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14. ORGANIC MATTER AT SITES 642, 643, AND 644, ODP LEG 104[1]

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ABSTRACT

Sedimentary extractable organic matter was analyzed at three ODP Leg 104 sites in the Norwegian Sea. Organic carbon content ranged from less than 0.1% to a maximum of 1.8%. Extractable organic matter content and unresolved complex mixture concentrations were low and randomly distributed. Low levels of aliphatic (branched and normal) and aromatic hydrocarbons were detected in all of the sediments analyzed. Total aliphatic and aromatic hydrocarbon concentrations ranged from 176 to 3,214 and 6 to 820 ppb, respectively. The concentrations of individual aliphatic (n-C_{15} to n-C_{32}) and aromatic (two- to five-ring) hydrocarbons were generally less than 50 ppb and less than 10 ppb, respectively. No significant trend with sub-bottom depth was observed in either bulk organic matter or individual hydrocarbon concentrations. The predominant source of Cenozoic sedimentary hydrocarbons is concluded to be ice-rafted debris from the adjacent continent. All sites contain a mixture of recycled, mature petroleum-related and terrestrially derived hydrocarbons.

INTRODUCTION

The ultimate distribution of organic matter in marine sediments is controlled by a number of factors including the amount and composition of the source material, depositional environment, depth of burial, diagenesis, and upward migration of liquids and gases from deeper accumulations (Kennicutt et al., 1987a). All of these factors can potentially influence the organic carbon content, isotopic composition, and molecular compositions of the extractable and residual carbon in sediments. The Vøring Plateau (Fig. 1) lies within a region that has been heavily influenced by glaciers in Plio-Pleistocene time. Ice-rafted material of terrigenous origin has been suggested as a significant source of sedimentary organic matter. Another potential source of organic matter to the sediment in this region is migration from deep petroleum sources, especially in the region of the inner Vøring Plateau (Morris, 1976). Sedimentary organic matter from Ocean Drilling Program (ODP) Leg 104 sites was analyzed in a continuing effort to understand the distribution, origin, and diagenesis of organic matter in oceanic sediments.

EXPERIMENTAL TECHNIQUES

Aliphatic and polynuclear aromatic hydrocarbon concentrations were analyzed by gas chromatography with flame ionization (GC/FID) and mass spectrometric detection (GC/MS), respectively. The analytical procedure provides quantitative aliphatic and aromatic hydrocarbon concentrations in the C_{10} to C_{15} n-alkane range as well as the C_{15}^{+} fraction. Freeze-dried samples were ground and extracted in a Soxhlet apparatus for 12 hr with methylene chloride. Copper turnings were added to the boiling flask to remove elemental sulfur. Internal standards C_{10} and C_{14} alkylbenzenes, d_8-naphthalene, d_{10}-phenanthrene, d_{10}-acenaphthene, d_{12}-chrysene, and d_{12}-perylene were added to the sediment prior to extraction. The deuterated aromatic compounds were used to correct for losses of analytes during analysis by GC/MS. The alkylbenzenes were used in a similiar fashion to quantify aliphatic hydrocarbon concentrations by GC/FID. Hexamethylbenzene was added just prior to GC/FID or GC/MS analysis to calculate absolute analyte recoveries. All cleaning procedures, contamination control, system blanks, spiked blanks, and standards (internal and external) conform to the NOAA Status and Trends Program described in detail elsewhere (Kennicutt et al., 1987a; MacLeod et al., 1985). Sample components were separated using a 50-m x 0.32-mm I.D. (0.52-μm film thickness) fused silica capillary column coated with a cross-linked methyl silicone liquid phase. Typical GC/MS and GC/FID operating conditions are presented in Tables 1 and 2.

A carbon preference index (CPI) was determined as the ratio of odd-numbered normal alkanes with 23 to 31 carbons, to the even-numbered normal alkanes with 24 to 32 carbons. The unresolved complex mixture (UCM) is defined as the rise above the instrumental baseline of the FID response under the given operating conditions. The UCM concentration was semiquantitatively determined using the FID response for a normal alkane eluting in the same gas chromatographic regions as the UCM. Extractable organic matter (EOM) concentrations were determined gravimetrically with a Cahn electrobalance.

RESULTS AND DISCUSSION

All data are summarized in the Appendix with selected subsets of data presented in a graphical form for discussion. The ranges and averages for various organic matter parameters are also summarized in Table 3.

Site 642—Outer Vøring Plateau

Site 642, on the outer Vøring Plateau, is 1272 meters below sea level (mbsl) (Fig. 1). The 320 m of cored sediment are predominantly pelagic-hemipelagic of Neogene and Quaternary ages, with approximately 50 interbedded ash layers (Eldholm, Thiede, Taylor, et al., 1987). Total organic carbon (TOC) at Site 642 averages 0.9% and ranges from 0.3% to 1.5% (Fig. 2, Table 3). This is similar to TOC's measured by Hood et al. (1976) and Erdman and Schorno (1976) in the same area. The highest values are present in Miocene sediments (164 m to 193 m sub-bottom) where sedimentation rates were estimated to be 1.7 cm/1000 yr. Abundant silicious components in this time period (middle Miocene) suggest enhanced marine productivity. Rock-Eval analysis confirms the presence of a mixture of marine and terrestrial organic matter at this site (kerogen Type II-III, Kvenvolden and McDonald, this volume).

Extractable organic matter (EOM) content ranges from 11 ppm to 18 ppm, with an average of 12 ppm (n = 6, Fig. 2, Table

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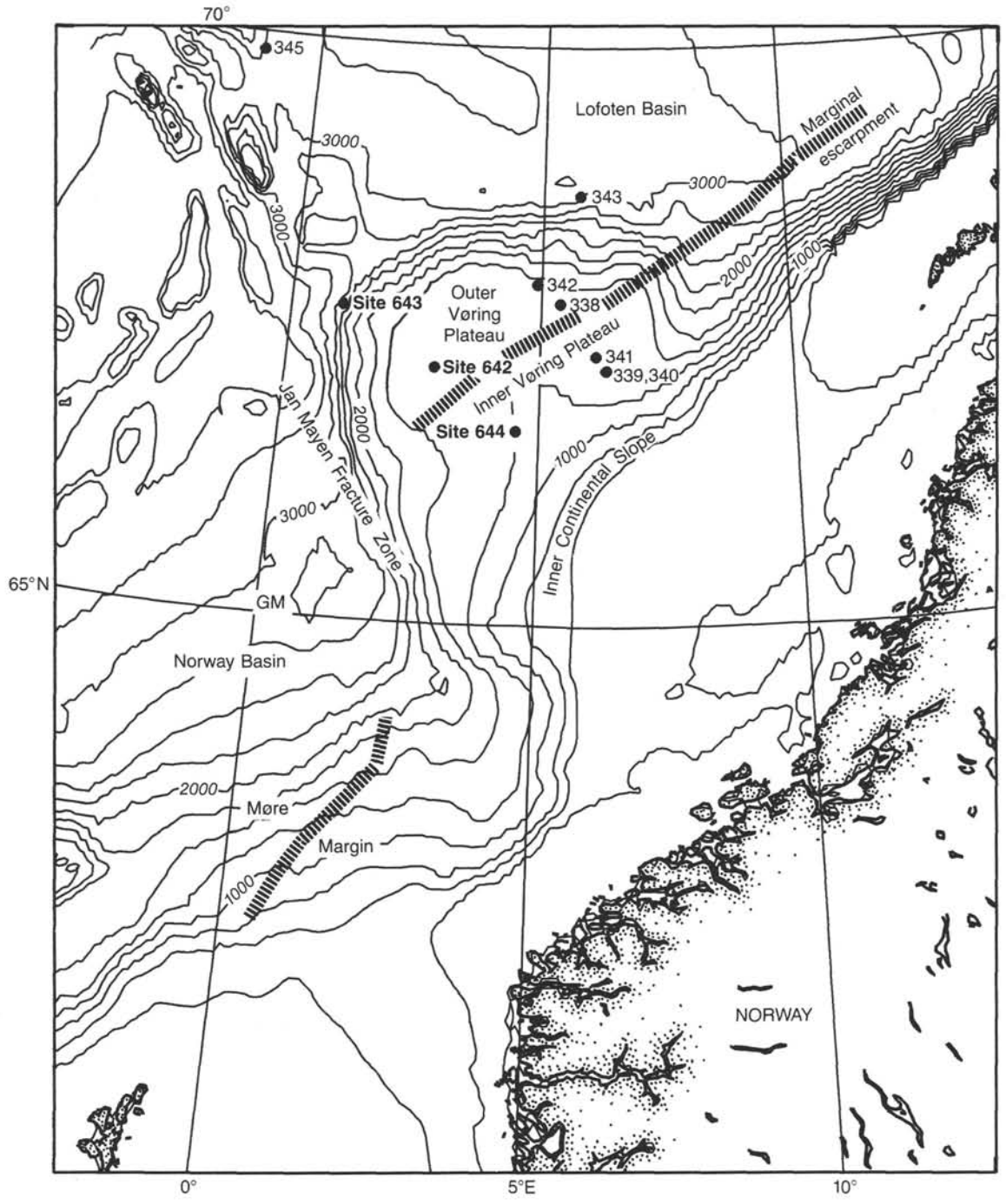

Figure 1. Vøring Plateau coring sites, ODP Leg 104. Contours in meters.

3). The unresolved complex mixture (UCM) varies from 8 to 13 ppm (Fig. 2, Table 3). Individual alkane concentrations vary from <5 to 371 ppb but are in general less than 50 ppb (Fig. 3, Appendix). Total n-alkane concentrations (sum of C_{15} to C_{32} normal alkanes) are low ranging from 239 to 1,478 ppb (Fig. 4). The carbon preference index ranges from 2.4 to 7.6 indicating a significant presence of odd-number chain length normal alkanes previously attributed to terrestrially sourced organic matter (Fig. 4; Kennicutt et al., 1987b). The aliphatic hydrocarbons represent a mixture of terrestrial and mature, petrogenic inputs with a small contribution from marine sources possible. Pristane and phytane are present in nearly equal amounts except in the shallowest and deepest sections (Fig. 4). No trend in aliphatic hydrocarbon concentrations with increasing depth is observed (Figs. 3 and 4). Polynuclear aromatic hydrocarbons (PAH) are also present at low concentrations and range from 24 ppb to 126 ppb (sum of the PAH's listed in the Appendix) and also show no apparent trend with depth (Figs. 5 and 6). With few exceptions individual PAH concentrations are less than 10 ppb (Fig. 3, Table 3). Based on the low concentrations of hydrocarbons detected, a lack of an increase with increasing depth, and supporting geological and stratigraphic data, we believe the majority of the hydrocarbons at Site 642 are derived from organic matter that was ice-rafted to its present location.

Site 643—Outer Vøring Plateau

ODP Site 643 is located on the lower slope near the foot of the outer Vøring Plateau at 2753 mbsl. Drilling penetrated

Table 1. Operating conditions for the analysis of polynuclear aromatic hydrocarbons by gas chromatography/mas spectrometry.

Mass Spectrometer—GC/MS HP 5996 linked with an HP1000 (RPN) Data System
or —GC/MSD HP 5970 Mass Selective Detector interfaced to an HP 5970 Gas Chromatograph configures to an HP 7946 computer linked with HP1000 (RPN) Data System

Ion source: 250°C	Multiplier voltage: 2500 V
Transfer line: 290°C	Entrance lens: 50 mVv/AMU
Analyzer: 250°C	Repeller: 9.8 V
Run time: 36 min	Ion focus: 16 V
Scan start time: 5 min	Axis gain: −63
Electron energy: 7O eV	Axis offset: −6
X-ray: 44 V	AMU gain: 149

Selected Ion Monitoring

M/Z	Dwell Time (ms)	Compounds Detected
91	30	*alkylbenzenes
128	30	naphthalene
136	30	*d_8-naphthalene
142	30	C_1-naphthalenes
154	30	biphenyl, acenaphthene
156	30	C_2-naphthalenes
162	30	*hexamethylbenzene
164	30	*d_{10}-acenaphthene
166	30	fluorene
178	30	phenanthrene/anthracene
188	50	*d_{10}-phenanthrene
192	50	C_1-3 rings
202	50	fluoranthene, pyrene
228	100	benz(a)anthracene, chrysene
240	100	*d_{12}-chrysene
252	100	benzopyrenes, perylene
264	150	*d_{12}-perylene
278	150	dibenzanthracenes

Gas Chromatography

Injector: 300°C, splitless mode
Total Run Time: 36 min
Column: 50 m, 0.52-μm film, 0.31-mm i.d., cross-linked methyl silicone (HP)

	Level 1
Temp 1	40°C
Time 1	0 min
Rate	10°C/min
Temp 2	300°C
Time 2	10 min

*Internal standards.

565 m of pelagic and hemipelagic Cenozoic sedimentary sequences. Total organic carbon ranges from < 0.1% to 1.8% (Fig. 2). Organic carbon concentrations increase irregularly with depth, reaching a maximum value in the Oligocene (347 mbsf) of 1.8% (Fig. 2). Underlying Eocene sediments have low organic carbon concentrations, averaging less than 0.1%. Rock-Eval analyses suggest that the organic matter at this site is a mixture of Types II and III (Kvenvolden and McDonald, this volume). EOM concentrations range from 6 ppm to 22 ppm and average 11 ppm (n = 16, Fig. 2, Table 3). UCM concentrations range from 5 ppm to 17 ppm (Fig. 2). As at Site 642, total n-alkane concentrations were low and ranged from 176 to 1,196 ppb with individual compound concentrations generally less than 50 ppb (Fig. 3 and 4). The CPI varies from 1.0 to 5.3 and pristane/phytane ratios vary from 0.6 to 3.9 (Fig. 4 and Appendix). PAH concentrations are also similiar to those at Site 642 with total PAH ranging from 6 ppb to 95 ppb (Figs. 5 and 6, Table 3). As at Site 642, no regular trends with depth are apparent and an ice-rafted mechanism of transport is suggested as the predominant source of hydrocarbons and organic matter at Site 643.

Table 2. Operating conditions for the analysis of aliphatic hydrocarbons by gas chromatography with flame ionization detection.

Gas Chromatographs:

Hewlett-Packard 5880

Temp. 1	60°C
Time 1	0 min
Rate	12°C/min
Temp. 2	300°C
Time 2	9 min
FID Temp.	300°C
Inj. Port	300°C
Carrier Gas	Helium
Make Up Gas	Helium
Splitless mode	

Column:
25-m Crosslinked methyl silicone
0.22-mm i.d.
0.33-μm film thickness
Hewlett-Packard

Site 644—Vøring Basin

ODP Site 644, located in the Vøring Basin close to the inner continental slope, overlies subsided continental crust at 1227 mbsl. Drilling at this site recovered 250 m of core. Organic carbon content ranges from 0.4% to 1.0%. No trend with depth is apparent (Fig. 2, Table 3). Typing by Rock-Eval suggests the presence of predominantly immature organic matter of terrestrial origin (Kvenvolden and McDonald this volume). EOM ranges from 12 ppm to 59 ppm and averages 27 ppm (n = 15, Fig. 2, Table 3). UCM concentrations range from 9 to 43 ppm (Fig. 2). Total n-alkane concentrations range from 825 ppb to 3,214 ppb (Fig. 4, Table 3). The CPI varies from 1.9 to 3.5 and pristane/phytane ratios vary from 0.5 to 4.3. Individual alkane concentrations were two- to three- fold higher at Site 644 than at Sites 642 and 643 and often exceed 50 ppb (Fig. 3). Total PAH concentrations range from 53 ppb to 820 ppb (Table 3). In general, PAH with three or more rings are significantly higher at Site 644 than at Sites 642 and 643 (Fig. 5 and 6). All sections contain a complex mixture of aromatic hydrocarbons indicative of mature petroleum-related compounds, but there is no apparent trend with depth (Figs. 5 and 6). The same ice-rafted source of hydrocarbons is suggested at Site 644 as at the other sites. At Site 644 the EOM, UCM, total alkanes, and terrestrially sourced hydrocarbons all covary with subsurface maxima at approximately 50, 150, and 200 m (Figs. 4 and 5). The aromatic hydrocarbon distributions also exhibit similar trends (Figs. 5 and 6). This covariation suggests a common source for both aliphatic and aromatic hydrocarbons that is closely associated with terrestrially derived materials, confirming the proposed recycled nature of the organic matter at these sites. The higher levels of hydrocarbons at Site 644 may be the result of (1) more organic material being ice-rafted to this site, (2) the original source material being enriched in hydrocarbons as compared to that which was the source of organic matter at the other two sites, and/or (3) the terrestrial input being less diluted with marine organic or inorganic material.

CONCLUSIONS

From recent investigations, it is well established that the major aspects of sediment distribution and morphology in the Vøring Plateau region are controlled by slumping and mass wasting which have occurred despite morphologically shallow gradients over many margin sediments. High sedimentation rates and li-

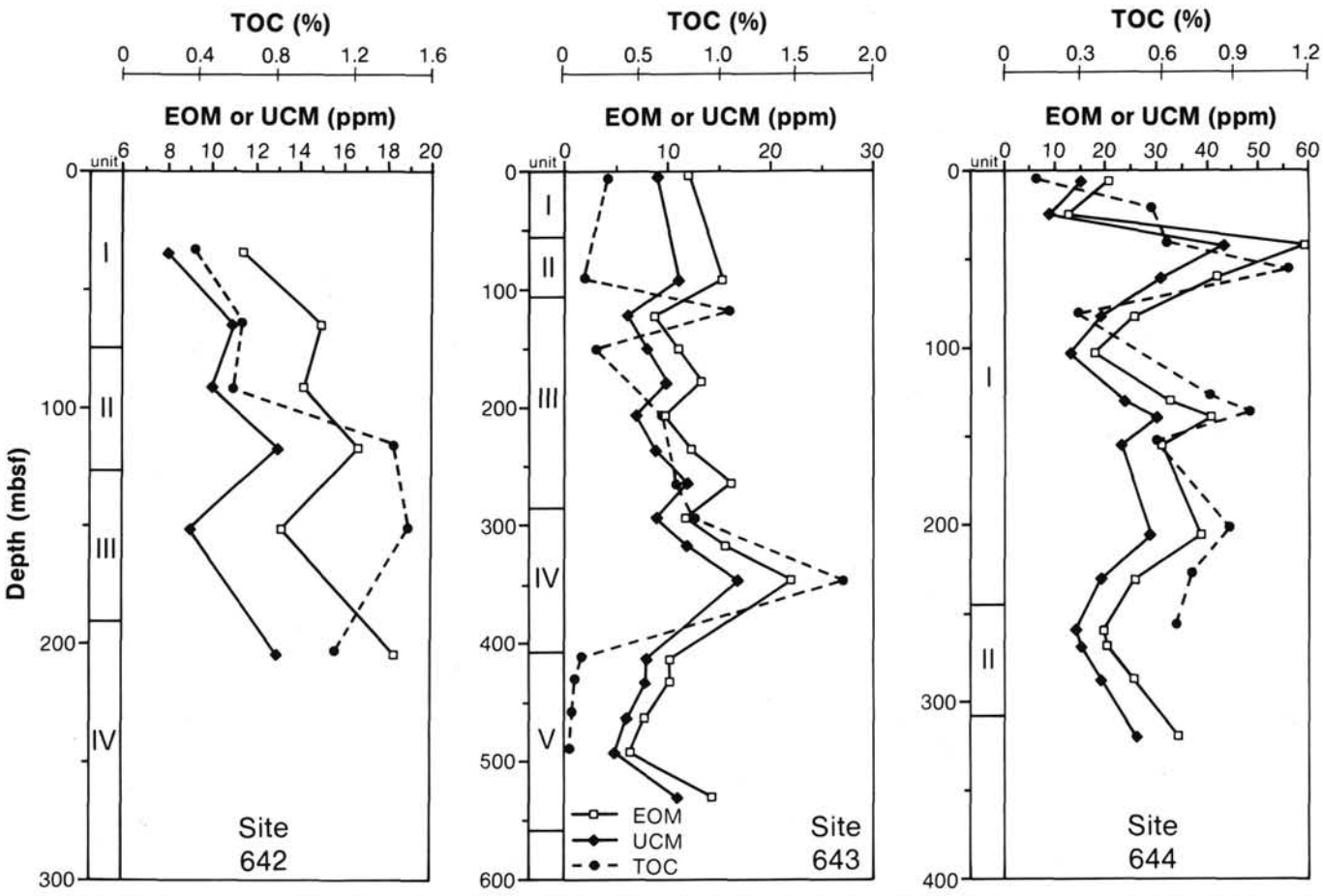

Figure 2. Variations in total organic carbon, extractable organic matter content, and unresolved complex mixture concentrations with depth at ODP Leg 104 sites.

Table 3. Summary of bulk organic matter and hydrocarbon parameters at Vøring Plateau, ODP Leg 104 sites.

Site Parameter[a]	642	643	644
TOC (%)	0.9[b] (0.3–1.5)[c]	0.5 (<0.1–1.8)	0.7 (0.4–1.0)
EOM (ppm)	12 (11–18)	11 (6–22)	27 (12–59)
UCM (ppm)	11 (8–13)	10 (5–17)	22 (9–43)
AH (ppb)	1,013 (239–1,478)	542 (176–1,196)	1,454 (825–3,214)
PAH (ppb)	55 (24–126)	37 (6–95)	196 (53–820)
CPI	3.7 (2.4–7.6)	3.3 (1.0–5.3)	2.7 (1.9–3.5)
Pristane/Phytane Ratio	1.1 (0.1–2.0)	1.6 (0.6–3.9)	1.8 (0.5–4.3)

[a] TOC—Total organic carbon; EOM—extractable organic matter; UCM—unresolved complex misture; AH—total aliphatic hydrocarbons (GC/FID); PAH—total aromatic hydrocarbons (GC/MS); CPI—carbon preference index.
[b] Average value.
[c] Range in values.

thology probably play key roles in the process (Eldholm, Thiede, Taylor, et al., 1987). At Sites 642, 643, and 644, aliphatic hydrocarbons, aromatic hydrocarbons, the unresolved complex mixture, and extractable organic matter concentrations are low and exhibit no relationship to sub-bottom depth. These distributions are most likely caused by the episodic nature of and variations in organic matter inputs. Slumping and mass wasting would also tend to redistribute the organic matter after deposition-producing erratic distributions (Kennicutt et al., 1987a). During the early Pliocene and Pleistocene, interglacial conditions prevailed and the majority of sediment transport was off of the continental shelf into the deeper water sites (Eldholm, Thiede, Taylor, et al., 1987).

Morris (1976) analyzed sediment from Site 341 (DSDP Leg 38) which is located near Site 644 of this report (Fig. 1). He determined that all of the sections sampled contained petroleum-like compounds, and that their concentrations increased with depth. He suggested that petroleum had migrated from a deep source upward into these shallow, immature sediments. Hydrocarbon analyses at all three sites from this study also suggest the presence of mature hydrocarbons. This conclusion is based on the detection of a complex mixture of alkanes, naphthalenes, phenanthrenes, and other high molecular weight aromatic compounds of a mature nature. In contrast to the Morris (1976) study, no regular trends with depth were observed, contradicting an upward migratory source. Yet the presence of mature hydrocarbons in immature sediments needs explanation. Hydrocarbons that are present, other than those related to petroleum, are predominantly of terrestrial origin i.e., plant biowaxes with 23 to 31 carbons (particularly the odd-number alkanes). The most probable source of hydrocarbons and organic matter at these sites is ice-rafted debris. This interpretation is suggested by the sporadic distribution of the hydrocarbons, the covariation in many organic matter characteristics, and the aforementioned lack of increasing amounts of hydrocarbons with increasing depth. The abundance of reworked Cretaceous and early Tertiary nannofossils present at these sites (Donnally, this volume) confirms that the recycling of mature, older sediments from the

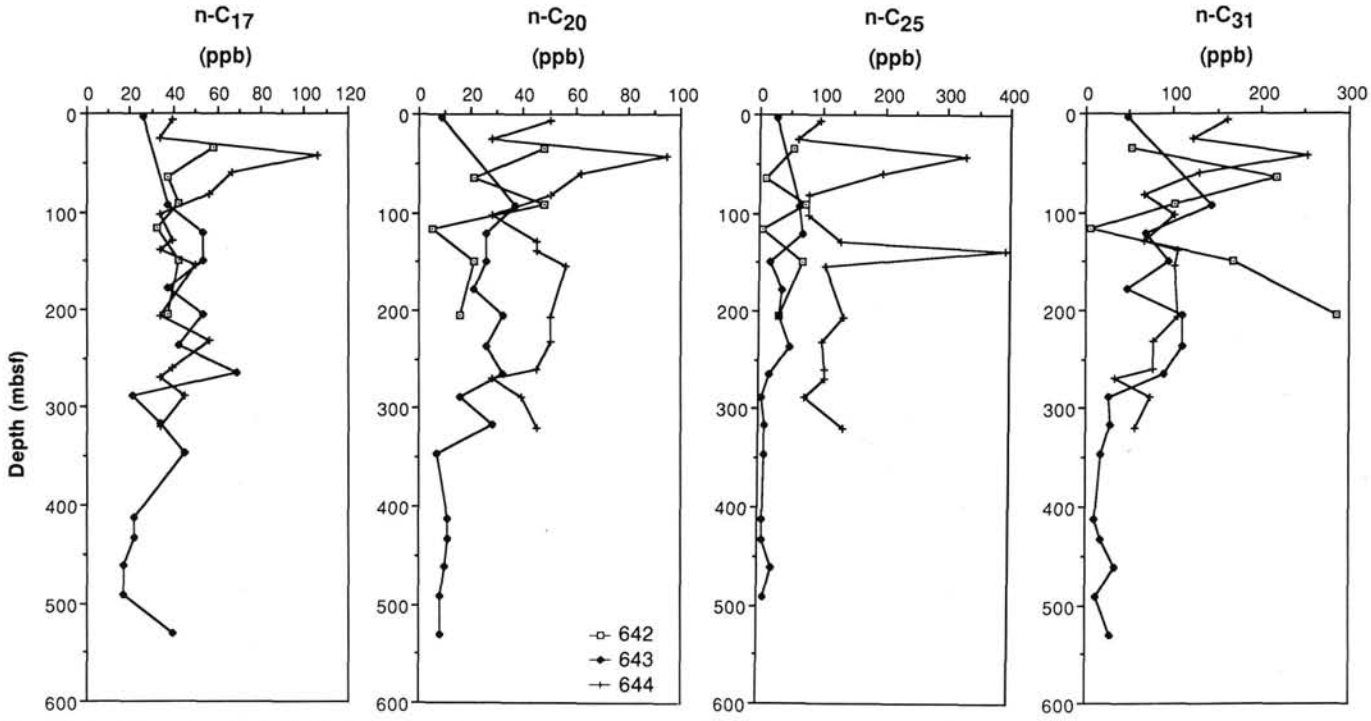

Figure 3. Variations in selected individual normal alkane concentrations with depth at ODP Leg 104 sites.

adjacent exposed continent has extensively influenced sedimentary organic matter on the Vøring Plateau.

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REFERENCES

Eldholm, O., Thiede, J., Taylor, E., 1987. *Proc. ODP, Init. Repts.*, 104: College Station, TX (Ocean Drilling Program).

Erdman, J. G., and Schorno, K. S., 1976. Geochemistry of carbon, DSDP Leg 38. *In* Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 791–799.

Hood, A., Castaño, J. R., and Kendrick, J. W., 1976. Petroleum-generating potential and thermal history of DSDP Leg 38 sediments. *In* Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 801–803.

Kennicutt, II, M. C., Denoux, G. J., Brooks, J. M., and Sandberg, W. A., 1987a. Hydrocarbons in Mississippi fan and intraslope basin sediments. *Geochim. Cosmochim. Acta*, 51: 1457–1466.

Kennicutt, II, M. C., Barker, C., Brooks, J. M., DeFreitas, D. A., and Zhu, G. H., 1987b. Selected organic matter source indicators in the Orinoco, Nile, and Changjiang Deltas. *Org. Geochem.*, 11: 41–51.

MacLeod W. D., Jr., Brown, D. W., Friedman, A. J., Burrows, D. G., Maynes, O., Pearce, R. W., Wigren, C. A., and Bogar, R. G., 1985. Standard analytical procedures of the NOAA analytical facility, 1985–1986. Extractable toxic organic compounds, 2nd edition. *NOAA Tech. Memo. NMFS F/NWC-92*: Washington (National Marine Fisheries Service, NOAA).

Morris, D. A., 1976. Organic diagenesis of Miocene sediments from Site 341, Vøring Plateau, Norway. *In* Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 809–814.

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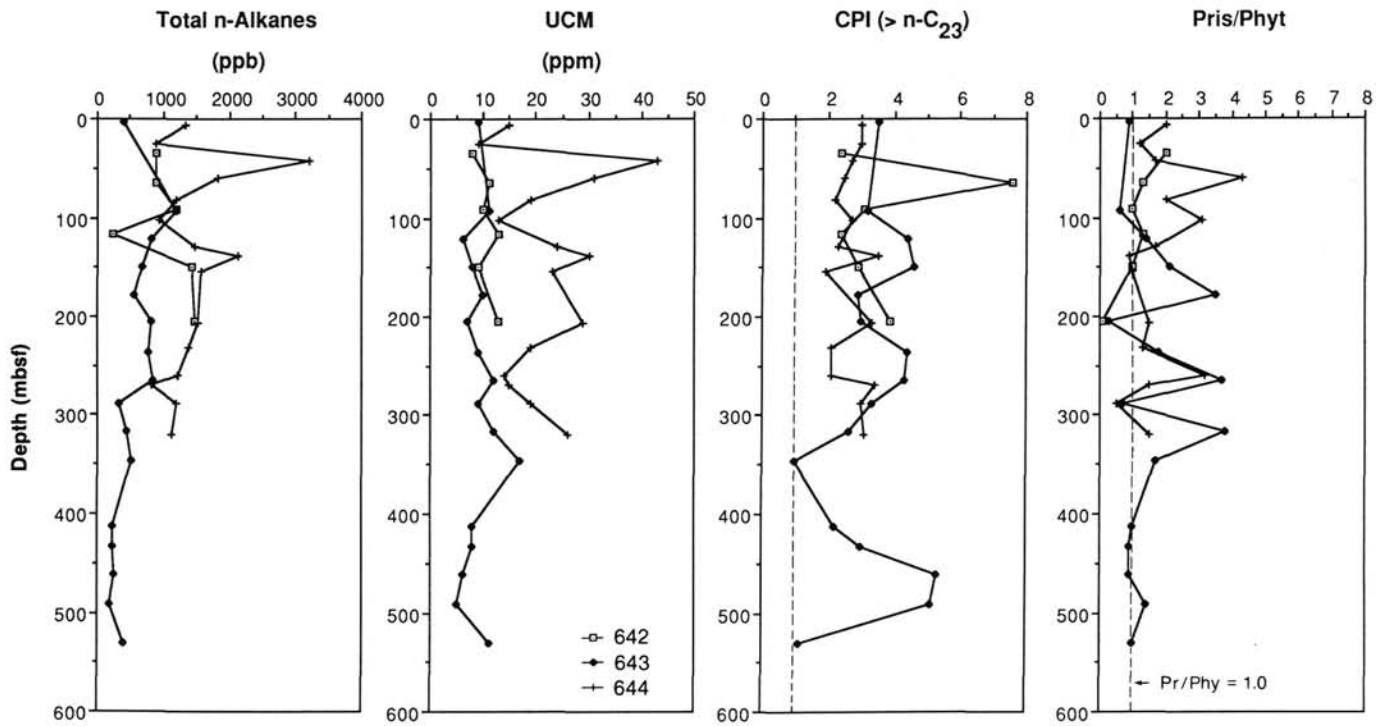

Figure 4. Variations in total n-alkane concentrations C_{15} to C_{32}, and in selected aliphatic hydrocarbon ratios, with depth at ODP Leg 104 sites.

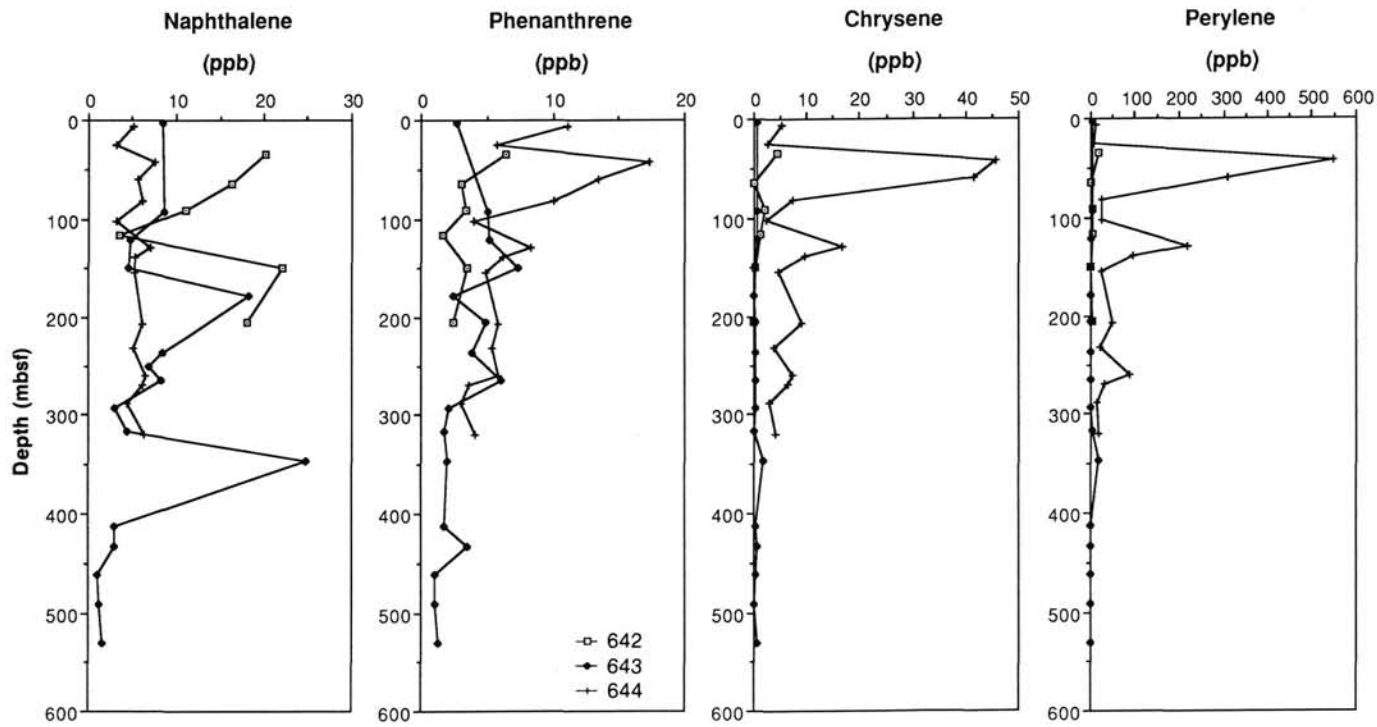

Figure 5. Variations in selected aromatic hydrocarbon concentrations with depth at ODP Leg 104 sites.

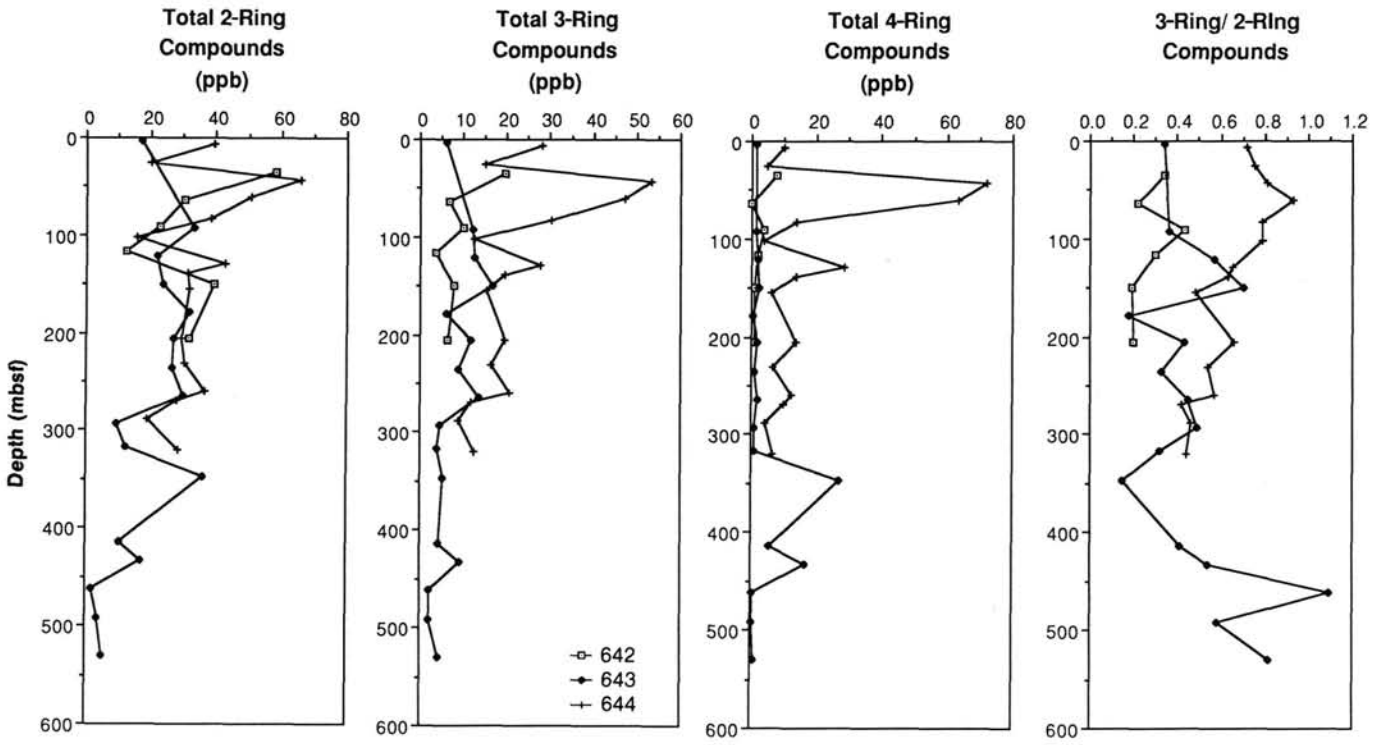

Figure 6. Variations in selected suites of aromatic hydrocarbons and the ratio of phenanthrenes to naphthalenes with depth at ODP Leg 104 sites (2-ring = naphthalene + methyl naphthalenes + dimethylnaphthalenes + biphenyl; 3-ring = phenanthrene + anthracene + methyl phenanthrenes; 4-ring = benz(a)anthracene + chrysene + pyrene; 5-ring = benzo(e)pyrene + benzo(a)pyrene + perylene + dibenzanthracene).

APPENDIX
Hydrocarbon Data

Normal alkane concentrations

Site	Depth (mbsf)	TOC (%)	EOM (ppm)	TOT UCM (ppm)	n-C_{11} (ppb)	n-C_{12} (ppb)	n-C_{13} (ppb)	n-C_{14} (ppb)	n-C_{15} (ppb)	n-C_{16} (ppb)	n-C_{17} (ppb)	Prist (ppb)	n-C_{18} (ppb)	Phyt (ppb)
642B	34.3	0.3	11	8	11	21	26	53	64	58	58	42	58	21
642D	64.3	0.5	15	11	7	21	21	53	48	37	37	21	37	16
642B	91.2	0.6	14	10	5	21	26	69	64	53	42	16	85	16
642D	116.8	1.4	17	13	5	6	9	26	26	26	32	7	37	6
642B	151.3	1.5	13	9	5	21	21	69	79	53	42	21	63	21
642B	205.3	1.2	18	13	8	26	21	53	48	37	37	3	37	21
643A	3.2	0.3	12	9	16	16	12	32	26	21	26	10	16	12
643A	92.3	0.1	15	11	16	26	26	69	64	53	37	16	69	26
643A	121.1	1.1	9	6	6	14	14	42	53	48	53	21	42	15
643A	149.6	0.2	11	8	10	21	21	58	58	48	53	16	42	7
643A	178.1	nd	13	10	9	16	12	37	37	32	37	16	32	5
643A	205.5	0.6	10	7	12	21	21	58	58	48	53	5	53	16
643A	235.6	0.7	12	9	7	12	16	37	37	37	42	37	37	21
643A	264.1	0.7	16	12	11	32	32	85	79	64	69	58	58	16
643A	282.5	0.8	12	9	6	11	12	26	21	21	21	7	26	10
643A	316.1	1.1	16	12	8	17	15	45	39	34	34	28	39	7
643A	346.6	1.8	22	17	15	22	22	62	56	45	45	28	56	17
643A	413.1	0.1	10	8	10	8	9	22	22	17	22	8	17	8
643A	433.5	0.1	10	8	1	2	4	13	17	16	22	4	17	5
643A	462.1	0.1	8	6	3	3	5	12	14	13	17	6	15	7
643A	492.1	0.1	7	5	3	5	6	16	17	15	17	5	13	4
643A	530.1	0.0	14	11	3	10	13	28	34	34	39	17	39	17
644A	6.1	0.4	21	15	17	22	28	50	56	45	39	22	28	11
644A	25.0	0.6	13	9	17	17	17	34	39	34	34	13	34	11
644A	42.6	0.7	59	43	34	50	67	106	129	118	106	106	151	62
644A	60.0	1.0	42	31	22	34	39	67	78	73	67	73	78	17
644A	82.0	0.5	26	19	34	45	45	78	73	67	56	34	62	17
644A	102.5	nd	18	13	10	17	17	34	34	34	34	22	39	7
644A	129.5	0.8	33	24	17	28	34	67	56	50	39	28	56	17
644A	139.0	0.8	41	30	17	17	28	50	45	39	34	10	62	11
644A	155.0	0.6	31	23	22	39	45	90	78	62	50	22	84	22
644A	205.6	0.8	39	29	39	34	34	62	56	39	34	17	67	11
644A	231.0	0.7	26	19	22	39	39	84	84	67	56	22	90	17
644A	259.6	0.7	19	14	22	28	34	62	62	50	39	39	73	12
644A	269.1	nd	20	15	17	22	22	50	45	39	34	13	45	9
644A	288.1	nd	26	19	13	22	28	62	56	50	45	12	73	22
644A	319.6	nd	34	26	22	34	34	78	73	50	34	17	56	11

nd = not determined. mbsf = meters below seafloor. tr = trace (<0.1 ppb).

PAH (ppb)

Site	Depth (mbsf)	CPI >n-C_{23}	Pris/phyt	Naph	2-methyl naph	1-methyl naph	Biphenyl	Dimeth 2,6 naph #1	Dimeth naph #2	Dimeth naph #3	Dimeth naph #4	Dimeth naph #5	Dimeth naph #6	Dimeth naph #7	Acenap
642B	34.3	2.4	2.0	20.2	12.3	13.4	1.6	0.7	2.4	tr	4.0	2.1	2.4	0.8	0.2
642D	64.3	7.6	1.3	16.4	2.5	1.7	1.1	0.6	1.8	0.9	2.0	1.9	1.5	0.8	tr
642B	91.2	3.1	1.0	11.0	2.6	2.2	tr	0.4	1.6	0.1	2.0	1.1	1.1	0.5	tr
642D	116.8	2.4	1.3	3.5	2.6	1.9	0.7	0.3	1.1	0.1	1.2	0.7	0.6	0.2	0.2
642B	151.3	2.9	1.0	22.1	5.2	3.3	1.4	0.5	2.3	tr	2.4	1.5	1.4	0.6	0.2
642B	205.3	3.9	0.1	18.0	3.4	2.2	1.1	0.5	2.1	0.7	1.7	1.3	1.5	0.3	tr
643A	3.2	3.5	0.9	8.5	2.4	1.1	1.0	0.5	1.3	0.2	1.4	0.8	0.8	0.2	tr
643A	92.3	3.2	0.6	8.6	9.2	4.4	2.1	0.5	2.9	tr	2.6	2.1	1.4	1.2	0.4
643A	121.1	4.4	1.4	4.7	6.5	3.4	1.4	0.5	1.7	tr	1.7	1.7	1.3	0.4	0.4
643A	149.6	4.6	2.1	4.6	4.2	2.8	2.2	0.8	3.2	tr	3.0	2.5	2.0	0.5	0.1
643A	178.1	2.9	3.5	18.3	4.1	3.0	tr	0.3	1.6	0.2	1.7	1.3	0.9	0.4	0.4
643A	205.5	3.0	0.3	6.8	5.7	3.2	1.6	0.7	3.0	tr	3.2	1.8	1.8	0.7	0.2
643A	235.6	4.4	1.8	8.4	6.0	3.9	1.3	0.8	1.7	tr	2.0	1.6	1.4	0.9	0.2
643A	264.1	4.3	3.7	8.3	6.3	3.7	2.1	0.7	2.9	tr	2.9	2.2	2.0	0.8	0.3
643A	282.5	3.3	0.7	2.9	1.7	0.8	0.8	0.4	1.1	0.1	0.9	0.9	0.7	0.1	0.1
643A	316.1	2.6	3.8	4.3	2.5	1.8	0.6	0.2	1.0	tr	0.9	0.9	0.5	0.2	tr
643A	346.6	1.0	1.7	24.8	3.7	2.0	0.9	0.4	1.5	tr	1.4	1.0	0.9	0.3	tr
643A	413.1	2.2	1.0	2.9	2.0	0.9	0.7	0.3	1.4	tr	1.0	0.5	0.7	0.5	0.2
643A	433.5	3.0	0.9	2.9	4.5	3.6	0.6	0.1	1.6	tr	1.5	1.3	1.1	0.6	0.2
643A	462.1	5.3	0.9	1.0	0.6	0.5	0.3	tr	tr	tr	tr	tr	tr	tr	0.1
643A	492.1	5.1	1.4	1.2	1.0	0.4	0.4	0.1	0.4	tr	0.3	0.2	0.3	0.1	0.1
643A	530.1	1.1	1.0	1.5	0.9	0.5	0.4	0.3	0.5	tr	0.7	0.5	0.3	0.2	0.2
644A	6.1	3.0	2.0	5.1	10.3	7.2	4.5	0.8	4.2	tr	4.6	2.9	3.0	1.0	0.3
644A	25.0	3.0	1.2	3.2	4.4	3.4	2.2	0.4	2.2	tr	2.3	1.7	1.8	0.6	0.3
644A	42.6	2.7	1.7	7.6	16.6	11.9	5.0	2.3	6.7	tr	8.8	4.7	5.4	1.9	0.8
644A	60.0	2.5	4.3	5.7	9.6	8.5	3.4	2.0	5.8	tr	8.0	4.3	5.1	1.8	0.9
644A	82.0	2.2	2.0	6.2	9.0	0.1	8.3	1.5	5.1	0.2	6.8	3.7	4.2	1.4	0.2
644A	102.5	2.7	3.1	3.2	3.0	3.1	1.1	0.1	1.2	0.1	1.9	1.1	1.3	0.4	0.2
644A	129.5	2.3	1.7	7.0	8.0	8.4	2.4	1.3	3.7	tr	6.6	2.9	3.8	1.1	0.2
644A	139.0	3.5	0.9	5.3	6.4	5.5	1.7	0.8	3.1	tr	4.4	2.4	2.5	0.9	0.2
644A	155.0	1.9	1.0	5.3	5.7	5.2	tr	1.0	3.2	tr	4.3	3.0	3.1	0.8	0.5
644A	205.6	3.3	1.5	6.2	6.0	5.1	1.4	0.7	2.4	tr	4.0	1.9	2.3	0.6	0.4
644A	231.0	2.1	1.3	5.1	7.6	7.5	1.1	0.2	2.0	tr	3.4	1.8	1.9	0.6	0.3
644A	259.6	2.1	3.2	6.5	8.1	8.1	1.2	0.7	2.7	tr	4.5	2.3	2.5	1.0	0.4
644A	269.1	3.4	1.5	6.2	5.2	5.1	1.4	0.6	2.1	0.1	3.9	2.0	2.1	0.8	0.4
644A	288.1	3.0	0.5	4.3	4.3	3.5	0.9	0.4	1.5	tr	2.1	1.0	1.3	0.3	0.2
644A	319.6	3.1	1.5	6.3	6.0	4.2	1.4	0.8	2.4	tr	3.9	2.2	2.1	0.7	0.4

nd = not determined. mbsf = meters below seafloor. tr = trace (<0.1 ppb).

APPENDIX (continued).

Normal alkane concentrations														
n-C_{19} (ppb)	n-C_{20} (ppb)	n-C_{21} (ppb)	n-C_{22} (ppb)	n-C_{23} (ppb)	n-C_{24} (ppb)	n-C_{25} (ppb)	n-C_{26} (ppb)	n-C_{27} (ppb)	n-C_{28} (ppb)	n-C_{29} (ppb)	n-C_{30} (ppb)	n-C_{31} (ppb)	n-C_{32} (ppb)	Total n-C_{15} to n-C_{32} (ppb)
53	48	13	42	53	37	53	32	74	32	69	21	53	3	884
21	21	22	16	9	16	9	11	90	37	196	C	217	5	855
48	48	8	21	48	37	74	42	180	64	207	48	101	3	1203
32	<5	8	8	6	10	5	<5	16	<5	10	<5	<5	3	239
32	21	21	21	37	32	69	48	217	85	286	95	169	9	1423
21	16	9	16	21	26	32	32	270	74	371	95	286	25	1478
10	9	11	10	11	7	26	16	48	16	58	11	48	4	396
42	37	21	26	42	26	64	42	154	64	212	42	143	15	1196
32	26	26	26	21	12	69	11	95	32	138	21	69	14	825
32	26	26	26	21	11	16	21	64	21	90	C	95	8	683
32	21	21	21	21	12	37	21	58	21	69	21	48	4	565
26	32	32	32	21	21	32	16	69	32	111	37	111	11	815
26	26	26	26	21	21	48	16	74	26	122	21	111	1	779
37	32	26	32	16	16	16	6	69	16	106	26	90	5	837
16	16	8	10	8	8	5	3	37	13	48	12	26	2	319
22	28	10	14	8	15	9	6	45	13	50	13	28	8	450
34	7	17	28	17	28	11	11	39	22	11	22	17	11	522
15	11	12	13	10	6	7	4	17	5	10	3	10	7	223
13	11	10	11	10	5	8	5	17	7	22	7	17	1	225
12	10	11	8	11	5	22	6	28	8	34	5	34	0	264
8	8	10	8	7	3	10	2	17	3	15	3	12	0	176
28	8	17	15	10	8	C	10	11	22	34	17	28	20	406
50	50	39	39	84	45	95	78	196	62	179	34	162	17	1333
28	28	22	28	50	34	62	50	118	39	118	28	123	7	900
157	95	123	123	185	106	330	134	353	134	375	95	252	78	3214
106	62	73	67	118	62	196	67	174	67	196	50	129	78	1831
62	50	50	45	73	45	78	45	146	50	101	34	67	35	1188
34	28	22	34	56	39	78	39	123	34	106	28	101	32	925
84	45	56	67	118	62	129	62	207	67	168	45	67	62	1484
73	45	34	50	118	62	392	39	515	73	213	17	106	196	2132
95	56	45	45	90	50	106	95	196	67	174	39	101	95	1574
56	50	45	45	112	62	134	78	269	112	230	6	106	0	1529
78	50	39	39	73	50	101	56	174	67	146	28	78	67	1383
62	45	34	34	67	45	106	67	146	56	118	28	78	45	1205
45	28	22	22	50	28	106	28	134	28	78	11	34	25	825
62	39	28	28	56	34	73	34	174	62	202	45	73	19	1184
39	45	28	22	50	34	134	39	168	39	151	56	56	13	1116

PAH (ppb)														
Fluorene	Phenan	Anthrac	3-methyl phenan	2-methyl phenan	9-methyl phenan	1-methyl phenan	Fluoranth	Pyrene	Benz(a) anthrac	Chrysene	Benzo(a) pyrene	Benzo(a) pyrene	Perylene	Dibenz anthrac
1.3	6.4	0.2	2.9	3.1	4.4	2.7	1.4	2.2	1.2	4.4	6.9	1.8	16.7	10.1
0.8	3.0	tr	0.6	0.7	1.5	0.9	tr	tr	tr	tr	tr	tr	tr	tr
0.8	3.4	tr	1.8	1.7	1.8	1.1	0.4	0.7	0.8	2.1	1.7	tr	4.1	tr
0.4	1.6	tr	0.5	0.6	0.6	0.3	0.7	0.3	0.2	1.3	0.2	0.2	4.1	0.1
1.0	3.5	tr	1.2	1.0	1.2	0.8	0.3	0.4	tr	0.4	tr	tr	1.4	tr
1.0	2.4	tr	1.1	0.8	0.9	1.1	tr	1.0	tr	tr	tr	tr	4.3	tr
0.6	2.7	tr	0.7	0.7	1.2	0.7	0.9	0.9	tr	0.5	1.0	tr	4.5	tr
1.3	5.0	0.2	1.7	2.0	1.9	1.1	0.5	0.6	0.4	0.6	3.2	tr	4.9	1.0
1.5	5.2	0.1	1.8	1.8	2.2	1.3	1.0	1.0	0.2	0.5	1.1	0.2	0.3	tr
2.1	7.4	0.1	2.4	2.8	2.4	1.5	1.3	2.1	0.2	0.3	0.9	tr	0.9	0.1
0.7	2.4	tr	0.8	1.2	1.0	0.5	tr	0.7	tr	tr	tr	tr	tr	tr
1.5	4.9	0.3	1.6	1.7	1.9	1.2	0.8	1.4	0.2	0.2	0.8	0.2	0.9	0.1
1.3	3.9	0.2	1.2	1.4	1.3	0.8	0.4	0.4	tr	0.4	0.2	0.2	0.6	0.3
1.8	6.1	0.3	1.8	1.8	2.1	1.4	0.3	1.2	0.3	0.3	0.3	0.2	0.9	0.2
0.7	2.1	0.1	0.6	0.7	0.7	0.5	0.4	0.7	tr	0.4	0.5	0.9	1.7	0.1
0.4	1.7	0.2	0.6	0.6	0.5	0.3	0.2	0.8	tr	tr	tr	tr	1.9	0.4
0.6	2.0	tr	1.0	0.9	0.8	0.6	0.7	23.7	1.5	1.9	2.1	4.9	17.6	tr
0.5	1.8	0.1	0.6	0.6	0.6	0.5	0.5	5.0	0.5	0.3	1.2	1.1	1.4	0.3
0.9	3.5	0.1	1.5	1.5	1.4	1.2	1.0	15.5	0.2	0.7	0.9	0.8	0.9	tr
0.2	1.0	tr	0.3	0.4	0.3	0.3	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1
0.3	1.1	tr	0.3	0.4	0.3	0.2	0.1	0.3	0.1	tr	0.1	tr	0.1	tr
0.4	1.3	0.1	0.8	0.9	0.8	0.5	0.1	0.2	0.3	0.6	0.1	0.1	0.3	tr
2.3	11.1	0.1	4.2	5.4	4.2	3.2	2.5	3.3	1.3	5.4	5.2	0.5	11.3	0.4
1.1	5.7	0.1	2.1	2.9	2.4	1.8	1.0	1.3	0.7	2.7	2.6	0.7	6.9	0.2
4.5	17.3	0.7	8.6	9.0	10.1	7.5	9.8	17.7	8.8	45.6	33.7	24.3	549.0	0.8
3.8	13.4	0.4	8.1	7.7	10.8	6.9	8.1	15.1	7.0	41.4	26.1	14.3	308.2	2.4
3.1	10.0	0.2	4.8	5.5	5.7	4.0	3.2	4.8	1.7	7.2	9.3	1.8	26.3	0.7
1.0	4.0	tr	2.0	2.2	2.4	1.7	1.0	1.3	0.1	2.2	2.5	0.8	25.9	0.4
3.2	8.3	0.3	4.2	4.6	6.3	3.9	4.2	6.6	5.1	16.7	23.3	14.0	216.7	3.8
2.0	6.2	tr	3.3	3.5	3.8	2.7	2.1	2.6	1.4	9.7	8.4	1.8	93.5	0.2
1.9	4.9	0.1	2.6	2.8	2.9	2.0	1.5	0.6	0.9	4.8	4.9	1.0	24.5	1.0
1.9	5.9	0.1	3.4	3.6	3.8	2.7	2.3	3.1	1.5	9.0	8.2	0.7	49.8	0.9
1.8	5.4	0.1	2.6	2.8	3.3	2.2	1.5	2.2	0.7	3.8	4.7	0.3	19.5	0.3
2.2	5.8	0.2	3.5	3.9	4.3	3.0	2.1	3.8	1.2	7.4	9.6	1.7	88.6	0.5
1.4	3.6	0.1	1.9	2.0	2.6	1.6	1.5	2.6	1.2	6.3	7.2	1.4	33.2	0.3
1.1	3.0	tr	1.3	1.5	1.7	1.2	0.7	1.0	0.4	2.9	3.4	0.9	14.8	tr
1.9	4.1	tr	2.2	2.1	2.5	1.7	1.2	1.8	0.7	4.1	3.3	0.5	1.3	tr