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ORGANIC CARBON AND NITROGEN IN THE SURFACE SEDIMENTS OF WORLD OCEANS AND SEAS: DISTRIBUTION AND RELATIONSHIP TO BOTTOM TOPOGRAPHY

Eugene T. Premuzic

June 1980

**ENVIRONMENTAL CHEMISTRY DIVISION AND
OCEANOGRAPHIC SCIENCES DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT**

**BROOKHAVEN NATIONAL LABORATORY
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ABSTRACT

Information dealing with the distribution of organic carbon and nitrogen in the top sediments of world oceans and seas has been gathered and evaluated. Based on the available information a master chart has been constructed which shows world distribution of sedimentary organic matter in the oceans and seas. Since organic matter exerts an influence upon the settling properties of fine inorganic particles, e.g. clay minerals and further, the interaction between organic matter and clay minerals is maximal, a relationship between the overall bottom topography and the distribution of clay minerals and organic matter should be observable on a worldwide basis. Initial analysis of the available data indicates that such a relationship does exist and its significance is discussed.

INTRODUCTION

Organic carbon and nitrogen analyses have been used extensively in determination of the amount and the distribution of sedimentary organic matter in the ocean. The results of such determinations are indicative of processes which are associated with sediment formation: terrigenous input, the input of organic matter from marine primary production, pelagic and benthic organisms, and the processes of diagenesis. Generally speaking, fine grain sediments are associated with higher content of organic matter than are the coarse sediments. Examples showing this distinct distribution pattern have been documented in the literature (e.g. Emery and Uchupi, 1972; Bordovskiy, 1964; Romankevich, 1977, and references therein). Representative average values for organic carbon content (% dry weight) are given in Table 1.

Table 1		
	Sediment	Avg. % Org. C.
Bering Sea	Clayey Silt	1.1
	Silt	1.19
	Sandy Silt	0.76
	Silty Sand	0.45
	Sand	0.31
Northern Baltic Sea	Clayey Silt	2.41
	Silt	2.09
	Sandy Silt	0.90
	Silty Sand	0.47
North Western Atlantic	Clay	1.14
	Silty Clay	1.28
	Clayey Silt	1.08
	Silty Sand	0.63
	Medium Sand	0.135
	Gravelly Sand	0.63

Although the carbon values shown in Table 1 have been determined in samples from different regions, the data is consistent with the fact that clays containing fine particles (less than 4 microns) have higher concentrations of organic matter. Clays, in addition, also have different sorption properties (e.g. Weiss, 1969; Morris and Calvert, 1975). For example, for fatty acids it has been shown (Meyers and Quinn, 1973) that bentonite and kaolinite are more adsorptive inorganic matrices relative to illite, montmorillonite and calcite, whose adsorptive capacity for fatty acids decreases in the order listed. Studies (Muller, 1977) on the interaction of organic matter with clays indicate that organic nitrogen compounds can be sorbed to clay minerals in a manner making them resistant to bacterial attack. Furthermore, this work (Muller, 1977) has demonstrated that pure carbonates, or sands devoid of clay minerals, show high C/N ratios, while their total organic matter content is low. This is attributed to preferential sorption and fixation of certain organic nitrogen compounds. Extensive studies dealing with the interaction of organic compounds with recent sediments (Suess, 1970, 1973; Suess and Muller, 1977) have also suggested that, due to selective sorption, there is a preferential enrichment of organic compounds on mineral surfaces which leads to a characteristic composition of the sediment. Thus, organic carbon and nitrogen values for a given sediment sample are bulk parameters and the actual chemical composition of organic matter represented by these parameters depends on the source of organic matter and the physico-chemical nature of the inorganic portion of the sediment.

Physical and chemical properties of the sediments reflect sedimentary regions whose bottom topography has been defined by the geophysical

processes active in that region. Settling properties of organic matter and fine inorganic particles (4 microns or less) are similar. Since the content and the interaction between organic matter and clay minerals (particles of 4 microns or less) is maximal, a relationship between the overall bottom topography of the continental margin and both clay minerals and organic matter should be evident. Such a relationship would provide a useful bulk parameter both reflecting the chemical composition of matter being retained by a given type of sediment and indicating the probability that this material may return to surface waters via the physical circulation. This information will have important future application dealing with artificial upwelling, the ultimate fate of waste disposal, and the storage of carbon dioxide in the oceans.

METHODOLOGY

In order to analyze the distribution of sedimentary organic matter in relation to bottom topography, an exhaustive literature search has been carried out on the distribution of organic matter in the surface sediments of large areas of the world's seas and oceans. Currently available information has been collected and incorporated into this document, and it is anticipated that this data base will be enriched and updated as additional analyses for organic carbon and nitrogen become available. In the preparation of the document, the following criteria has been adhered to:

1. Percent organic carbon. Only analyses carried out on calcium carbonate free sediment samples and expressed as percent dry weight of the sample have been considered (Maciolek, Hartman, 1971; Wakeel, 1956; Gaudette, 1974; Hulsemann, 1966; Kolpack, 1968; Gaskell, 1975).

2. Organic nitrogen. Kjeldahl nitrogen determinations, expressed as percent dry weight of the samples have been used exclusively (Martin, 1968; Kabat, 1948).

3. Wherever possible, data obtained by different workers, involving overlapping regions, have been presented. A reasonably good fit (better than $\pm 15\%$) of sets of data obtained by different workers is considered as proof of the accuracy and the reliability of chemical determinations.

The total area considered has been divided into five major regions: Northern, Atlantic, Indian, Pacific, and Southern. The extent of each region is given in Table 2. Using all the available data, a master map has been constructed in which the percent organic carbon has been contoured and reproduced on a transparency. The transparency is then superimposed on a World Ocean Floor map. Detailed information for each region and subregion has been assigned a number and positioned on a master map in the geographically appropriate location (Fig. 138). Each number also refers to a figure in the text where the detailed information is given. The master map and individual figures represent the distribution of organic carbon in the upper (0 to 15 cm) portion of sediments. Complimentary nitrogen measurements have been presented in the regional data base along with the organic carbon information. At present, there is more organic carbon than nitrogen data available for the surface sediments of the world oceans and seas. The literature covers the period starting with Trask's original work (1932) up to the present time.

Table 2

NORTHERN REGION

Bering, Chukchi, Beaufort, North, Barents, White, Kara, and Norwegian Seas, as well as areas on and north of 60° latitude including the Arctic

ATLANTIC REGION

The East coast of the Americas, and the coasts of Western Europe & Africa. Baltic, Mediterranean, Black, Azov, and Caspian Seas are also included in this region

PACIFIC REGION

The east coast of Asia, Australia, and the west coast of the Americas

INDIAN REGION

Including Coasts of Australia and East Africa

SOUTHERN REGION

South of 60° latitude including Antarctica

NORTHERN REGION

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% C_{org} IN REGIONS
A AND B OF THE
ARCTIC

Figure 1. The Arctic (based on Romankevich, 1977).⁹⁰

Figure 2. % Corg. in the present sediments of the western half of the Bering Sea (Bordovskiy, 1961).¹⁷

Figure 3. % Corg. in the Southeastern Bering Shelf sediments (Sharma, 1974).¹⁰⁵

Figure 4. % Corg. in the upper layer sediments of Bering Sea (Gershanovich, 1962).³⁶

Figure 5. % Corg. in the Bering Sea sediments (Lisitzin, 1966).⁵⁸

Figure 6. % N in the Bering Sea sediments (Lisitzin, 1966).⁵⁹

Figure 7. Distribution of the C/N ratios in the bottom sediments of the Bering Sea (Lisitzin, 1966).⁵⁹

Figure 8. % Corg. in the top sediments of the Chukchi Sea (Creager and McManus, 1966).²²

Figure 9. % Corg. in the bottom sediments of Beaufort Sea, Canada Basin, West Arctic Ocean (Naidu and Hood, 1972, Naidu et al., 1976; Naidu, 1979).^{74,75,76}

Figure 10. % C_{org.} in the sediments of the Southern Beaufort Sea (Pelletier, 1975; Pelletier, 1979). 81, 83

Figure 11. % C_{org.} in the sediments of Northern Baffin Bay (Grant, 1965).⁴⁰

Figure 12. % C_{org.} in the bottom sediments of Hudson Bay (Leslie, 1963, Pelletier, 1968).^{57,82}

Figure 13. % Corg. (first number) and % N (second number) in the sediments of the Northern North Sea (Jansen et al., 1979).^{50,51}

Figure 14. Location-identification of sampling area in the Northern North Sea (Compare to Figure 13).

Figure 15. Approximate values of organic carbon content in the North Sea (see insert) obtained by determination of loss on ignition at 450°C (Moore, 1979).⁶⁹

Figure 16. % C_{org}. in the North Sea Sediments (van Weering, 1979).118

Figure 17. % Corg. in the sediments of the Norwegian Sea (Gorshkova, 1962).³⁹

Figure 19. % Corg. in the sediments of Barents Sea (Gorshkova, 1975).38

Figure 18. % Corg. in the North Kara and Barents Sea Sediments (Naidu, 1979).73

Figure 20. % C_{org}. White Sea Sediments (Gorshkova, 1975).³⁸

Figure 21. % C_{org}. in the Kara Sea Sediments (Kuznetsov, 1976).⁵⁶

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ATLANTIC REGION

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Figure 22. % C_{org.} (first number) and % N (second number) in sediments from the Gulf of St. Lawrence and adjacent waters (Pocklington and Morash, 1979; Pocklington, 1979).^{86,87}

Figure 24. % Corg in the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 25. % Corg. in the Atlantic Coast sediments of the United States
(Hathaway, 1971).⁴⁶

Figure 26. % N in the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 27. % N in the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 28. % N in the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 29. C/N ratio of the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 30. C/N ratios of the Atlantic Coast sediments of the United States (Hathaway, 1971).⁴⁶

Figure 33. % C_{org.} in the sediments of the Middle Atlantic Bight Region (Wigley and Theroux).¹²²

Figure 34. C/N ratios in the sediments of the Atlantic Coast of the United States of America (Saila, 1973).¹⁰¹

Figure 35. % N in the Atlantic Coast sediments of the United States of America (Saila, 1973).¹⁰¹

Figure 36. Organic matter in the surface sediments off the coast of Florida and the Gulf of Mexico Continental Margins (Emery and Uchupi, 1972).³⁰

Figure 37. Texture of bottom sediments, western Penobscot Bay, Maine and percent organic carbon in bottom sediments (Folger, 1972).³²

Figure 38. % Corg. in the sediments of Boston Harbor, Mass. (Mencher et al., 1968).⁶⁶

Figure 39. % C_{org.} in the bottom sediments, Boston Harbor, Mass. (Folger, 1972).³²

Figure 40. % C_{org.} in the bottom sediments, Charleston Harbor, South Carolina (Folger, 1972).³²

Figure 41. % Corg. in the bottom sediments, Pamlico Sound, North Carolina (Folger, 1972).³²

Figure 42. % Corg. in the sediments of Pamlico Sound, North Carolina (Pickett, 1965).⁸⁵

Figure 43. % C_{org}. in the sediments of Chesapeake Bay (Biggs, 1967).¹¹

Figure 44. % C_{org}. in the bottom sediments, Chesapeake Bay, Maryland and Virginia (Folger, 1972).³²

Figure 47. % N in the sediments of St. Joseph's Bay, Florida (Stewart and Gorsline, 1962).¹⁰⁹

Figure 48. Distribution of C/N ratio in St. Joseph's Bay, Florida (Stewart and Gorsline, 1962).¹⁰⁹

Figure 49. % C_{org.} in the bottom sediments, Apalachicola Bay, Florida (Folger, 1972).³²

Figure 50. % C_{org.} and C/N ratio in the sediments off southwestern Florida. (Scholl, 1963).¹⁰³

Figure 51. % Corg. sediments of coastal Southwestern Florida, White Water Bay and the adjacent region (Scholl, 1963 and Folger, 1972). 32,103

Figure 52. C/N ratio in the sediments of coastal southwestern Florida (Scholl, 1963).103

Figure 53. Location maps for Figures 45-52.

Figure 54. Location map for Figures 55 and 56.

Figure 55. % Corg. sediments off the coasts of Mississippi and adjacent states (Upshaw et al., 1966).¹¹⁵

Figure 56. % Corg. sediments off the coasts of Mississippi and adjacent states (Upshaw et al., 1966).¹¹⁵

Figure 58. % Corg. in the deep sediments of the Gulf of Mexico (Rowe and Menzel, 1977).⁹⁶

Figure 59. First No.: % C_{org.}; Second No.: % N in recent sediments of the Gulf of Paria (Van Andel and Postma, 1954).¹¹⁷

Figure 60. % C_{org.} in the sediments of the Gulf of Paria (Van Andel and Postma, 1954).¹¹⁷

Figure 61. % N in the sediments of the Gulf of Paria (Van Andel and Postma, 1954).¹¹⁷

Figure 62. % N in the shelf sediments off Northeastern Brazil (Summerhayes et al., 1975).¹¹³

Figure 63. C/N ratios in samples from the shelf off northeastern Brazil (Summerhayes et al., 1975).¹¹³

Figure 64. % N in the sediments from the North Brazilian continental margin (Barreto et al., 1975).⁴

Figure 65. C/N ratios from the north Brazilian continental margin (Barreto et al., 1975).⁴

Figure 66. % N content of reef and sediment samples off southeastern Brazil (de Melo Ubirajara et al., 1975).²⁴

Figure 67. Ratio of C/N in sediments and reef deposits off southeastern Brazil (de Melo Ubirajara et al., 1975).²⁴

Figure 68. % N in the surface sediments of southern Brazil (da Rocha et al., 1975).²³

Figure 69. Ratio of organic carbon to nitrogen in the sediments from southern Brazil (da Rocha et al., 1975).²³

Figure 70. % C_{org.} in sediments of the south-western Atlantic (Zaharov, 1974).¹²⁶

Figure 71. % C_{org.} in the sediments of the Baltic Sea (Blazhchishin, 1976).¹³

Figure 72. % C_{org.} in the Baltic Sea sediments (Gorshkova, 1962).⁴¹

Figure 73. % C_{org}. in the Black Sea sediments (Glagoleva, 1961).³⁷

Figure 74. % C_{org}. in the Black Sea sediments (Kochenov A.V. et al., 1963).⁵⁴

Figure 75. % C_{org.}, Caspian Sea (Bordovskiy, 1969).¹⁴

Figure 76. % C_{org.} in the Caspian Sea sediments (Bordovskiy, 1974).¹⁶

Figure 77. % C_{org.} in the upper layer of the Azov Sea sediments (Gorshkova, 1961).^{39a}

Figure 78. % C_{org.} in the Sea of Azov sediments (Gorshkova T.I., 1970 based on Ref. 90).⁹⁰

Figure 79. % C_{org.} in the sediments of the Mediterranean Sea (Kochenov et al., 1963).⁵⁴

Figure 80. % N in the sediments off the coast of Spanish Sahara (Milliman, 1977).^{68a}

Figure 81. % C_{org.} (first number), % N (second number) and C/N (third number) off the African coast, Atlantic, off Spanish Sahara (Row et al., 1976, 1977).^{98,99}

Figure 82. % N in the sediments off the coast of Southern Spanish Sahara (Summerhayes et al., 1976).¹¹² The legend is the same as in Fig. 83.

Figure 83. % N in the continental margin sediments from central Morocco (Summerhayes et al., 1976).¹¹²

Figure 84. % Corg. in the sediments of the Southwest African Shelf (Calvert and Price, 1971).¹⁹

Figure 85. % Corg. S.W. Africa (Emel'yanov and Senin, 1969).²⁶

Figure 86. % Corg. in the sediments off African coast in the southeastern Atlantic (Emel'yanov and Romankevich, 1977).²⁷

Figure 87. % Corg. in the sediments of the Southwest African Shelf (Avilov and Gershanovich, 1970).³

Figure 88. % C_{org.} in the sediments of False Bay, South Africa (Bowie et al., 1968).¹⁸

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INDIAN REGION

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Figure 90. % Corg. in the upper sediments of the Persian Gulf and the Gulf of Oman (Seibold and Closs, 1971).¹⁰⁴

Figure 91. % N in the upper sediments of the Persian Gulf and the Gulf of Oman (Seibold and Closs, 1971).¹⁰⁴

Figure 92. % N in the sediments of the Persian Gulf (Emery, 1956).²⁸

Figure 93.. C/N Ratio in the upper sediments of the Persian Gulf and Gulf of Oman (Seibold and Closs, 1971).¹⁰⁴

Figure 94. C/N Ratio in the sediments of the Arabian Sea (Wiseman and Bennett, 1934).¹²³

Figure 95. % C_{org.} in the sediments of the Arabian Sea (Wiseman and Bennett, 1934).¹²³

Figure 96. % Corg. of the sediments in Warnbro Sound, Western Australia (Carrigy, 1956).²⁰

Figure 97. % N of the sediments in Warnbro Sound, Western Australia (Carrigy, 1956).²⁰

Figure 98. C/N ratio in the sediments of Warnbro Sound, Western Australia (Fremantle region near Perth) (Carrigy, 1956).²⁰

Figure 99. % N, Andaman Basin surface sediments (Rodolfo, 1969).⁸⁹

Figure 100. % C_{org}. Andaman Basin surface sediments (Rodolfo, 1969).⁸⁹

Figure 101. % C_{org}. surface sediments of Malacca Strait and adjacent Andaman Sea (Keller and Richards, 1967).⁵³

Figure 102. % N surface sediments of Malacca Strait and adjacent Andaman Sea (Keller and Richards, 1967).⁵³

Figure 103. C/N Ratio of the sediments of Malacca Strait and adjacent Andaman Sea (Keller and Richards, 1967).⁵³

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PACIFIC REGION

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Figure 104. % N, surface sediments of the Gulf of Thailand and the adjacent continental shelf (Emery and Niino, 1963).³¹

Figure 105. C/N ratio of the sediments in the Gulf of Thailand and adjacent continental shelf (Emery and Niino, 1963).³¹

Figure 106. % Corg. in the sediments of the Gulf of Tonkin (Niino and Emery, 1961).⁷⁷

Figure 107. % Corg. in the sediments from Taiwan Strait and shelf off the coast of south China (Niino and Emery, 1961, 1979).⁷⁷

Figure 108. % Corg. of the East China Sea sediments (Niino and Emery, 1961, 1979).⁷⁷

Figure 109. % Corg. in sediments of the Japan Sea (Niino and Emery, 1969, 1979).⁸⁰

Figure 110. % Corg. bottom sediments of the continental shelf off Vladivostok (Niino and Emery, 1966).⁷⁹

Figure 111. % Corg. in the sediments off the coast of Kamchatka (Romankevich, 1970).⁹²

Figure 112. % C_{org.} bottom sediments of the continental shelf off western Kamchatka (Niino and Emery, 1966).⁷⁹

Figure 113. % C_{org.} in the sediments of the Sea of Okhotsk (Bezrukov, 1960).⁹

Figure 114. % C_{org}. in the Sea of Okhotsk upper layer sediments (Petelin and Ostroymov, 1961).⁸⁴

Figure 115. % C_{org}. in the top layer sediments of the North Pacific (Bezrukov et al., 1961).¹⁰

Figure 116. % Corg. in the surface layer of bottom deposits in the extreme Northern Pacific, %. (1) <0.50, (2) 0.50-1.00, (3) 1.00-1.50, (4) 1.50-2.00, (5) >2.00 (Gershanovich, 1965).³³

Figure 117. % N in the upper sediments of the Pacific Ocean. (1) <0.03; (2) 0.03-0.06, (3) 0.06-0.10; (4) 0.10-0.20; (5) 0.20-0.40; (6) >0.40; 7 and 8 sampling stations. Combined effort of many workers (Romankevich, 1977).⁹⁰

Figure 118. % N in the surface layer of Pacific Ocean. (1) <0.05; (2) 0.05-0.1; (3) 0.1-0.2; (4) 0.2-0.25; (5) >0.25 (Romankevich, 1968).⁹³

Figure 119. % C_{org.} in the surface layer of Pacific sediments (1) <0.5; (2) 0.5-1.0; (3) 1.0-3.0; (4) >3.0 (Romankevich, 1968).⁹³

Figure 120. % Corg. in the sediments of the western part of the Pacific Ocean
(1) <0.25%; (2) 0.25-0.50%; (3) <0.5%; (4) 0.5-1.00%; (5) >1.00%
(Romankevich, 1960).⁹¹

Figure 121. % Corg. in the bottom sediments, Deep Inlet, Alaska
(Anderson, 1962).²

Figure 122. % C_{org} in the sediments of the continental shelf of the N.W. United States and Vancouver Island (Gross et al., 1967 and 1972).^{42,43}

Figure 123. % C_{org} in the surface sediments off the Washington-Oregon Coast (Gross, 1966 and 1972).^{42,44}

Figure 124. % Corg. in the bottom sediments, San Francisco Bay, California (Folger, 1972).³²

Figure 125. % Corg. South San Francisco Bay sediments (Conomos, 1963).²¹

Figure 126. % N in the sediments of the Southern California Mainland Shelf. Point Conception, Santa Barbara, and Mugu Shelves (State of California, 1956; Emery, 1960). 29,107

Figure 127. % N in sediments of the Southern California Mainland Shelf. Santa Monica, Palos Verdes, and San Pedro shelves (State of California, 1965; Emery, 1960). 29, 107

Figure 128. % N in the sediments of the Southern California Mainland Shelf. Newport-La Jolla and San Diego shelves (State of California, 1965; Emery, 1960). 29,107

Figure 129. % Corg. (first number) and % N (second number) in the bottom sediments from Mexico to Point Conception (60 m water depth) (Word and Mearns, 1975; Emery, 1960; Bascom, 1979). 5, 29, 124

Figure 130. % Corg. in the Gulf of California sediments (Van Andel and Shor, 1964). 117

Figure 131. % C_{org}. (upper number) and % N (lower number) in the sediments of the Gulf of Guayaquil (Rowe, 1978).¹⁰⁰

Figure 132. % C_{org}. in the sediments of the Coast of Peru. A B Transect (Rodinova et al., 1973).⁸⁸

Figure 133. % C_{org.} in the sediments off the coast of Peru (Rowe, 1971).⁹⁴

Figure 134. % C_{org.} in the sediments off the coasts of Peru and Chile (Logvinenko and Romankevich, 1973).⁶²

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SOUTHERN REGION

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Figure 136. % C_{org}. Antarctic Region (Based on Lisitzin, 1972).⁶⁰

Figure 137. % C_{org}. in the top sediments of world oceans and seas.

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WORLD OCEAN FLOOR
Adapted from Heezen, B.C.
and M. Tharp, World Ocean
Floor, U.S. Navy, Office
of Naval Research, 1977.

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Figure 138. Numbers refer to detailed maps of the corresponding coastal and open sea area as indicated. Individual maps can be located by the figure numbers on pages.

Figure 139.

Figure 140.

Figure 141.

Figure 142.

Figure 143.

Figure 144.

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Figure 146.

Figure 147.

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DISCUSSION AND CONCLUSIONS

It is clear from the data presented that high concentrations of sedimentary organic matter are associated with the continental shelves and slopes, with considerable accumulation between the shelf-break and the upper slope areas. Examples of the latter are the Bay of Bengal, the coast of southwest Africa (Fig. 137) and the western shelf of Mexico (Stetson and Trask, 1953; Figs. 51-58). The organic carbon and nitrogen analyses which represent this organic matter were carried out on samples derived from the upper 0 to 15 cm sedimentary layer. It is reasonable to assume that most geophysical, chemical, and biological processes have already acted upon the sedimentary matter in the layer under consideration, and that the organic and inorganic matter are in a state of equilibrium with their surroundings at the time of sampling. This seems to be a reasonable assumption since, in a given region, the relative concentrations of organic matter (expressed as % C_{org} . and N) tend to remain constant for long periods of time, small fluctuations being insignificant on a geological time scale (Eglinton, 1969; Yen, 1977).

Bearing in mind that the sorbed and nonsorbed matter is quantitatively inherent in such an equilibrium, chemical information about the predominant clay mineral and its association with organic matter, i.e. concentration of organic matter expressed as organic carbon and nitrogen, would then allow for a reasonable prediction of the type of organic matter sorbed vs. that released to the aqueous phase.

From graphic presentations of the data base (Figs. 1 to 137) an overall pattern of the depth distribution of organic matter in the sea is recognizable. In the light of the above discussion, can this existing information be reduced to a form which may lead to a chemical parameter relating bottom topography and the content of clay mineral and organic matter?

In an attempt to answer this question, the Eastern U.S. coast has been chosen as a representative system, because this is a region for which most of the data of interest are available (Hathaway, 1971). Plots of organic carbon, nitrogen, calcium carbonate, and sediment particle size against depth are shown in Figs. 139 to 147. Although the scatter is considerable (e.g. Fig. 139) and regional localized effects have not been taken into consideration in this data treatment (Benkovitz et al.), a remarkably consistent pattern, summarized in Table 3, does emerge.

Table 3

Depth	0-150m	151-600m	601-1050m	1051-1800m	1801-3000m
% C _{org}	increasing	max	min	2nd max	shoulder decr.
% N	increasing	max	min	2nd max	shoulder decr.
C/N	increasing	max	min	shoulder	level off
% CaCO ₃	min	increasing	max	min	slight increase level off
% Coarse	max	min	small max	---	---
% Medium	decrease	min	max	decreasing	shoulder decr.
% Fine	increasing	max	min	2nd max	increasing

There is a similarity between the offshore distribution of organic carbon and nitrogen, but a change occurs in the C/N ratios, which may reflect a difference in sources of the sedimentary material (Walsh, 1979). Calcium carbonate exhibits a maximum in the region where organic carbon and nitrogen show a minima. Organic carbon and nitrogen maxima are associated with maxima of fine grain particles, while the calcium carbonate maximum is associated with the maximum in the medium grain size fraction (Table 3). Distinct maxima and minima of these properties occur in the 200m to 2000m region, i.e., the continental slope. This region's bottom deposits (Milliman et al., 1972) are characterized by subarkosic to arkosic fine grain

sediments from 35°N to 75°N, and by high carbonate, glauconitic sands and very high carbonate sands between 25°N and 35°N. The distribution of clay minerals in the fine grain size fraction is dominated by three types: from 35°N and northward by 60-80% illite, between 25°N and 33°N by 40-60% montmorillonite and between 27°N and 35°N by 60-40% kaolinite (Emery and Uchupi, 1972). The major sources of sedimentary calcium carbonate in the 200 to 2000m region of the Atlantic continental margin are plankton foraminifera, with an additional coral contribution in a relatively small region north of Florida (Emery, 1972).

The maximum of calcium carbonate occurs at about 750m, and coincides with the minimum for organic carbon and nitrogen. This is consistent with the observations of Muller and Suess (1977) who have studied in detail the relationship between organic carbon, nitrogen, C/N, particle size, and biogenic carbonate fragments. High concentrations of calcium carbonate coincide with low concentrations of organic carbon and nitrogen also on a global basis (compare Biscaye, Kolla, Turekian, 1976; Kolla et al., 1976; and Berger et al., 1976; Simoneit and Burlingame, 1973 with Fig. 137, this paper). It should also be noted that the calcium carbonate maximum appears at a depth shallower than the 1000m mark, coinciding with the reported maximum degree of calcite saturation (Berner 1974). The CaCO₃ maximum also coincides with the region of minimum rate of dissolution for the foraminifera sediments (Berner, 1974).

The organic carbon and nitrogen maxima occur in the 300m region and coincide with the oxygen minimum zone for the entire continental slope between Mexico and Georges Bank (Emery and Uchupi, 1972). The region northeast of 35°N consists of subarkosic to arkosic fine grained sediments,

and since such sediments are known to contain much feldspar, which can be easily destroyed by chemical processes such as weathering, one might assume that these sediments have not travelled long distances from their source rock. Organic matter sorbed on such sediments, particularly in the low oxygen zone, should be fairly well preserved and enriched in compounds which do not react or react very slowly with the inorganic matrix of these sediments under the present conditions of the region. Similar sediment characteristics should be expected southward of the 35°N latitude, with one exception, namely that past the boundary between arkosic sands and calcium carbonate sediments there should be a sharp decline in organic matter. This is indeed reflected in the overall % C_{org} and N distribution (see Figs. 25, 28, and 31) which represents an area of a large calcium carbonate deposit.

At the present time, there is insufficient data which would support the reality of the second offshore maximum for organic carbon and nitrogen, although the plots, as shown in Figures 139 to 147, suggest one at about 1500m. However, it can be stated with a reasonable degree of confidence that organic matter in the sediments of the 1500m region has been subjected to many chemical and biological processes, therefore, these sediments should be characterized by an enrichment in chemically and biologically stable compounds.

Because the 200 to 2000m region is rich in feldspars and silicate minerals (e.g. illite) one may anticipate that compounds containing nitrogen, e.g. amines and compounds which have been converted during diagenesis to amines and/or ammonia, will be fixed in the form of ammonium ions in the interlayers of highly charged aluminum silicates (Muller, 1977); therefore, Kjeldahl nitrogen values may represent nitrogen containing both nonfixed and

fixed organo-mineral compounds. These data clearly indicate that useful chemical information can be deduced from organic matter content (expressed as % C_{org} and N) and its distribution as a function of depth and mineral clay type. However, more detailed analysis of the relationship between the organic matter constituents and the physical-chemical nature of the predominant mineral clay in a given sedimentary region are still lacking.

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