

65. GEOCHEMISTRY OF CARBON: LEGS 56 AND 57, DEEP SEA DRILLING PROJECT

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INTRODUCTION

Forty-three core sections from Sites 434, 435, 438, 439, and 440 on the landward side and six core sections from Site 436 on the seaward side of the Japan Trench (Figures 1 and 2) were obtained through the JOIDES Organic Geochemistry Advisory Panel for study of the origin and state of genesis of the organic matter associated with these continental slope, accretionary wedge, and outer trench slope sediments of the Japan Trench. The lipid fraction of these sediments is derived primarily from terrigenous organic matter and thus is allochthonous to the area. The associated kerogen fraction is of mixed allochthonous and autochthonous origin. The total organic carbon content seaward of the trench is less than that on the landward side. The composition of this organic matter is similar but not identical to that found in the landward side sediments.

The organic matter within these sediments is in a diagenetic state in which geopolymerization of biogenic organic matter is nearly complete, but microbial alteration is still occurring.

SAMPLING AND STUDY PROCEDURES

Where possible, the sampling and analysis procedures used in this report are the same as those described in the *Initial Reports* for Leg 44 (Erdman and Schorno, 1978). Because of the paucity of soluble organic matter (lipid) in these sediments, only the carbon isotopic composition of the lipid fraction and gas chromatographic (gc) profile of the *n*-heptane soluble portion of lipid fraction are determined. The gc-profiles of several of the Leg 56 and 57 samples are generated from a 50' × 0.02" OV101 SCOT column. The data used in calculating *n*-alkane distributions and the ratio of pristane to phytane originate from these profiles. With the exception of *n*-C₂₈, the resolution of *n*-alkanes on this column is sufficient for determining the average odd-even ratio ($\overline{\text{OEP}}$) of odd to even *n*-alkanes as given by Scalan and Smith (1970). Because *n*-C₂₈ is not resolved on this column, its area is an estimate obtained by averaging the areas of *n*-C₂₆ and *n*-C₃₀. In these cases the resolution of pristane from *n*-C₁₇ and phytane from *n*-C₁₈ is not sufficient for estimating pristane to phytane ratios. For the remaining samples the 50' × 0.02" OV101 SCOT column used previously is replaced with a high resolution 150' × 0.01" OV101 glass capillary column. By so doing, complete resolution of the *n*-alkanes is achieved and approximately 90 per cent resolution of the isoprenoids pristane and phytane from *n*-C₁₇ and *n*-C₁₈, respectively.

RESULTS

The organic geochemical data accumulated during this study are given in Tables 1 and 2. The 49 cores examined are mostly diatomaceous muds and mudstones. The carbonate content of these muds is low, averaging 1.9 per cent of the total sediment with a maximum of only 7.2 per cent.

The organic carbon content averages 0.57 per cent. The average organic carbon content in the sediments farthest from shore on the seaward side of the trench from Site 436 is well below the average of all cores studied (0.13 versus 0.57 per cent) and is equal to the average value for open marine DSDP sediments (0.1 per cent). The organic carbon contents of the midslope terrace cores from Site 440 are the highest values (1.2 per cent each) of that of all the cores studied in this work. The organic content in the continuous stratigraphic section from Sites 438 and 439 decreases with depth from a high of 1.0 per cent at 223 meters to a low of 0.1 per cent at 994 meters. No obvious trends in this value with depth are noted elsewhere in the study area.

The average of the lipid content of these cores is 125 ppm. The highest values are found in the midslope terrace cores in the narrow depth interval between 571 and 666 meters in Hole 440B. The average value for the percentage of lipid carbon in the total organic carbon content is 2.3 per cent (Table 1). The highest values (13.5 and 20.0 per cent) are found in the midslope terrace Cores 440B-46-3 and 440B-51-3, respectively. These same cores also contain the highest lipid content — 1203 and 1021 ppm, respectively.

The average value for $\overline{\text{OEP}}$ for these cores ($\overline{\text{OEP}}_{\text{av}} = 2.9$) is indicative of sedimentary organic matter in an early state of genesis. Only in Core 439-31-5 does the indicator of maturity $\overline{\text{OEP}}$ drop within the range of mature organic matter (1.3). $\overline{\text{OEP}}$ values of less than 1.3 are typical of either organic matter in an advanced stage of genesis or a mixture of mature and immature organic matter caused by oil migrating from below. Because both the lipid content and the portion of the total organic carbon that is lipid are low — 55 ppm and 2 per cent, respectively — it is highly unlikely that oil has migrated up into this section. Furthermore, because $\overline{\text{OEP}}$ decreases regularly from 2.2 to 1.7 in the units directly above this one, there is no reason to doubt that the value of 1.1 is not consistent with this trend.

The average value of the stable carbon isotopic ratio for both the lipid and kerogen fractions given as $\delta^{13}\text{C}_{\text{PDB}}$ are -26.0 and -23.3, respectively. The kerogen δ values for the shallow cores (less than 335 meters) are

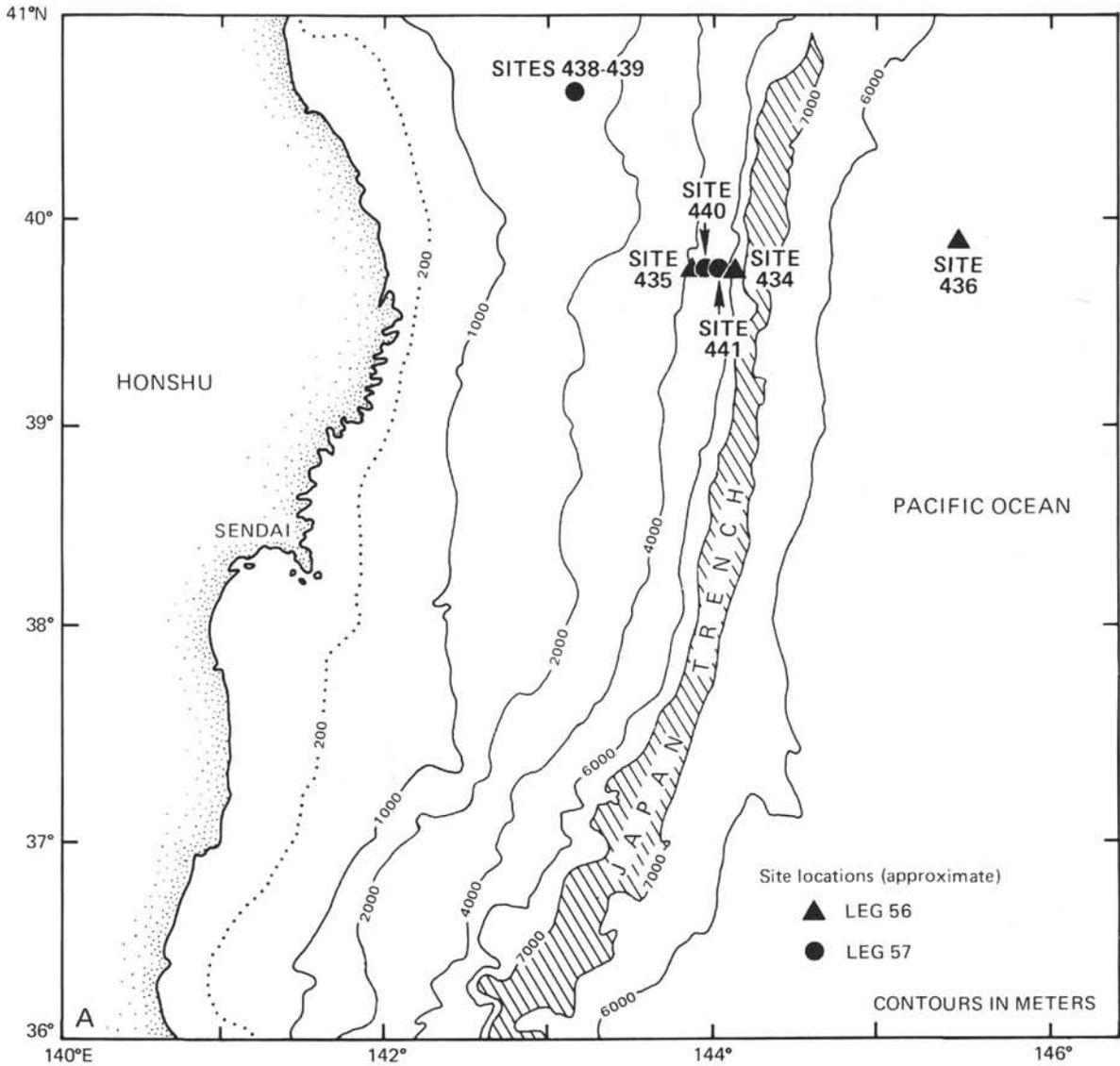


Figure 1. Site locations for DSDP Legs 56 and 57 showing where samples for geometric study were obtained.

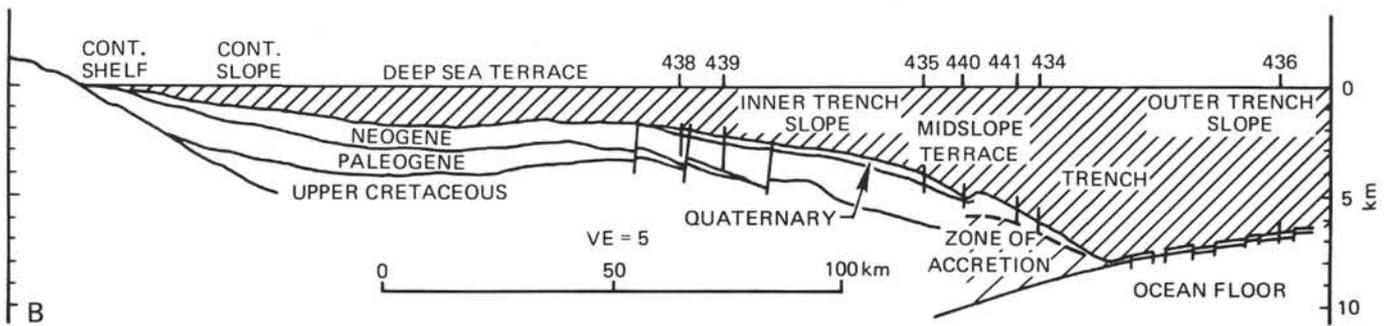


Figure 2. Schematic cross section showing chronostratigraphy and depth.

slightly heavier than that of the deeper cores. The range of values for any one depth, however, can be as large as 2.06 units. Because kerogens normally become heavier with depth owing to selective ^{12}C - ^{12}C bond breakage during genesis, the increase in lighter kerogens with depth is probably due to source rather than to maturity.

The δ values of the lipid and kerogen fractions of the middle Miocene to Oligocene suite of cores between 722.3 and 1093.1 meters from Sites 438 and 439 are constant (-26.0 ± 0.5 and -24.9 ± 0.8 , respectively). The consistency of these δ values within these depth and time intervals suggests that the source of original sedi-

TABLE 1
Geochemical Data from DSDP Legs 56 and 57, Chronostratigraphy, Depth, Carbonate and Organic Carbon, Carbon Isotopic Composition, and OEP Values

Core	Section	Interval (cm)	Chronostratigraphy	Sub-bottom Depth (m)	Carbonate		Organic Carbon		Lipid/Total Organic Carbon (wt. %)	OEP ^a	Carbon Isotopic Composition ($\delta^{13}C_{PDB}$)			Kjeldahl Nitrogen (ppm)		Atomic Ratio Organic C/Organic N
					Carbon (wt. %)	AS CaCO ₃ (wt. %)	Total (wt. %)	Lipid (ppm)			Lipid	Kerogen	Diff. L-K	Ammonium Nitrogen (half)	Organic N (full-half)	
Midslope terrace, landward side of Japan Trench, at water depth of 5986 m																
Hole 434, Unit 1	3	125-150	Pleistocene	4.25-4.50	0.6	5.0	0.6	55	0.9	2.8	-26.0	-20.6	-5.4	194	1266	6
Hole 434, Unit 2	15	0-29	Lower Pliocene	133.00-133.29	0.2	1.7	0.4	16	0.4	3.6	-23.8	-24.4	+0.6	231	524	9
	23	125-150	Lower Pliocene	208.75-209	0.6	5.0	0.6	148	2.5	2.9	-27.4	-22.3	-5.1	217	737	9
Hole 434B, Unit 3	15	117-142	Lower Pliocene	419.17-419.42	0.2	1.7	0.7	153		3.6	-24.5	-23.6	-0.9	389	841	10
Midslope terrace, upper slope of the landward side of Japan Trench, at water depth of 1565 m																
Hole 435, Unit 1	5	115-150	Pleistocene	42.15-42.50	0.1	0.8	0.8	199	2.5	3.3	-25.8	-22.2	-3.6	151	879	11
	13	125-150	Middle Pliocene	115.25-115.50	0.2	1.7	0.8	61	0.8	4.1	-26.2	-26.7	+0.5	260	641	15
Trench outer slope, seaward side of Japan Trench, at water depth of 5240 m																
Hole 436, Unit 1	7	100-130	Pleistocene	61.00-61.3	0.0	0.2	0.1	48	4.0	1.7	-26.0	-22.3	-3.7	38	167	7
	11	115-150	Upper Pliocene	99.15-99.50	0.1	0.8	0.2	90	4.7	2.7*	-23.9	-21.7	-2.2	55	319	7
Hole 436, Unit 2A	19	115-150	Lower Pliocene	172.15-172.50	0.2	1.7	0.2	78	3.4	2.8	-25.3	-22.4	-2.9	51	363	6
	24	120-150	Lower Pliocene	218.20-218.5	0.1	8.0	0.2	58	3.8	2.2	-25.3	-23.4	-1.9	82	385	6
Hole 436, Unit 3B	31	90-120	Upper Miocene	284.40-284.70	0.1	0.8	< 0.1	1	0.4	2.7	-25.1	-24.6	-0.5	50	163	2
UNIT 4																
Hole 436, Unit 4	36	100-130	Upper Miocene	335.0-335.30	0.2	1.7	0.1	32	6.3	b	-23.8	-19.9	-3.9	49	365	3
Fault-bounded block on trench inner slope, landward side of Japan Trench, at water depth of 1565 m																
Hole 438, Unit 1	5	100-130	Lower Pleistocene	37.50-37.80	0.1	0.8	0.4	32	0.7	3.0	-25.7	-23.3	-2.4	100	500	9
	10	100-130	Upper Pliocene	86.50-86.50	0.1	0.8	0.9	53	0.6	2.5	-26.2	-22.0	-4.2	300	900	12
Hole 438A, Unit 2	4	120-150	Pleistocene	47.70-48.00	0.2	1.7	0.3	12	0.4	1.8*	-26.6	-23.6	-3.0	200	300	12
Hole 438A, Unit 2, Sub-unit 2A	18	100-130	Lower Pliocene	223-223.3	0.2	1.7	1.0	8	0.1	2.1	-24.8	-22.8	-2.0	1000	200	58
	24	120-150	Lower Pliocene	283.2-283.5	0.4	3.3	0.9	59	0.6	2.5	-26.5	-22.9	-3.6	600	600	18
	29	125-150	Lower Pliocene	332.25-332.5	0.1	0.8	0.9	20	0.2	1.8*	-26.1	-22.4	-3.7	600	600	18
Hole 438A, Unit 2, Sub-unit 2B	34	120-150	Lower Pliocene	379.7-380.0	0.2	1.7	0.7	52	0.8	3.4	-25.2	-22.7	-2.5	500	500	16
	40	125-150	Upper Miocene	436.75-437	0.8	6.7	0.3	72	2.2	1.5*	-26.5	-22.7	-3.8	500	500	7
	46	120-150	Upper Miocene	492.7-493	0.2	1.7	0.6	2	0.0	2.2*	-26.2	-23.7	-2.5	700	300	23
	50	110-140	Upper Miocene	532.1-532.4	0.1	0.8	0.5	101	1.7	2.5*	-25.7	-23.9	-1.8	500	400	15
	55	120-150	Upper Miocene	581.2-581.5	0.1	0.8	0.6	12	0.2	3.4	-28.4	-24.0	-4.4	302	812	9
Hole 438A, Unit 2, Sub-unit 2C	65	115-150	Middle Miocene	676.15-676.5	0.2	1.7	0.5	71	1.4	b	-28.8	-24.7	-4.1	309	643	9
	70	125-150	Middle Miocene	722.25-722.5	0.1	0.8	0.6	33	0.5	b	-26.7	-25.4	-1.3	500	500	14
	79	110-140	Middle Miocene	806.1-806.4	0.1	0.8	0.6	166	2.5	2.9	-25.3	-25.2	-0.1	301	524	13
Hole 438A, Unit 3	84	115-140	Middle Miocene	850.65-850.9	0.2	1.7	0.6	b	b	2.7	-26.2	b	b	283	521	13
	4	90-130	Middle Miocene	861.7-862.1	0.1	0.8	0.6	29	0.5	3.0	-25.7	-24.9	-0.8	352	686	10
Hole 439, Unit 3	9	110-135	Lower Miocene	893.1-893.35	0.2	1.7	0.5	66	1.1	2.7*	-25.3	-24.8	-0.5	250	540	11
Hole 438B, Unit 3	12	114-122	Lower Miocene	935.84-935.92	0.3	2.5	0.5	b	b	3.6*	-25.8	-24.8	1.0	251	784	7
Hole 438B, Unit 4	19	120-140	Lower Miocene	997.50-997.70	0.2	1.7	0.3	12	0.4	1.6	-26.3	-23.3	-3.0	250	540	6
Hole 439, Unit 5	21	100-125	Lower Miocene	994.5-994.75	0.2	1.7	0.1	4	0.8	2.2	-26.6	-26.4	-0.2	110	60	19
	25	125-150	Oligocene	1035.75-1036.	0.3	2.5	0.4	37	1.0	1.7	-25.8	-24.8	-1.0	80	310	14
	31	5-20	Oligocene	1093.05-1093.2	0.9	7.5	0.3	55	2.0	1.1	b	-24.8	b	90	300	12
Midslope terrace, landward side of Japan Trench, at water depth of 4515 m																
Hole 440, Unit 1	5	15-20	Pleistocene	42.65-43.0	0.3	2.5	1.2	645	5.4	4.7	b	-22.2	b	90	1630	9
Hole 440A, Unit 2	7	110-135	Pleistocene	138.6-138.85	0.4	3.3	1.2	12	1.0	3.5	-29.5	-21.8	-7.7	380	1170	12
Hole 440B, Unit 2	3	120-150	Pleistocene	165.7-166.0	0.3	2.5	0.9	78	1.9	3.5	-25.6	-22.9	-2.7	370	890	12
	8	110-140	Pleistocene	211.6-211.9	0.2	1.7	0.5	81	5.4	4.5	-25.0	-22.9	-2.1	350	1480	4
	12	100-130	Pleistocene	249.5-249.8	0.3	2.5	0.4	64	3.4	3.4	-25.9	-22.6	-3.3	290	440	11
	17	110-150	Pleistocene	298.6-299	0.3	2.5	0.7	122	0.9	5.4	-26.3	-23.0	-3.3	420	800	10
	23	125-150	Pleistocene	354.25-354.56	0.3	2.5	1.0	113	1.5	2.7	b	b	b	b	b	b
Hole 440B, Unit 3	29	125-150	Upper Pliocene	409.75-410.00	0.3	2.5	0.8	70	0.9	2.6	-25.2	-22.5	-2.7	380	880	11
	34	110-140	Upper Pliocene	457.1-457.40	0.3	2.5	0.5	66	1.2	3.0	-25.6	-22.5	-3.1	360	1030	6
	39	100-135	Upper Pliocene	504.0-504.85	0.2	1.7	1.2	151	1.3	4.6	-24.9	-22.3	-2.6	370	620	23
	46	110-150	Upper Pliocene	571-571.50	0.5	4.2	0.9	1203	13.5	1.9	-26.6	-22.7	-3.9	788	9212	1
	51	110-150	Upper Pliocene	618.6-619.0	0.2	1.7	0.6	b	b	3.3	-26.2	-22.4	-3.8	273	1100	6
	56	100-140	Upper Pliocene	660-666.40	0.2	1.7	0.5	1021	20.0	2.5	-27.2	-23.9	-3.3	878	222	26
	63	110-150	Upper Miocene	732.6-733.0	0.4	3.3	0.5	159	2.9	3.1	-25.0	-23.7	-1.3	317	683	9
	68	120-150	Upper Miocene	778.7-779.0	0.2	1.7	0.4	32	0.8	2.8	-27.0	-23.7	-3.3	287	613	8

^a Calculated from oil extract fraction, those values marked with aster are calculated from $n-C_{23}$ to $n-C_{33}$.

^b Sample insufficient or unsuitable for misdetermination.

TABLE 2
A Computation of the Ratio of Pristane to Phytane
and $(n-C_{21} + n-C_{22})/(n-C_{28} + n-C_{29})$ (S)

Site/Core/Section	Pristane Phytane	$\frac{(n-C_{21} + n-C_{22})}{(n-C_{28} + n-C_{29})}$
434-1-3	1.2	0.4
434-15-3	1.6	0.4
434-23-2	2.2	0.6
434B-15-1	2.2	0.4
435-5-4	2.6	0.4
435-13-2	3.0	0.4
436-7-4	2.4	0.5
436-11-4	—	0.6
436-19-2	—	0.6
436-24-1	—	0.3
436-31-1	—	0.7
436-36-3	—	0.9
438-5-3	—	0.6
438-10-4	—	0.6
438A-4-4	—	0.3
438A-18-2	—	1.9
438A-24-2	—	0.4
438A-29-5	—	0.9
438A-34-5	2.8	0.8
438A-40-5	—	0.8
438A-46-3	1.6	0.7
438A-50-4	1.3	3.1
438A-55-5	2.3	0.7
438A-65-5	—	0.8
438A-70-4	—	—
438A-79-3	2.6	0.4
438A-84-1	1.8	0.6
438A-4-6	0.7	0.4
438B-12-5	1.5	0.6
438B-19-2	4.5	2.0
439-9-4	—	0.3
439-21-2	—	0.5
439-25-4	0.9	0.9
439-31-5	3.7	2.2
440-5-6	1.6	0.3
440A-7-6	2.3	0.4
440B-3-5	0.5	0.2
440B-8-4	1.5	0.2
440B-12-4	0.7	0.5
440B-17-5	0.8	0.4
440B-23-4	1.1	0.8
440B-29-3	0.6	0.2
440B-34-3	0.7	1.7
440B-39-3	0.9	2.5
440B-46-3	0.8	1.5
440B-51-3	1.0	0.5
440B-56-3	2.2	0.7
440B-63-3	1.7	0.3
440B-68-2	0.4	0.8

Note: em-dash indicates that no pristane to phytane ratios were estimated.

mentary organic matter throughout this interval is similar. The δ values of the kerogen of these cores are in general lower than those from other cores in the study area. Likewise, the average of the differences of the lipid minus the kerogen δ values (L-K, Table 1) is smaller for this suite of samples than that of the remaining cores from the study area (-1.0 versus -3.0). Because there is only a slight variation in δ values of both the lipid and kerogen fractions between sites, the identification of organic facies lines based on these δ values between sites is questionable.

The average values for the ammonium and organic nitrogen contents and atomic ratio of carbon to nitrogen given in Table 1 are 321 ppm, 615 ppm, and 17, respectively. These three values are relatively constant for the cores from Site 436 on the seaward side of the trench — 54 ± 15 ppm, 294 ± 102 ppm, and 5 ± 2 ppm, respectively — and are less than the total averages for all samples studied in this work. One may conclude that these low values indicate a common source for the sedimentary organic matter at this site. Other geochemical parameters given in Table 1 do not necessarily support this conclusion.

The average for the \overline{OEP} values given in Table 1 is 2.9. In general \overline{OEP}_{av} for the accretionary wedge sediments (Sites 434 and 435) is higher than the total average (3.4 versus 2.9), indicating a possible variation in either the source or maturity of the lipid in sediments of the accretionary wedge. In general, \overline{OEP} is higher than the average for sediments of similar age from other holes in the study area. Even so, the high \overline{OEP} in all of these younger cores can still be derived from either of the aforementioned sources.

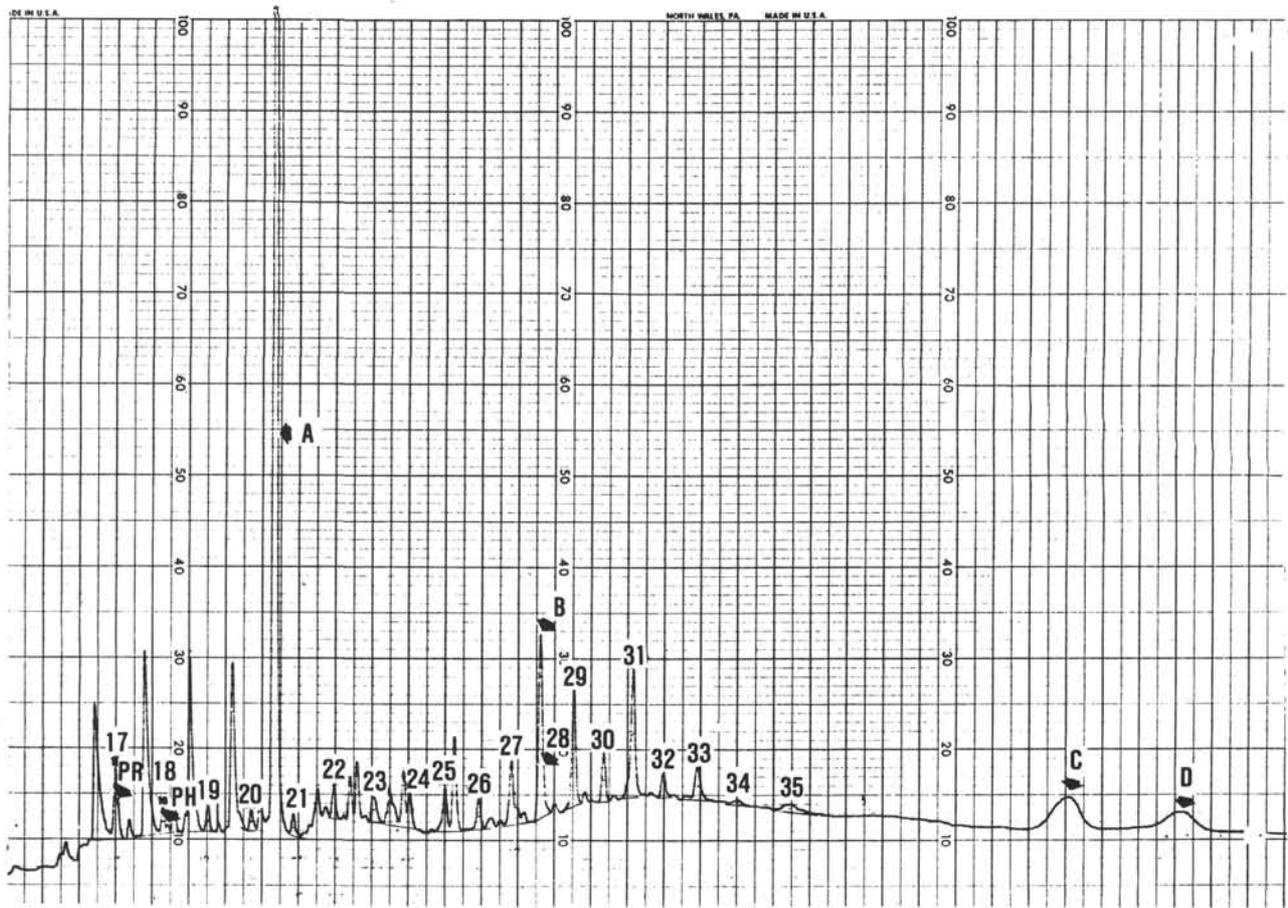
The average of the ratios of marine to terrigenous n -alkanes, defined as,

$$S = (n-C_{21} + n-C_{22})/(n-C_{28} + n-C_{29}),$$

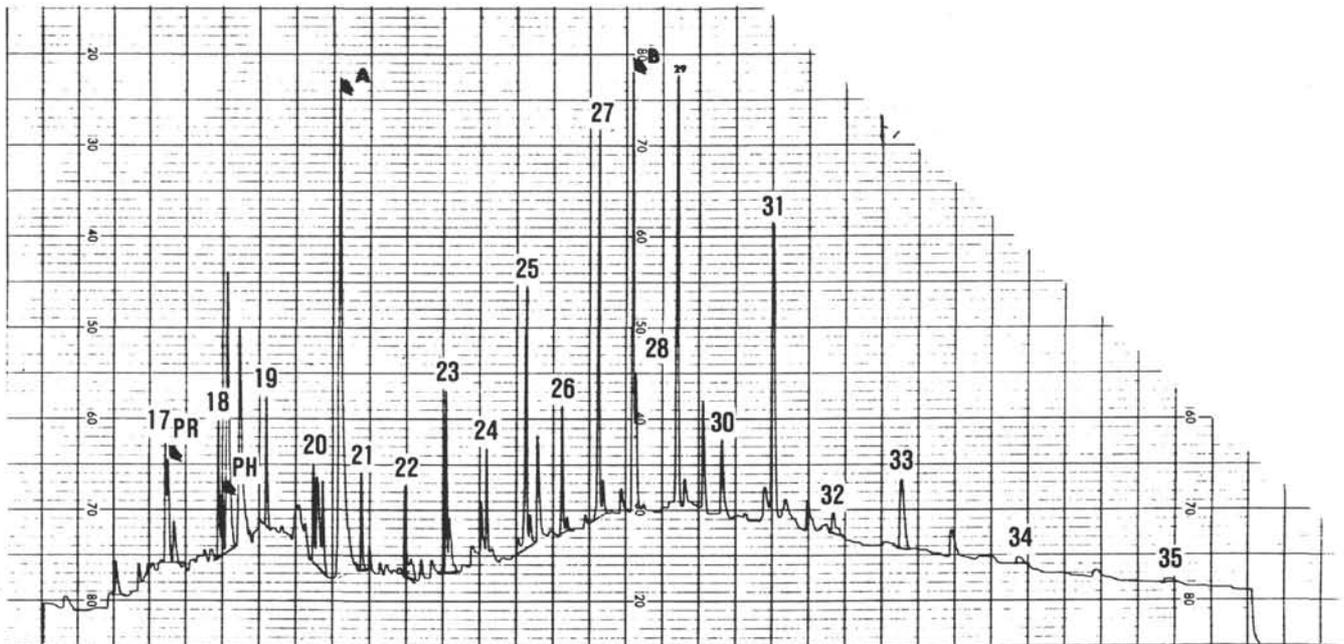
for the 46 samples for which S is measurable is 0.8 ± 0.6 . S is greater than 1.5 for only 7 of these 46 samples. These seven samples are randomly distributed throughout the holes studied. According to Philippi (1974), S ranges from 0.6 to 1.2 for terrigenous n -alkane sources and from 1.5 to 5 for marine n -alkane sources.

Pristane to phytane ratios for those samples for which pristane is measurable are given in Table 2. The quality of this data is demonstrated by the resolution of pristane from $n-C_{17}$ in chromatograms A and B, Figure 3. Chromatogram A shows the best and B the poorest resolution of these two compounds. Even though this ratio is only an estimate, the average values of these ratios and their trends with depth are significant. The average value for the 32 ratios given in Table 2 is 1.6, with a range from 0.4 to 4.5. According to Powell and McKirdy (1973), pristane to phytane ratios greater than 1.5 are indicative of terrigenous sediments. This ratio for core from Hole 439, Unit 5, increases with depth. The increase is due to variations in either the source or maturity of the organic matter in these cores. In this case the associated \overline{OEP} suggests the latter.

Four large unknown peaks, A, B, C, and D, are noted in the gas chromatograms shown in Figure 3A. Peak A is the largest component in 33 of the 49 chromatograms. It is possible that this compound is a contaminant — probably a plasticizer. Compound B occurs in nearly every chromatogram. However, the amount present in each varies considerably, with apparent concentrations bracketing $n-C_{28}$. This compound is either a contaminant or possibly a sterane or terpane. Two major peaks occur in most of the chromatograms of lipid samples from cores from Hole 434B and Sites 435 and 436 at long retention times (greater than that of $n-C_{37}$). Substituting a high resolution capillary column for part of the



A



B

Figure 3. Gas chromatograms showing peaks A, B, C, D (in A) and the best resolution of pristane from n - C_{17} , (in B) and poorest (in A). A. Chromatogram of lipid fraction of 436-24-1. B. Chromatogram of lipid fraction of 438B-4-6.

gc-profile analysis produces an increase in the retention times of the *n*-alkanes. To shorten the gc-run-time, the chromatograms are stopped after the elution of *n*-C₃₆, and the two lone eluting compounds are not detected thereafter.

DISCUSSION AND CONCLUSIONS

The positions of the sites relative to each other and the trench axis are shown in Figure 2. The large number of holes from the study area drilled during Legs 56 and 57 provides an excellent opportunity to obtain samples for mapping organic facies perpendicular to the trench axis. However, the geochemical parameters given in Tables 1 and 2 vary so much as to make facies identification questionable. In general, the total influx of organic matter into this area varies from hole to hole and to some extent within each hole in an irregular fashion. The variation, however, is neither large nor systematic for any but the trench outer slope sediments from Hole 436. In this case, the organic content is low, averaging 0.13 per cent as compared to 0.57 per cent for the average for all cores studied but slightly above the average of deep marine DSDP samples — 0.1 per cent. In addition, the δ values of the kerogen fractions of Hole 436 are generally heavier than the values from the sediments on the continental shelf, indicating a greater input of marine organic matter. However, because terrigenous *n*-alkanes are the major compounds of the *n*-heptane soluble lipid fraction, a considerable amount of terrigenous organic matter from the continent must have reached Site 436.

The amount of plant wax *n*-alkanes in these samples indicated by a low *S* value is high in 40 of the 47 samples for which *S* is measurable. Thus the lipid fraction of these 40 samples contains mainly terrigenous organic matter. The remaining seven samples have a predominance of marine organic matter (a high *S* value). These are randomly distributed throughout the sites studied and are not correlatable with depth, age, or organic type. Because *S* is relatively constant throughout the sites studied, it does not indicate changes in organic type; thus either the organic type is relatively constant throughout the study area or *S* is not sufficiently sensitive to detect slight changes in organic facies.

Because both the geologic and paleontologic data (see site summaries, this volume) indicate that the study area contains either pelagic (Site 436) or hemipelagic sediments (remaining sites studied), our findings in at least the former case are partially contradictory. A possible explanation for this contradiction, as noted earlier, is that the lipid fractions in most of these sediments are allochthonous, whereas the kerogens are a mixture of both allochthonous and autochthonous material. The allochthonous organic matter decreases across the trench axis in a seaward direction. However, its imprint is still visible in the lipid fraction of these sediments.

The ratio of pristane to phytane is to some extent diagnostic of source (Powell and McKirdy, 1973). The major precursor of pristane and phytane in sediments is

phytol. Pristane is considered a product of the oxidation–decarboxylation–reduction degradation of phytol. Pristane, however, is also synthesized by certain marine organisms. Phytane, on the other hand, is considered a product of the dehydration–reduction of phytol. Phytane is also synthesized by marine bacteria (Torabene, 1978). If the marine source of pristane is considered only minor, then pristane should predominate in an oxidative environment and phytane in a reducing environment. If we assume that oxic environments are associated with terrigenous organic sources, then pristane should be the major isoprenoid in these sediments. The shallow section of the study area is anoxic (see site summaries, this volume), and thus phytane should be the major isoprenoid present if phytol is the major precursor of both. As noted in Table 2, pristane predominates. These data support the earlier conclusion that the lipid fraction is primarily terrigenous.

The carbon isotopic composition of both the lipid and kerogen fractions is to some extent source-diagnostic. There has been more research on this aspect on the lipid than on the kerogen fractions. We have in the past assigned δ values for marine, brackish, and terrigenous lipid within the ranges of $> -29\%$, $< -29\%$ to -30% , $< -30\%$, respectively. The values of the lipid fractions presented in Table 1 fall within the range of marine organic matter, in agreement with the geologic data given in the site reports (this volume). In light of the previous discussion of the *n*-alkane and phytane content of these sediments, the traditional interpretation of lipid δ values as just noted may not be applicable. In this case, near-shore sediments may contain organic matter from a mixed source and have δ values as heavy as -25 .

With the exception of Sample 439-31-5, all of the samples studied are in an early stage of diagenesis. Tissot and Welte (1978) classify the various stages of kerogen genesis into diagenic, catagenic, and metagenic stages. A diagenic stage is characterized by a low geothermal gradient (temperatures of less than approximately 50°C) at the point at which both biogenic and abiogenic organic reactions are occurring. $\overline{\text{OEP}}$ for this stage is probably no less than 1.5. During the catagenic stage, abiogenic reactions, primarily thermal reactions, predominate. For this stage, $\overline{\text{OEP}}$ approaches 1. The metagenic stage is characterized by the decomposition of the lipid fraction to carbon. In only one case (Section 439-31-5) does $\overline{\text{OEP}}$ drop below 1.5 into the catagenic stage. Because $\overline{\text{OEP}}$ drops systematically with depth within the cores above this section, either a regular change from the diagenic to the catagenic stage of organic genesis is occurring in these sediments, or petroleum is migrating from lower sections. Because lower sections are not analyzed in this study, a distinction between the two cannot be made at this time.

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REFERENCES

- Erdman, J. G., and Schorno, K. S., 1978. Geochemistry of Carbon: Deep Sea Drilling Project Leg 44. In Benson, W. E., Sheridan, R. E., et al., *Init. Repts. DSDP, 44*: Washington (U.S. Govt. Printing Office), 605-615.
- Philippi, G. T., 1974. The influence of marine and terrestrial source material on the composition of petroleum. *Geochim. Cosmochim. Acta*, 36, 947-966.
- Powell, T. E., and McKirdy, D. M., 1973. Relationship between ratio of pristane to phytane, crude oil composition and geological environment in Australia. *Nature Phys. Sci.*, 243, 37-39.
- Scalen, R. S., and Smith, E. E., 1970. An improved measure of the odd-even predominance in the normal alkanes of sediment extracts and petroleum. *Geochim. Cosmochim. Acta*, 34, 611-620.
- Tissot, B. P., and Welte, D. H., 1978. *From Kerogen to Petroleum in Petroleum Formation and Occurrence*: New York (Springer-Verlag), chap. 5.
- Torabene, T. G., 1978. Squalenes, Phytanes and Other Isoprenoidal Oily Lipids of Methanogenic and Thermoacidophilic Archoebacteria [paper presented at the 177th National ACS Meeting, Waikiki].