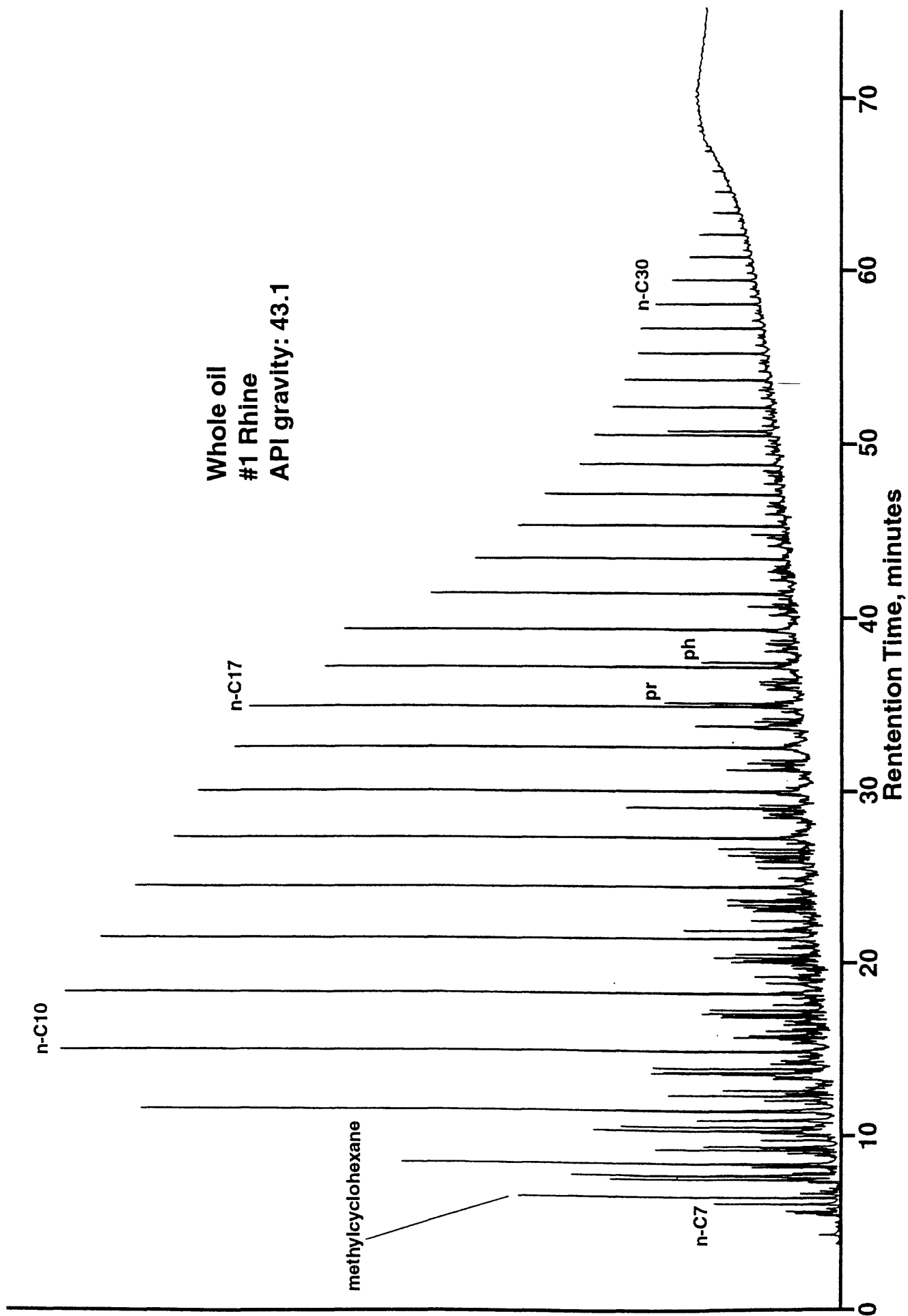


Figure 7A: Whole oil gas chromatogram, sample 97MCR8, #1Rhine. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#1 Rhine
API gravity: 43.1

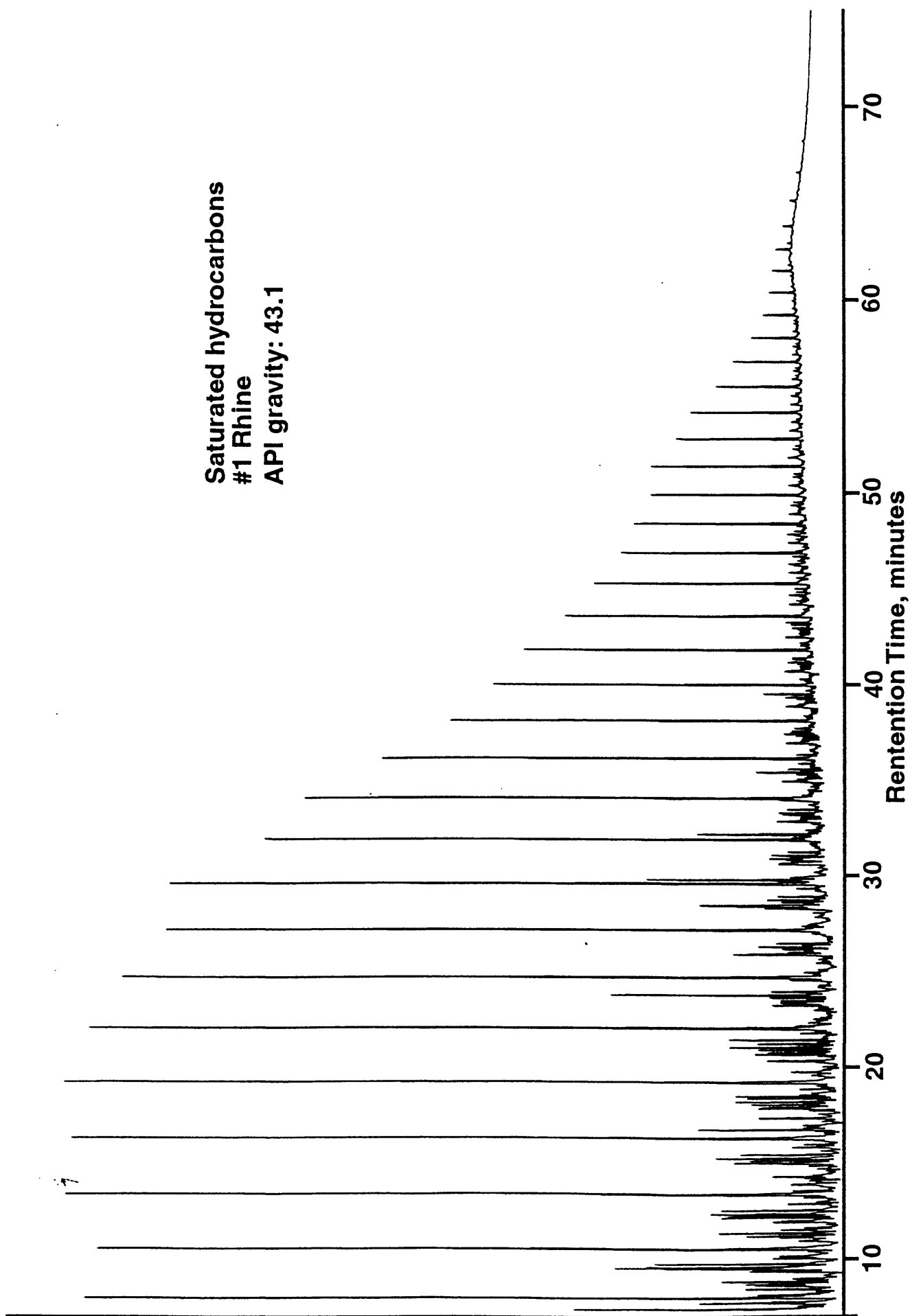


Figure 7B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR8, #1 Rhine.

Aromatic hydrocarbons
#1 Rhine
API gravity: 43.1

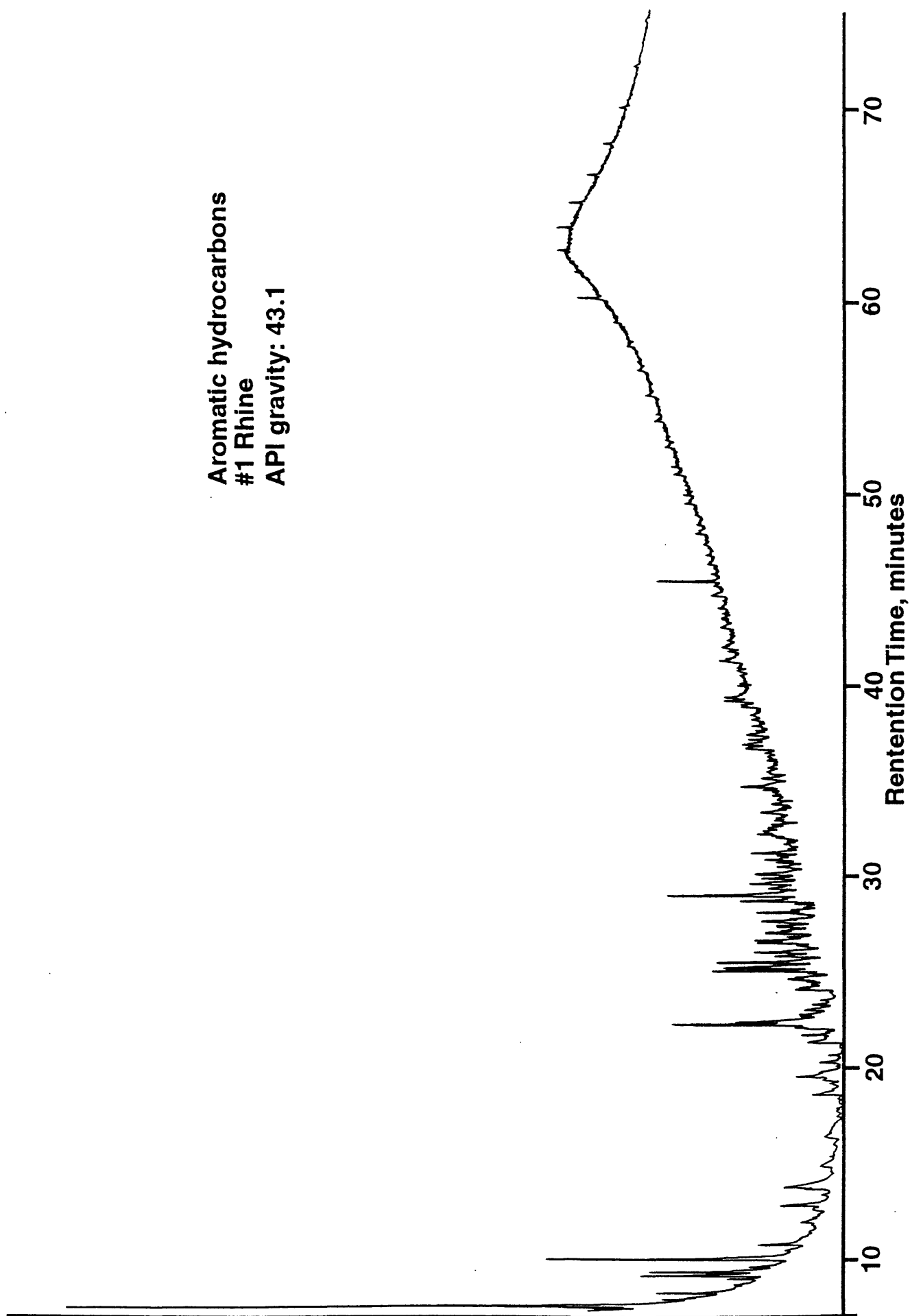


Figure 7C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR8, #1 Rhine.

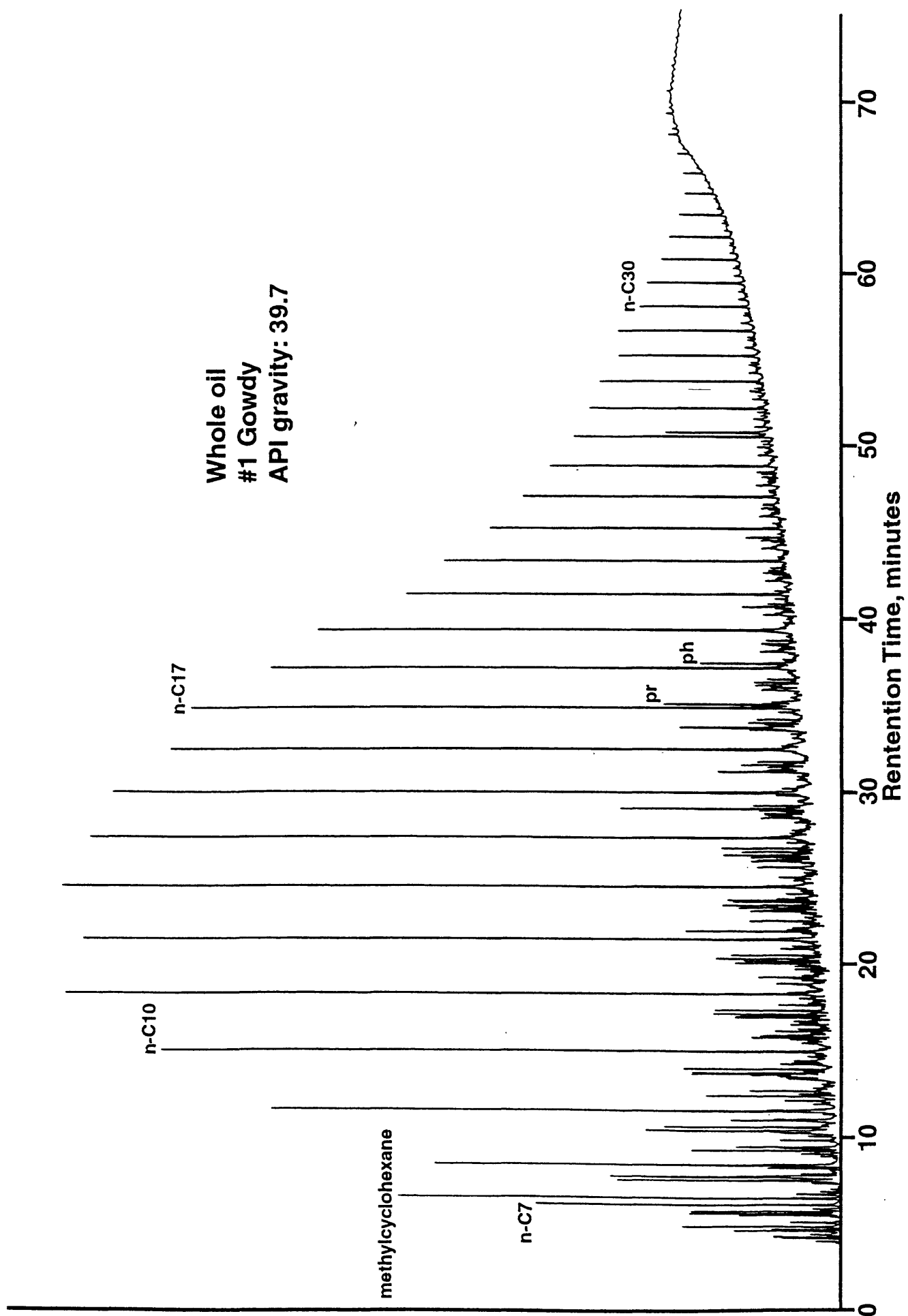


Figure 8A: Whole oil gas chromatogram, sample 97MCR9, #1 Gowdy. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#1 Gowdy
API gravity: 39.7

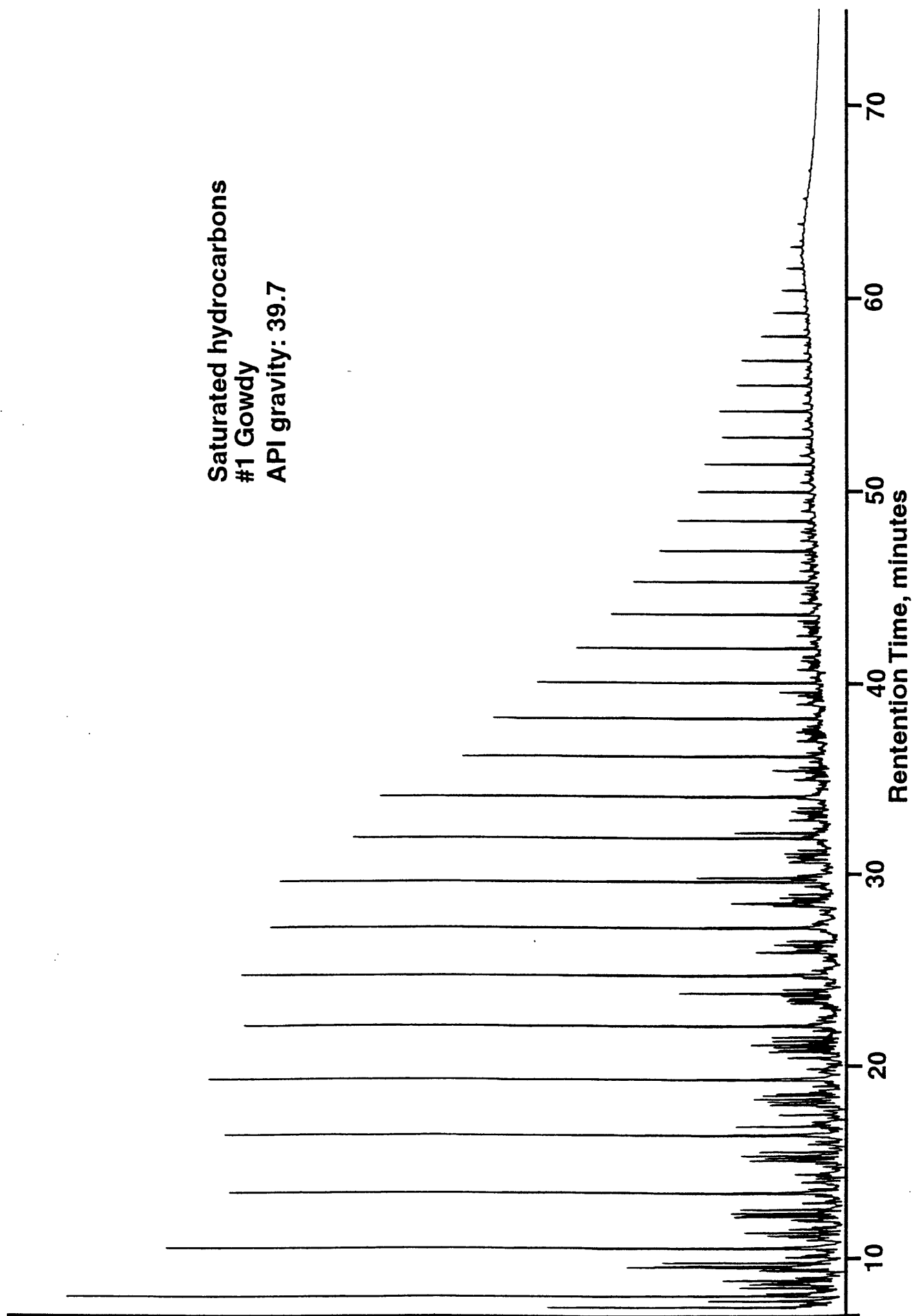


Figure 8B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR9, #1 Gowdy.

Aromatic hydrocarbons
#1 Gowdy
API gravity: 39.7

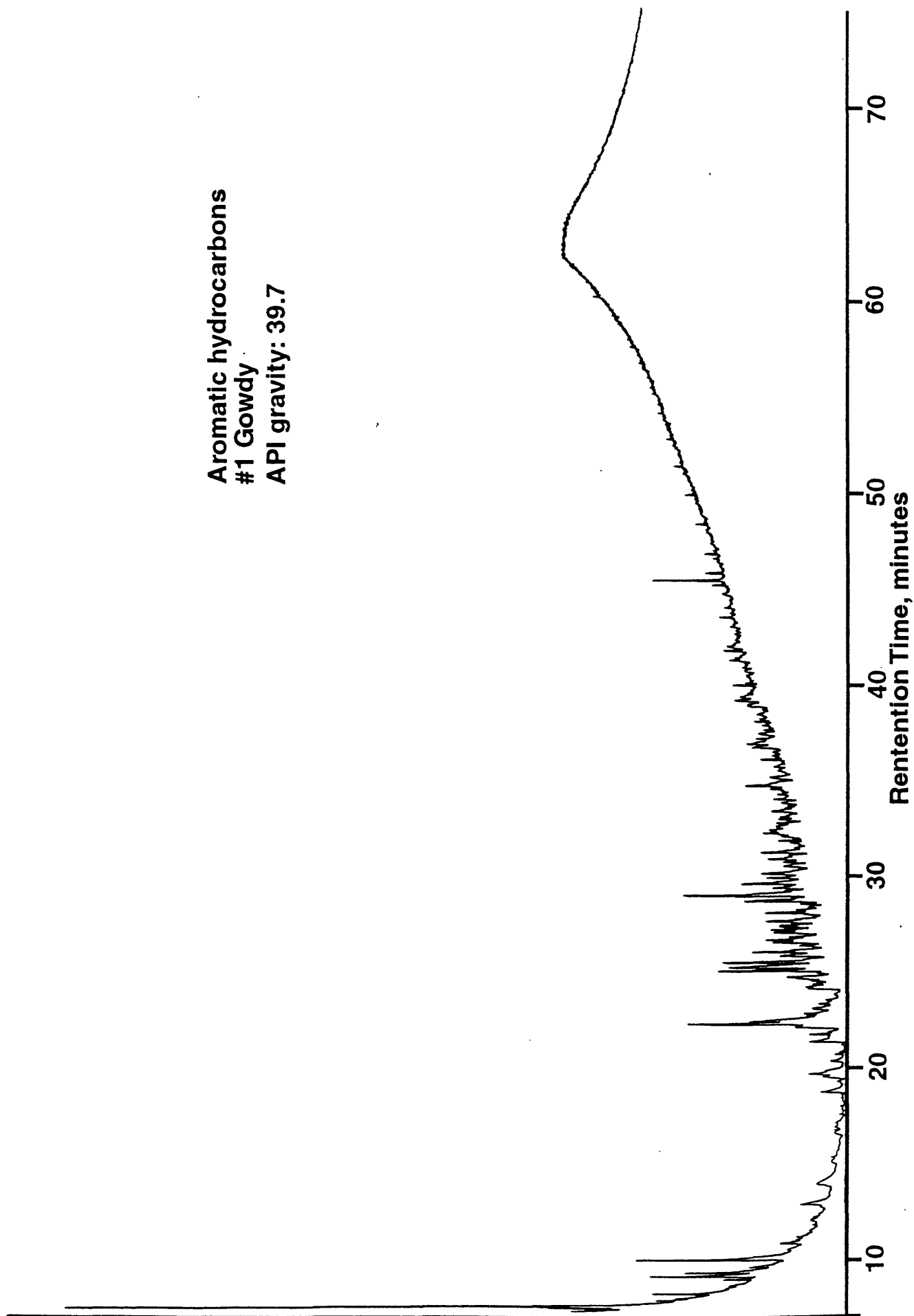


Figure 8C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR9, #1 Gowdy.

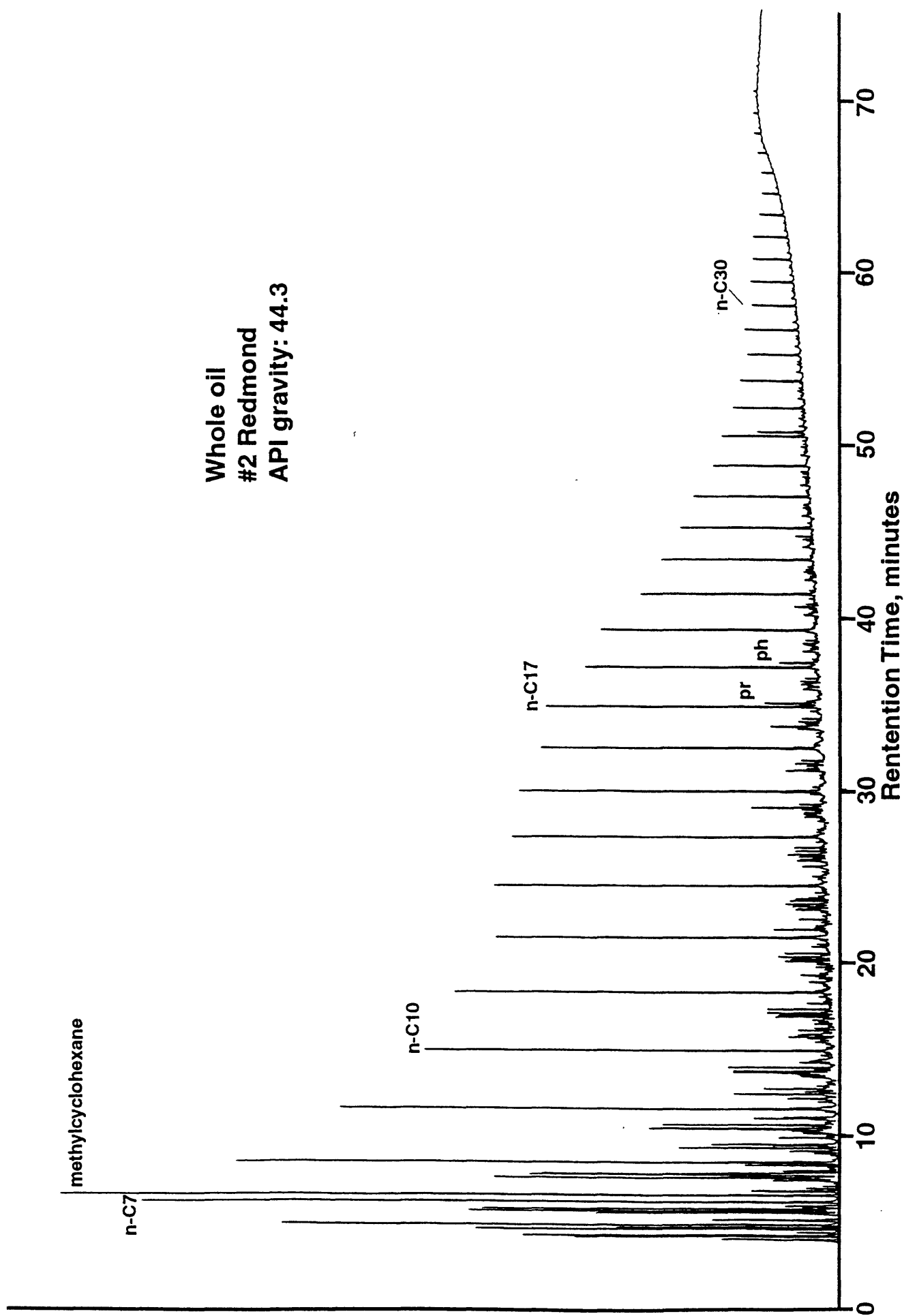


Figure 9A: Whole oil gas chromatogram, sample 97MCR10, #2 Redmond. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#2 Redmond
API gravity: 44.3

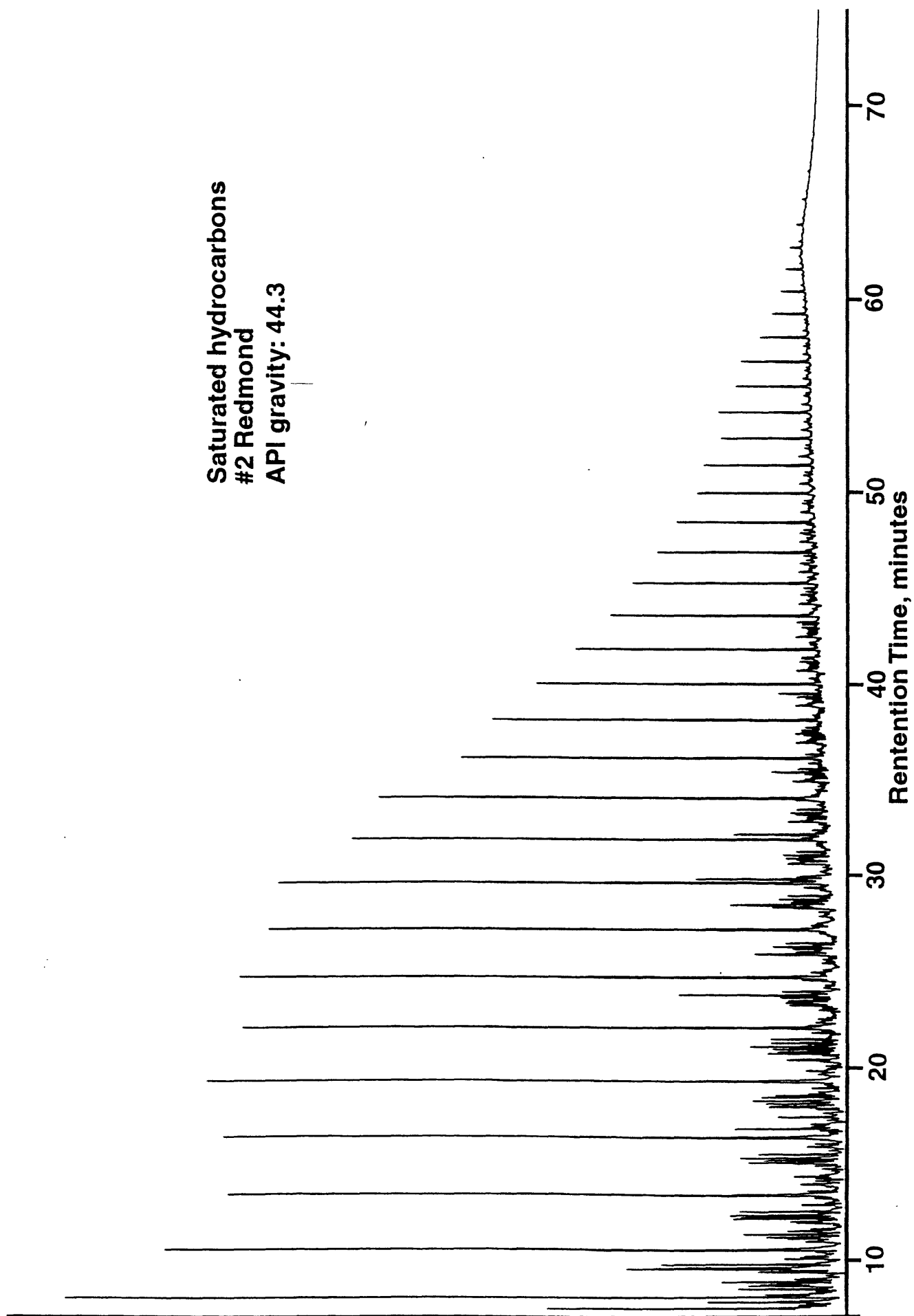


Figure 9B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR10, #2 Redmond.

Aromatic hydrocarbons
#2 Redmond
API gravity: 44.3

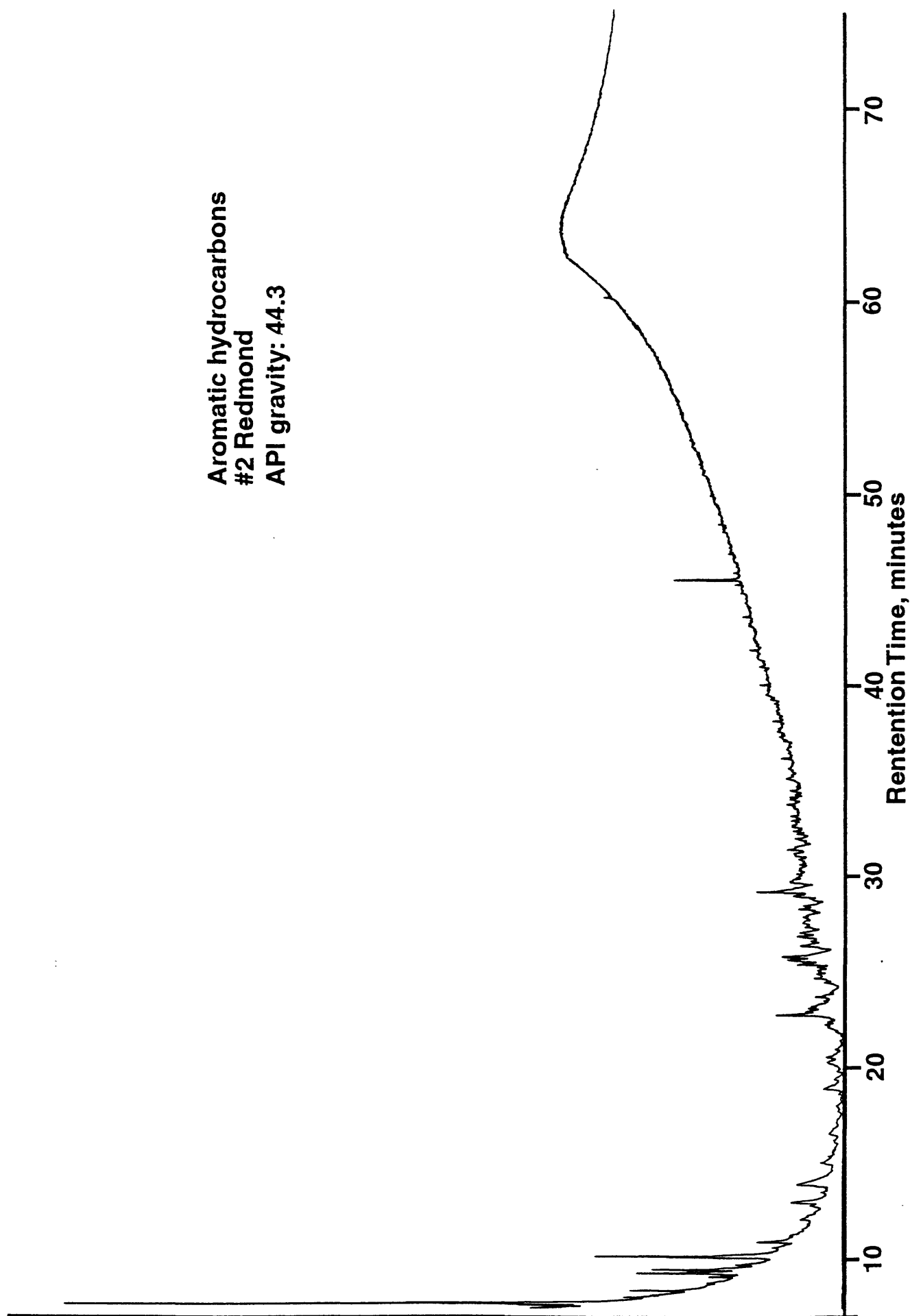


Figure 9C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR10, #2 Redmond.

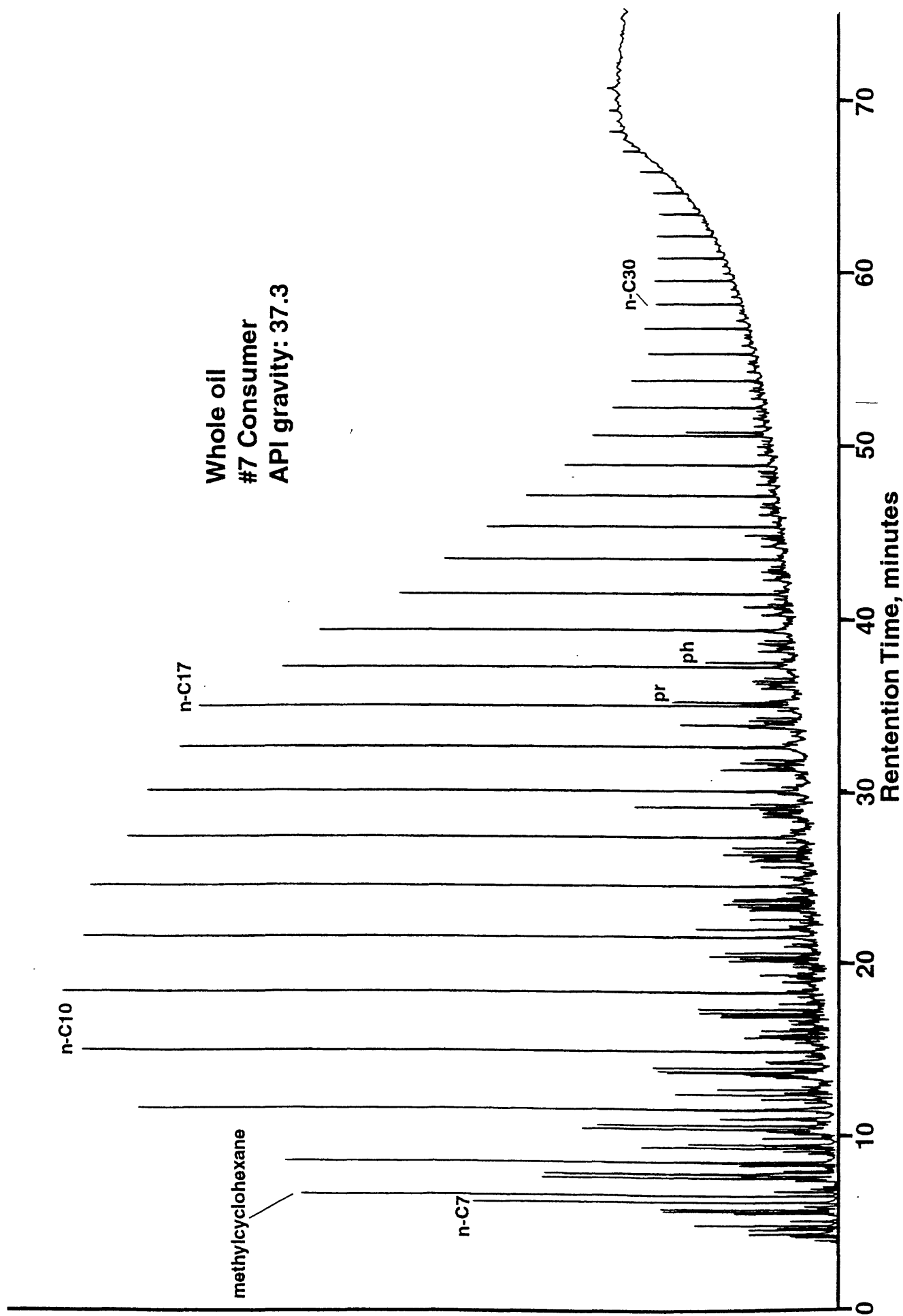


Figure 10A: Whole oil gas chromatogram, sample 97MCR11, #7 Consumer. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturated hydrocarbons
#7 Consumer
API gravity: 37.3

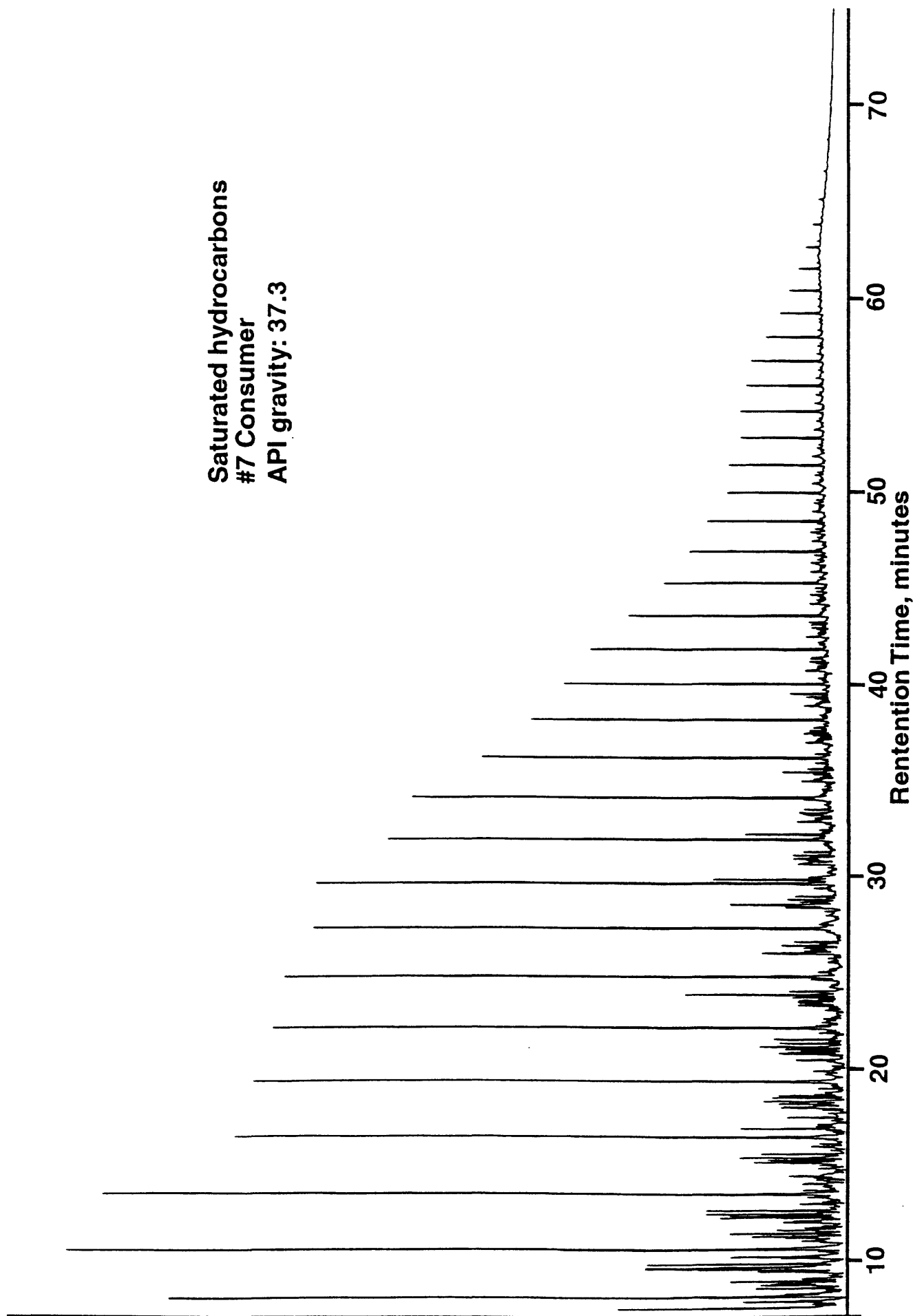


Figure 10B: Saturated hydrocarbon fraction gas chromatogram, sample 97MCR11, #7 Consumer.

Aromatic hydrocarbons
#7 Consumer
API gravity: 37.3

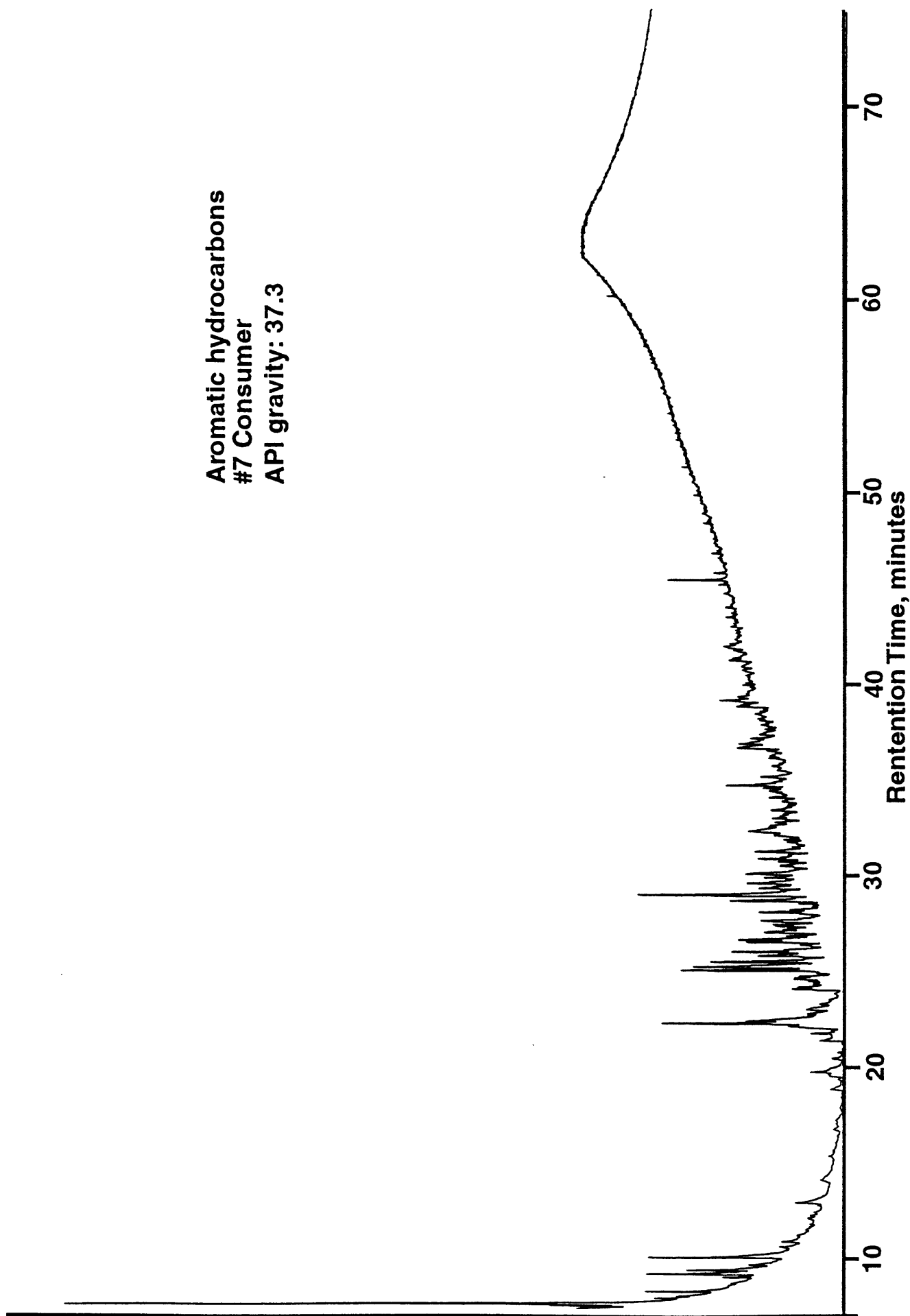


Figure 10C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR11, #7 Consumer.

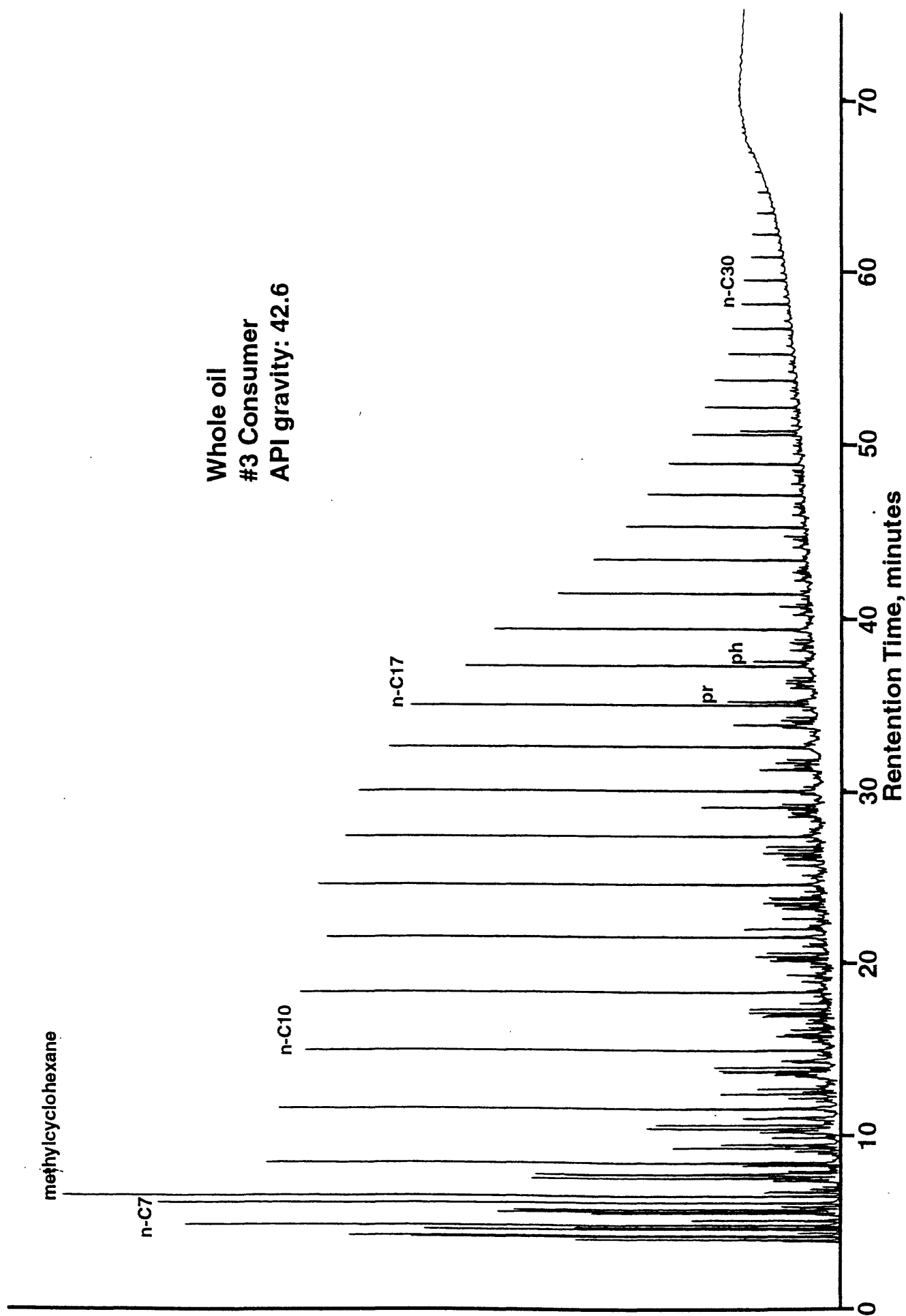


Figure 11A: Whole oil gas chromatogram, sample 97MCR12, #3 Consumer. Selected peak identifications: n-CX, normal alkanes where X is the carbon number; pr, pristane; ph, phytane.

Saturate hydrocarbons
#3 Consumer
API gravity: 42.6

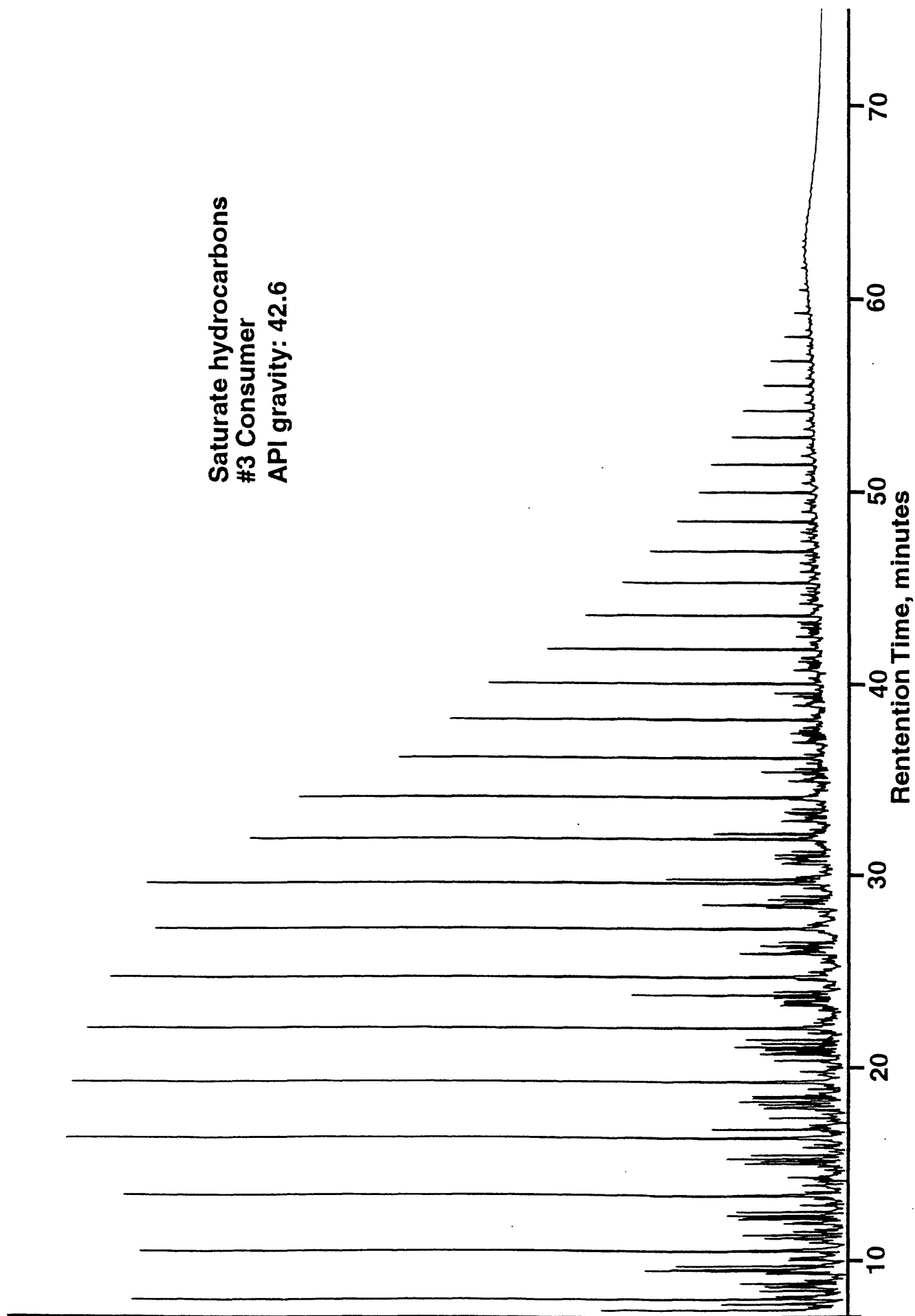


Figure 11B: Saturate hydrocarbon fraction gas chromatogram, sample 97MCR12, #3 Consumer.

Aromatic hydrocarbons
#3 Consumer
API gravity: 42.6

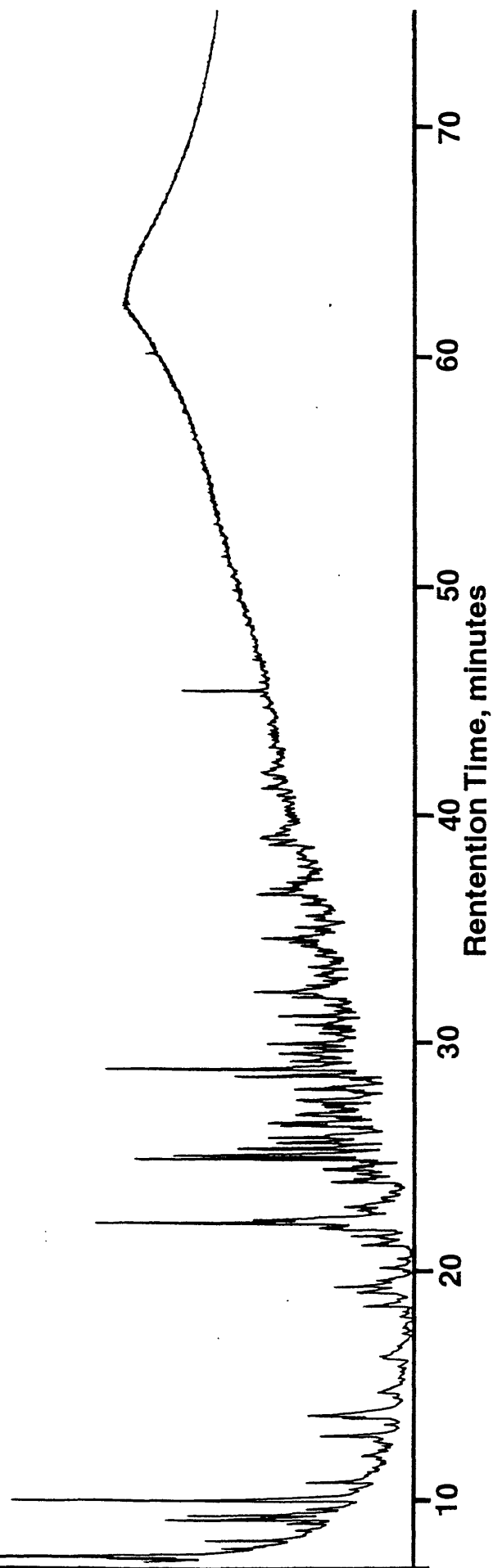


Figure 11C: Aromatic hydrocarbon fraction gas chromatogram, sample 97MCR12, #3 Consumer.

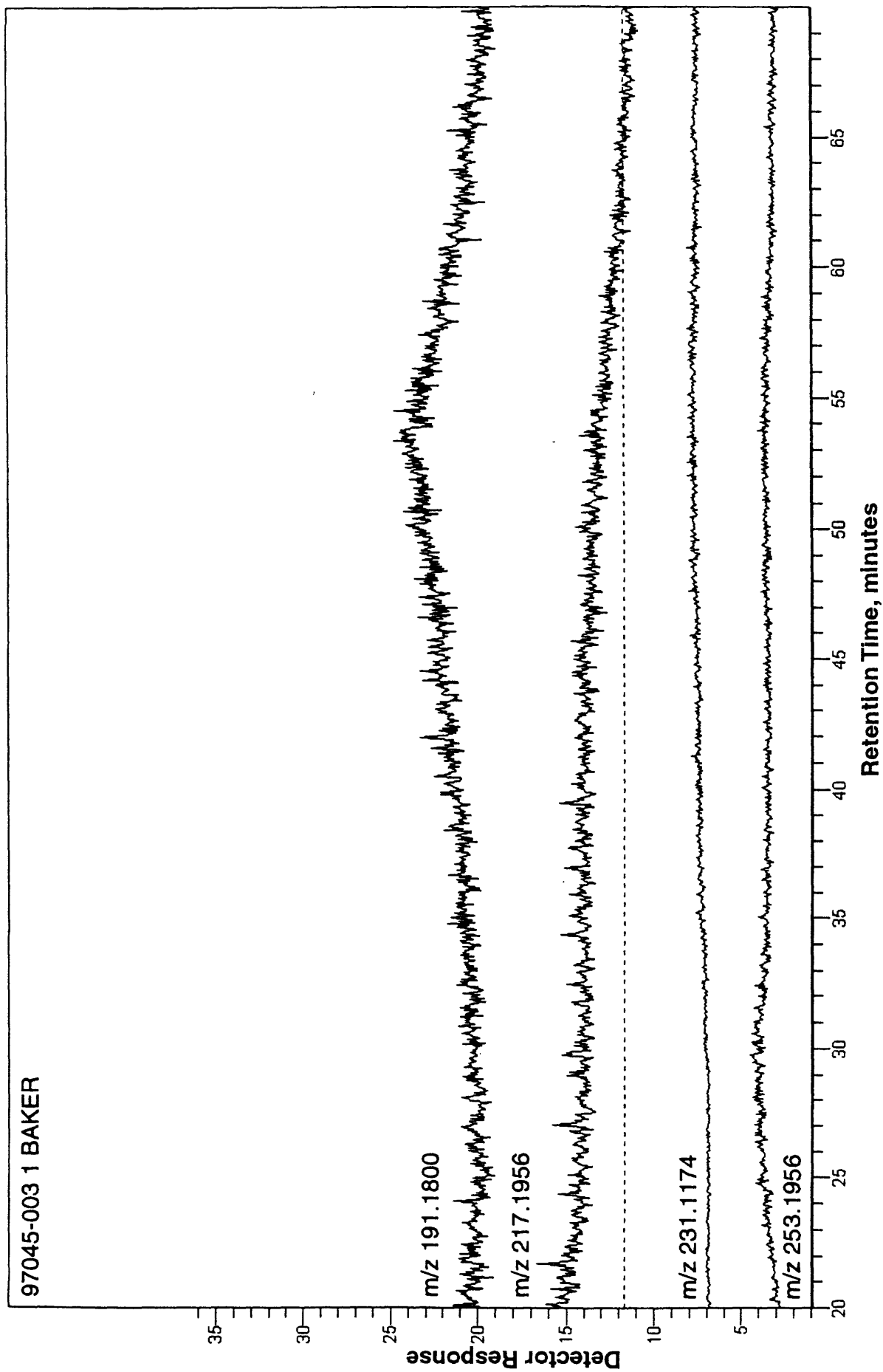


Figure 12: Biomarker mass fragmentograms, sample 97MCR5, #1 Baker.

Sample ID	Well name	Saturated HC characteristics					
		pr/ph	pr/n-C ₁₇	ph/n-C ₁₈	CPI	% n-alk	Cond. Index
97MCR3	#1 Governor	1.57	0.41	0.33	1.09	37.50	9.64
97MCR4	#1 Wargo	1.61	0.38	0.29	1.06	39.65	8.08
97MCR5	#1 Baker	1.63	0.41	0.32	1.04	38.03	9.30
97MCR6	#2 Clemens	1.63	0.40	0.31	1.04	38.89	8.93
97MCR7	#2 Krantz	1.35	0.38	0.33	1.04	39.64	8.41
97MCR8	#1 Rhine	1.07	0.32	0.33	1.01	42.41	8.44
97MCR9	#1 Gowdy	1.27	0.34	0.31	1.03	43.10	7.44
97MCR10	#2 Redmond	1.32	0.33	0.30	1.04	40.53	7.97
97MCR11	#7 Consumer	1.24	0.32	0.30	1.06	41.12	9.05
97MCR12	#3 Consumer	1.58	0.34	0.27	1.08	41.58	7.84

Table 4: Properties of the saturated hydrocarbon fraction of the crude oils.

pr/ph: pristane/phytane; CPI: carbon preference index; % n-alk: % of n-alkanes in total saturate fraction; Cond. Index: condensate index defined by Lewan and Buchardt, 1989, % n-C₁₁ of n-C₁₀ to n-C₃₀.

software that calculates these properties. This low a value is not apparent from the relative peak heights in the gas chromatogram in Figure 7B.

However, two groups of oils apparently can be defined on the basis of the pr/ph ratio, one with pr/ph about 1.6 and another with pr/ph about 1.3.

Whether or not this difference is significant will require analysis of additional samples to identify the full range of variation in this property of oils produced from the Clinton/Medina sandstones.

Mass fragmentograms from gas chromatography-mass spectrometry (GCMS) of crude oil sample 97MCR5 from the #1 Baker well are shown in **Figure 12**. The most striking feature of all four fragmentograms is that no ions were detected for the triterpane, sterane, hopane, or aromatized equivalent biomarkers. This indicates that this oil has an unusual composition with no detectable biomarkers. All the other oils were examined in a reconnaissance mode, and no biomarkers were detected.

Discussion

The data shown in the tables and the gas chromatograms demonstrate that these gases and oils have a remarkably uniform composition. Two of the oils that show evaporative loss of low molecular weight hydrocarbons, #1 Wargo and #7 Consumer, were obtained from the flowline to the stock tank or the stocktank itself. These oils were open to the atmosphere prior to sampling and evaporative loss is expected. The other oils with evidence of loss of low molecular weight compounds, #1 Rhine and #1 Gowdy, were

sampled from the separator and analyzed at the same time as the other samples. Different amounts of evaporative loss from individual samples during analysis are unlikely, and the cause of this aspect of the oils is unknown.

The possible grouping of the oils based on a small distinction in the pristane/phytane ratio needs further examination with other geochemical parameters. The fact that the anomalously low pristane/phytane ratio in one sample appears to be an artifact of the software that calculates this parameter suggests that small variations in this parameter must be evaluated carefully.

All the oils have a slight odd-carbon predominance (average 1.05, based on the carbon preference index, CPI, reported in Table 4). This is similar to the odd-carbon predominance in oils from Ordovician age reservoirs in Ohio reported by Ryder, Burruss, and Hatch (1998).

The most unusual feature of the oils is the absence of common biomarker compounds. The fragmentograms in Figure 12 show baseline response with no detectable compounds that yield ions for terpanes (m/z 191), steranes and hopanes (m/z 217) or the aromatized equivalents of these compounds (m/z 231 and 253). Normal alkanes are present in the molecular weight range of the biomarkers (carbon number 21 to 35) demonstrating that no physical fractionation process such as phase separation has removed all the compounds in this molecular weight range. Tests were performed on the analytical method to ensure that no problems occurred during sample preparation. As a final test, the sample was sent to another laboratory outside

of the USGS. This laboratory could not detect biomarkers in the oil (J. David King, written and oral communications, 1997).

The absence of biomarkers in these oils is puzzling. Some lower Paleozoic source rocks generate oils with low concentrations of biomarkers, experimental studies demonstrate that most biomarkers are released from the source during the early stages of generation, and biomarkers can be thermally cracked and eliminated from an oil at high levels of thermal maturity. A combination of these factors could lead to oil with no biomarkers. There are, however, no examples documented in the literature.

Conclusions

The 10 oils and 3 natural gases sampled from 10 wells producing from the "Clinton" sands in Trumbull County, Ohio, are remarkably uniform in composition. The oils are similar in composition to other Lower Silurian oils from Ohio reported by Cole and others (1987) and the gases are similar to gases in Lower Silurian reservoirs in Ohio reported by Laughrey and Baldassarre (1998). The isotopic composition of the gases and the chemical composition of the oils suggest that they experienced high levels of thermal maturity possibly greater than the present day burial conditions of the reservoir rocks.

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