

27. DISTRIBUTION, ORIGIN, AND HYDROCARBON POTENTIAL OF ORGANIC MATTER IN SEDIMENTS FROM THE PACIFIC MARGIN OF GUATEMALA¹

Colin P. Summerhayes and Debbie Gilbert, Exxon Production Research Company, Houston, Texas

ABSTRACT

Marine-derived amorphous organic matter dominates hemipelagic and trench sediments in and around the Middle America Trench. These sediments contain, on the average, 1% to 2% total organic carbon (TOC), with a maximum of 4.8%. Their organic facies and richness reflect (1) the small land area of Guatemala, which contributes small amounts of higher land plant remains, and (2) high levels of marine productivity and regionally low levels of dissolved oxygen, which encourage deposition and preservation of marine organic remains. These sediments have good potential for oil but are now immature. For this reason, gaseous hydrocarbons like the ethane identified in the deep parts of the section, as at Sites 496 and 497, are probably migrating from a mature section at depth. The pelagic sediments of the downgoing Cocos Plate are lean in organic carbon and have no petroleum potential.

INTRODUCTION

As part of an ongoing program of organic geochemical studies of sediments recovered by the Deep Sea Drilling Project, we have analyzed the types, amounts, and thermal alteration indices of organic matter collected from the Pacific continental margin of Guatemala on DSDP Leg 67 (Fig. 1; Table 1). The samples were pieces of core frozen aboard ship. Four of the samples were analyzed by pyrolysis (Table 3), and two for heavy C₁₅₊ hydrocarbons and nonhydrocarbons (Table 4), to find out if they were derived from marine or land plants and to determine their hydrocarbon potential.

The samples come from three main depositional environments—the continental slope, the Middle America Trench, and the Cocos Plate seaward of the trench (Fig. 1). This transect across the trench is the second of a pair, the first of which was made off Acapulco on Leg 66. According to von Huene, Aubouin, et al. (1980), the pre-Pliocene pelagic deposits that cover the Cocos Plate extend beneath the Middle America Trench as far as the foot of the continental slope. Beneath the slope their age-equivalent deposits are distal hemipelagic sediments. Both sequences are buried by rapidly deposited Pliocene/Pleistocene hemipelagic sediments or, in the trench, by turbidites.

As in Leg 66, our main objectives were to find out how much organic matter was being deposited; to establish whether it was from marine or terrestrial sources; to determine what controlled its deposition; to estimate its potential for hydrocarbon generation; and to compare and contrast the sedimentation of organic matter here with that on other Pacific margins.

TYPE AND AMOUNT OF ORGANIC MATTER

We treated the samples with dilute HCl to remove calcium carbonate, then measured their total organic carbon (TOC) content with a LECO analyzer (Table 1).

Using the classification scheme of Masran and Pocock (1979) (Table 1), we visually identified the different types of organic matter on slides prepared as described by Staplin (1969). Averages of organic richness (TOC) and organic matter type for different facies are presented in Table 2, with the same information from Leg 66 included for comparison.

Deep Sea Pelagic Facies

The deep sea pelagic carbonates found beneath hemipelagic and trench sediments at Sites 495, 499, and 500 have almost no organic matter (avg., 0.05% TOC; Table 2). Off Mexico, an equivalent facies deposited somewhat more rapidly is also carbon poor, containing an average 0.08% TOC (Summerhayes and Gilbert, in press). Low TOCs like these are typical of very slowly accumulating pelagic sediment, because at slow rates of sedimentation benthic organisms and bacteria recycle and decompose almost all except the most refractory organic matter (Aizenshtat et al., 1973).

Hemipelagic Oceanic Facies

On the Cocos Plate (Site 495), the deep sea pelagic facies is buried by a hemipelagic facies representing overflow deposits from the Middle America Trench (von Huene, Aubouin, et al., 1980). The equivalent deposits off Mexico were called "trench deposits" by Summerhayes and Gilbert (in press). In both areas, this sedimentary facies contains moderate amounts of organic matter, but has quite different organic facies² (Tables 1 and 2). The Guatemalan trench samples are dominated by amorphous organic matter, whereas their Mexican equivalents are rich in land-derived plant remains (Tables 1 and 2).

Trench Fill Facies

The trench fill facies consists of the turbidites that fill the Middle America Trench. This facies was not sam-

¹ Aubouin, J., von Huene, R., et al., *Init. Repts DSDP, 67*: Washington (U.S. Govt. Printing Office).

² The organic facies is defined as the assemblage of organic matter types.

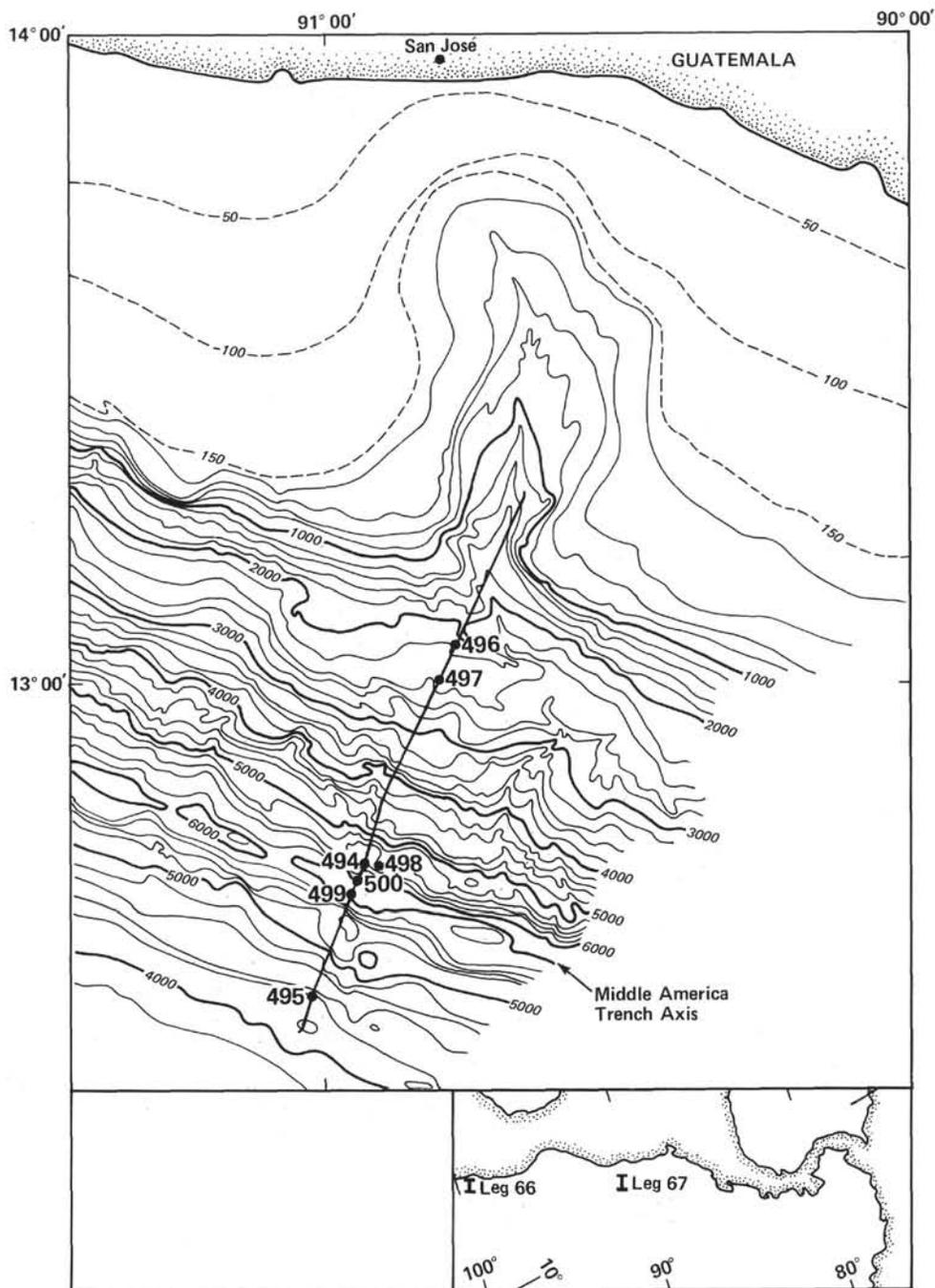


Figure 1. Location of DSDP Leg 67 drill sites off Guatemala (depths are in meters).

pled off Mexico. The organic facies of these sediments is identical to that of the hemipelagic oceanic facies (Tables 1 and 2).

Distal Slope Facies

The older sediments at Site 494, near the base of the slope, constitute a distal slope facies that was deposited more slowly and farther from shore than either its landward lateral equivalents or the younger sediments at this and other Leg 67 slope sites (von Huene, Aubouin, et al., 1980). We analyzed only one sample of this sedimentary facies (Tables 1 and 2). Its composition is almost identical to that of samples of the trench and hemipe-

lagic oceanic sedimentary facies. In the absence of more analyses, we cannot regard as significant the slight differences in the assemblage of organic matter between these deposits. As is the case for the hemipelagic oceanic facies, the distal slope facies has much more amorphous and less terrestrial organic matter than found in comparable sediments off southern Mexico (lower-middle slope sediments) (Table 2).

Proximal Slope Facies

The younger sediments at Site 494 and all upslope samples (Sites 496, 497) have a more proximal facies than that found at the base of the section at Site 494

Table 1. Age, lithology, sedimentation rate, organic matter, and thermal alteration index of DSDP Leg 67 samples.

Hole No.	Core No.	Section No.	Interval (cm)	Sub-bottom Depth (m)	TOC (%)	Type of Organic Matter (%)					TAI	Age ⁺	SR ⁺ (m/m.y.)	Lithology ⁺	Facies	Mean TOCs ⁺ (%)
						ST	PS	C	AM	SM						
Cocos Plate																
495 (depth, 4140 m)	3	5	135-144	32.3	2.00	10	—	—	90	—	1+	Q	41	Diatomaceous hemipelagic mud	Hemipelagic Oceanic	1.05
	9	5	139-144	93.4	0.64	5	—	—	85	10						
	15	4	120-125	148.8	0.78	10	—	—	90	—	1+	P	41	Diatomaceous silty mud		
	21	6	120-126	208.7	0.07	()	()	()	()	()	1+	UM	9	Diatomaceous mud		
	27	4	120-129	262.7	0.04	()	()	()	()	()	1+	MM	9	Nannofossil ooze	Deep Sea Pelagic	—
	34	3	120-140	327.7	0.04	()	()	()	()	()	1+	LM	16	Nannofossil ooze		
											1+	LM	16	Nannofossil ooze		
Middle America Trench																
499 (depth, 6102 m)	2	6	120-125	34.2	1.84	5	—	—	90	5	1+	Q	300	Biogenic mud	Trench Fill	1.40
	10	7	120-128	112.0	1.82	10	—	—	80	10	1+	Q	300	Biogenic sandy mud		
	17	4*	120-130	173.7	1.86	5	—	—	85	10	1+	Q	300	Biogenic mud		
	22	4*\$	120-140	221.2	1.10	10	—	—	80	—	1+	Q	300	Biogenic siliceous mud		
499B	3	2	120-130	247.2	0.04	()	()	()	()	()	1+	UP	80	Nannofossil chalk	Deep Sea Pelagic	0.03
	8	2	120-131	294.7	0.05	()	()	()	()	()						
500 (depth, 6090 m)	3	4	120-128	52.7	2.32	5	—	—	95	—				Nannofossil chalk	Trench Fill	2.14
	10	2	120-130	116.2	0.07	()	()	()	()	()	1+	Q	70	Diatomaceous mud		
	17	3	120-135	184.2	0.04	()	()	()	()	()				Nannofossil ooze	Deep Sea Pelagic	0.03
Guatemalan Continental Slope																
494A (depth, 5427 m)	2	6	144-150	113.0	1.80	10	5	—	75	10	1+	Q	55	Diatomaceous silty mud	Proximal Slope	2.11
	22	3	120-130	298.2	1.52	5	—	—	85	10	1+	O-M	3	Blue gray claystone	Distal Slope	1.25
497 (depth, 2347 m)	2	5	120-127	25.2	0.64	10	10	—	80	—	1+	Q	100	Hemipelagic mud	Proximal Slope	2.45
	2	7	145-150	28.5	2.71	10	5	—	75	10	1+	Q	100	Hemipelagic mud		
	14	2	120-130	134.8	2.66	5	—	—	85	10	1+	Q	70	Biogenic mud		
	20	4	120-150	194.8	4.82	5	—	—	90	5	1+	Q	SL	Hemipelagic mud		
	26	1	130-150	247.3	1.60	10	5	—	75	10	1+	UP	23	Siliceous mudstone		
	35	6*\$	120-130	340.3	1.60	—	—	—	95	5	1+	LP	130	Hemipelagic mudstone		
	41	4	120-140	394.2	1.58	10	—	—	85	5	1+	LP	130	Nannofossil mud		
496 (depth, 2049 m)	2	4	120-126	28.2	2.40	5	—	—	95	—	1+	Q	205	Diatomaceous mud	Proximal Slope	2.67
	9	5	110-120	96.2	2.24	20	5	—	70	5	1+	Q	205	Diatomaceous mud		
	20	2	120-125	196.2	1.22	10	5	—	85	—	1+	Q	205	Hemipelagic mud		
	27	3*	120-126	264.2	1.08	—	—	—	10	80	10	1+	LP	Diatomaceous sandy mud		
	40	4	15-30	388.2	2.28	20	5	—	65	10	1+	LM	60	Mudstone	Proximal Slope	0.93

Note: ST = structured terrestrial, PS = pollen and spores, C = charcoal, AM = amorphous, and SM = structured marine types of organic matter analyzed by methods described by Masran and Pocock (1979). ⁺ = data from *DSDP Initial Reports*. * = samples analyzed by pyrolysis. \$ = samples analyzed by liquid chromatography. () = too little organic matter for analysis. Q = Quaternary; P = Pliocene (Lower, Middle, Upper); M = Miocene (Lower, Middle, Upper); O = Oligocene. SL = slump? SR = sedimentation rate. TAI = thermal alteration index.

Table 2. Average organic matter compositions of different facies in the Middle America Trench.

Facies	TOC (%)	Organic Matter Type (%)					Sum of ST + PS + C (%)	Maximum Sedimentation Rate (m/m.y.)
		ST	PS	C	AM	SM		
Guatemala (Leg 67)								
Deep Sea Pelagic	0.05	()	()	()	()	()	15	
Hemipelagic Oceanic	1.14	9	—	—	88	3	41	
Trench Fill	1.80	7	—	2	86	5	300	
Distal Slope	1.50	5	—	—	85	10	3	
Proximal Slope	2.0	9	3	1	81	6	205	
Mexico (Leg 66) (Quaternary)								
Trench	1.6	20	10	10	50	10	40	
Lower-Middle Slope	2.1	21	3	8	52	16	32	
Upper Slope	2.1	13	—	5	60	22	18	

Note: Table 1 shows which samples belong to which facies off Guatemala; Mexican data are from Summerhayes and Gilbert (in press). () = too little organic matter for accurate analysis. See Table 1 for definition of organic matter types.

(von Huene, Aubouin et al., 1980). This sedimentary facies contains the most organic matter (2% TOC on the average) and has a slightly larger amount of terrestrial organic material than do the other sedimentary facies off this coast (Tables 1 and 2). In many respects the proximal slope facies is very similar to the upper slope sediments of southern Mexico but has more amorphous and less terrestrially derived organic matter (Table 2).

CHEMICAL DATA

Four samples were analyzed by pyrolysis (Table 3); techniques like those described by Hunt (1979) were used. Pyrolysis determines the likelihood that a given

Table 3. Interpretation of pyrolysis analyses.

Sample (interval in cm)	Sub-bottom Depth (m)	Potential	Oil or Gas Prone	Age	Location
499-17-4, 120-130	173.7	Good	Oil	Q	Trench
499-22-4, 120-140	221.2	Good	Oil + Gas	UP	Trench
497-35-6, 120-130	340.3	Good	Oil	LP	Slope
496-27-3, 120-126	264.2	Good	Gas	LP	Slope

Note: Q = Quaternary; LP = lower Pliocene; UP = upper Pliocene.

sample will yield oil or gas and whether the potential for doing so will be good or poor (Table 3). Two of these four samples were analyzed also, by methods described by McIver (1972), for the heavy C₁₅₊ hydrocarbons and nonhydrocarbons in the extractable bitumen fraction (Table 4). Using both the TOCs (Table 1) and the bitumen data we can make another evaluation of the oil and gas potential (Table 4). Apart from potential, these data also tell us something about the nature of the organisms from which the sedimentary organic matter was derived. The remains of marine plants are usually oil prone, those of the higher land plants are gas prone, and spores and pollen may yield both gas and oil (Hunt, 1979). Most of the samples that we analyzed chemically are oil prone (Tables 3 and 4), which implies that the amorphous material that dominates these sections is largely derived from the remains of marine organisms.

Table 4. Results of analyses of benzene-methanol C₁₅₊ extract (i.e., characteristics of bitumen or soluble organic matter).

Sample (hole-core-section)	Total HC (ppm)	HC% of TOC	Soluble Organic Matter (ppm)	S A NSO ASPH				Potential	Oil or Gas
				(% bitumen)					
499-22-4	12	0.12	223	3.3	2.0	31.0	63.8	Good	Oil
497-35-6	32	0.21	595	3.2	2.2	36.7	57.9	Good	Oil

Note: HC = hydrocarbons; S = saturates; A = aromatics; NSO = N, S, and O compounds; ASPH = asphaltenes.

THERMAL ALTERATION AND HYDROCARBON POTENTIAL

None of the samples that we analyzed had thermal alteration indices higher than 1+, so we consider them to be immature (Table 1). Thus although the chemical data indicate good potential for oil generation, this potential has not been realized in the drilled sections represented by our samples. The lack of maturation explains the virtual absence of ethane and the higher gaseous hydrocarbons here (von Huene, Aubouin, et al., 1980).

DISCUSSION

The sediments of the Guatemalan continental margin have an amorphous-dominated organic facies derived largely from the remains of marine organisms. The contribution of land-derived plant remains is less than in similar sediments from the same geological settings off the southern margin of Mexico (Table 2).

An obvious difference in Quaternary sedimentation between the two areas is that the rate of sedimentation is about 50% slower off Guatemala than off Mexico, reflecting both the small size of landmass and the limited extent of drainage basins. We suggest that this difference in sedimentation rate may also be associated with (1) changes in the ratio of marine to terrestrial organic matter deposited or (2) changes in the proportion of organic matter that is converted to amorphous material. Because of the differences in land area, the ratio of marine/terrestrial organic matter supplied to the bottom may be lower off Mexico than it is off Guatemala. Alternatively, the ratio may be the same, but bacterial activity at the slower rates of sedimentation typical of Guatemala may more effectively convert structured terrestrial organic materials to amorphous organic matter.

Regardless of the difference in type of organic matter, the TOCs remain about the same in the two areas (Table 2). Either this is because of a fortuitous similarity in the supply ratio of organic matter to mineral grains or it may reflect the scavenging efficiency of benthic organisms and bacteria (that is, these organisms may cease to decompose and remove organic matter at these rates of sedimentation when the ratio of organic matter to mineral grains within the sediment corresponds to about 1% to 2% TOC). We do not know the answer.

Compared with the margins of Japan, where terrestrial plant remains predominate and TOCs are low, the sediments of the margins of California, Mexico, and Guatemala are all enriched in organic matter, much of which is marine-derived and amorphous. We consider that this regionally consistent pattern reflects (1) the ex-

ceptionally high productivity typical of the areas of upwelling that characterize the American coasts in middle and low latitudes (Lisitzin, 1972) and (2) the consequent extreme depletion in oxygen in subsurface waters off the western Americas (Kester, 1975). The high productivity explains why marine-derived organic matter should be abundant in these areas; the oxygen deficiency promotes the preservation of this material once it has been deposited (Calvert, 1964; Demaison and Moore, 1980; Summerhayes and Gilbert, in press). Productivity is much lower and oxygen concentrations are much higher off Japan, where only small amounts of refractory terrestrial components remain to be incorporated into the sediment (Gilbert et al., 1980).

The high productivity of the eastern side of the Pacific has led to the development of reducing conditions and consequent preservation of large amounts of organic matter (more than 4% TOC) within the oxygen minimum zone off Mexico and California (Gilbert and Summerhayes, 1981 and in press). At first glance, because most TOCs are less than 4% off Guatemala (Table 1), it seems that there may not have been a well-developed oxygen minimum off this coast. However, these deposits are all from sites deeper than 2000 meters, whereas the oxygen minimum is best developed (that is, most reducing) at depths of 300 to 1500 meters (Kester, 1975). The rich sample at 195 meters sub-bottom depth at Site 497 (TOC = 4.82%) may be a slide mass from an upslope oxygen minimum zone that is reducing. The same arguments apply to TOCs of about 4% reported in both Sites 496 and 497 reports.

An interesting feature of the Guatemalan margin is that although turbidites usually contain more terrestrially derived plant remains than are found in the nearby slope sediments, as in the Guaymas Basin (Gilbert and Summerhayes, in press) and in the Middle America Trench off Mexico (Summerhayes and Gilbert, in press), we do not see this relationship off Guatemala. We infer that the outer shelf and upper slope areas where the turbidity currents originate (according to biostratigraphic data) do not contain substantial amounts of terrestrially derived plant remains. Alternatively, much of the material found in the turbidites is displaced proximal slope sediment.

CONCLUSIONS

The organic facies of Guatemalan slope and Middle America Trench sediments, and of hemipelagic sediments on the landward edge of the Cocos Plate, are dominated by amorphous material that is derived mostly from marine organisms. These sediments are moderately enriched in organic matter, averaging 1% to 2% TOC. The pelagic sediments underlying the trench and on the Cocos Plate are carbon poor (avg. TOC about 0.05%).

The organic facies and richness of these sediments are controlled by climate, drainage, and regional circulation. Guatemala has a small land area with low runoff, so the input of the remains of higher land plants is unusually low. Marine productivity is high, and so is the rate of supply of marine organic material to subsurface waters. As a result, oxygen is low, and substantial

amounts of organic matter are preserved on the bottom. An indeterminate proportion of this organic matter probably moves laterally into the sampling area from areas of greater oxygen depletion and preservation located upslope within the oxygen minimum zone.

This sequence has good future potential for oil generation. Currently, it is immature and incapable of generating liquid hydrocarbons. The high ethane values recorded at Site 496 and the downward decrease in the methane/ethane ratio reported at Sites 496 and 497 probably are caused by migration into the section from a mature section at depth (von Huene, Aubouin, et al., 1980).

ACKNOWLEDGMENTS

Chemical analyses were made at Exxon Production Research Company by M. S. Bisotooni and E. E. Brown. D. Gilbert made the kerogen analyses and determined thermal alteration indices. We thank Exxon Production Research Company for continued support of this work and for permission to publish these results. W. A. Young and J. P. Shannon reviewed the manuscript.

REFERENCES

- Aizenshtat, Z., Baedeker, M. T., and Kaplan, I. R., 1973. Distribution and diagenesis of organic compounds in JOIDES sediment from Gulf of Mexico and Western Atlantic. *Geochim. Cosmochim. Acta*, 37:1881-1989.
- Calvert, S. E., 1964. Factors affecting distribution of laminated diatomaceous sediments in Gulf of California. In van Andel, Tj. H. and Shor, G. G. (Eds.), *Marine Geology of the Gulf of California*, 3: Tulsa (Am. Assoc. Petrol. Geol.), 311-330.
- Demaison, G. J., and Moore, G. T., 1980. Anoxic environments and oil source bed genesis. *Org. Geochem.*, 2:9-31.
- Gilbert, D., and Summerhayes, C. P., 1981. Distribution of organic matter in sediments along the Californian continental margin. In Yeats, R. S., Haq, B. U., et al., *Init. Repts. DSDP*, 63: Washington (U.S. Govt. Printing Office), 757-761.
- , in press. Organic facies and hydrocarbon potential in the Gulf of California. In Curray, J. R., Moore, D. G., et al., *Init. Repts. DSDP*, 64: Washington (U.S. Govt. Printing Office).
- Gilbert, D., Summerhayes, C. P., and Johnson, D. L., 1980. Nature, origin, and source potential of organic matter from Deep Sea Drilling Project Sites 434, 435, 438, and 440 in the Japan Trench. In Langseth, M. G., Okada, H., et al., *Init. Repts. DSDP*, 56, 57, Pt. 2: Washington (U.S. Govt. Printing Office), 1327-1329.
- Hunt, J. M., 1979. *Petroleum Geochemistry and Geology*: San Francisco (W. H. Freeman and Co.).
- Kester, D. R., 1975. Dissolved gases other than CO₂. In Riley, J. P., and Skirrow, G. (Eds.), *Chemical Oceanography*: New York (Academic Press), pp. 498-556.
- Lisitzin, A. P., 1972. Sedimentation in the world ocean. *Soc. Econ. Paleontol. Mineral. Spec. Publ.*, 17.
- McIver, R. D., 1972. Geochemical significance of gas and gasoline-range hydrocarbons and other organic matter in a Miocene sample from Site 134—Balearic Abyssal Plain. In Ryan, W. B. F., Hsü, K. J., et al., *Init. Repts. DSDP*, 13, Pt. 2: Washington (U.S. Govt. Printing Office), 813-816.
- Masran, Th. C., and Pocock, S. A. J., 1979. Classification of plant-derived particulate organic matter in sedimentary rocks. In Staplin, F. L. (Ed.), *Kerogen-Visual and Chemical Relationships, a Symposium*: Dallas (Am. Assoc. Strat. Palynol).
- Staplin, F. L., 1969. Sedimentary organic matter, organic metamorphism, and oil and gas occurrence. *Bull. Can. Petrol. Geol.*, 17: 47-66.
- Summerhayes, C. P., and Gilbert, D., in press. Distribution, origin, and hydrocarbon potential of organic matter in sediments from the Pacific margin of southern Mexico. In Watkins, J. S., Moore, C., et al., *Init. Repts. DSDP*, 66: Washington (U.S. Govt. Printing Office), 541-546.
- von Huene, R., Aubouin, J., et al., 1980. Leg 67: The Deep Sea Drilling Project Middle-America Trench transect off Guatemala. *Geol. Soc. Am. Bull.*, 91(Pt. 1):421-432.