IRC. 702

GEOLOGICAL SURVEY CIRCULAR 702

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Movement and Effects of Spilled Oil Over the Outer Continental Shelf—Inadequacy of Existent Data For the Baltimore Canyon Trough Area

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GEOLOGICAL SURVEY CIRCULAR 702

1974

United States Department of the Interior
ROGERS C. B. MORTON, *Secretary*

Geological Survey
V. E. McKelvey, *Director*

Free on application to the U.S. Geological Survey, National Center, Reston, Virginia 22092

CONTENTS

ILLUSTRATIONS

TABLES

Movement and Effects of Spilled Oil Over the Outer Continental Shelf—Inadequacy of Existent Data for the Baltimore Canyon Trough Area

By H. J. KNEBEL

ABSTRACT

A deductive approach to the problem of determining the movement and effects of spilled oil over the Outer Continental Shelf requires that the potential paths of oil be determined first, in order that critical subareas may be defined for later studies. The paths of spilled oil, in turn, depend primarily on the temporal and spatial variability of four factors: the thermohaline structure of the waters, the circulation of the water, the winds, and the distribution of suspended matter. A review of the existent data concerning these factors for the Baltimore Canyon Trough area (a relatively well studied segment of the Continental Shelf) reveals that the movement and dispersal of potential oil spills cannot be reliably predicted. Variations in the thermohaline structure of waters and in the distribution of suspended matter are adequately known; the uncertainty is due to insufficient wind and storm statistics and to the lack of quantitative understanding of the relationship between the nontidal drift and its basic driving mechanisms. Similar inadequacies should be anticipated for other potentially leasable areas of the shelf because an understanding of the movement of spilled oil has not been the underlying aim of most previous studies.

INTRODUCTION

Many areas of the Continental Shelf of the United States are likely to be considered for petroleum exploration (and possibly production) in the near future. According to the National Environmental Policy Act of 1970, the decision to lease any of these areas for exploitation must be accompanied by statements on the environmental impact of petroleum-related activities. The movement and effects of oil that may be spilled during drilling and transfer operations should be a major topic of the environmental assessment because (1) the sources of oil spills are numerous (including losses from waterborne traffic and pipelines as well as from submarine drilling operations), (2) oil spills are tangible phenomena to a relatively large segment of the population of the United States, and (3) a knowledge of this aspect is essential to related social, political and economic studies.

This study considers the existent data in relation to the movement and effects of potential oil spills within the Baltimore Canyon Trough area. The Baltimore Canyon Trough is a depression in the basement rocks beneath the shelf off the coasts of New Jersey, Delaware, and Maryland (Maher, 1965; Maher and Applin, 1971) (fig. 1). This depression, as outlined by the 10,000-foot (3,048-meter) structural contour, parallels the shelf edge for approximately 150 miles (240 kilometers) and extends southward from about lat 40°N. to lat 38°N., where it crosses the shelf break, to the Continental Slope. Near its axis, the trough contains more than 16,000 feet (4,876 meters) of sedimentary rocks, which are mainly Cretaceous marine beds (fig. 1).

The Baltimore Canyon Trough area as used herein is bounded by lines that extend orthogonally across the shelf off northern New Jersey and Cape Charles, Va., on the north and south, respectively, by the shelf break on the east, and by the coastline (exclusive of Delaware Bay) on the west (fig. 2). These limits encompass not only the part of the shelf directly over the Baltimore Canyon Trough but some of the sur-

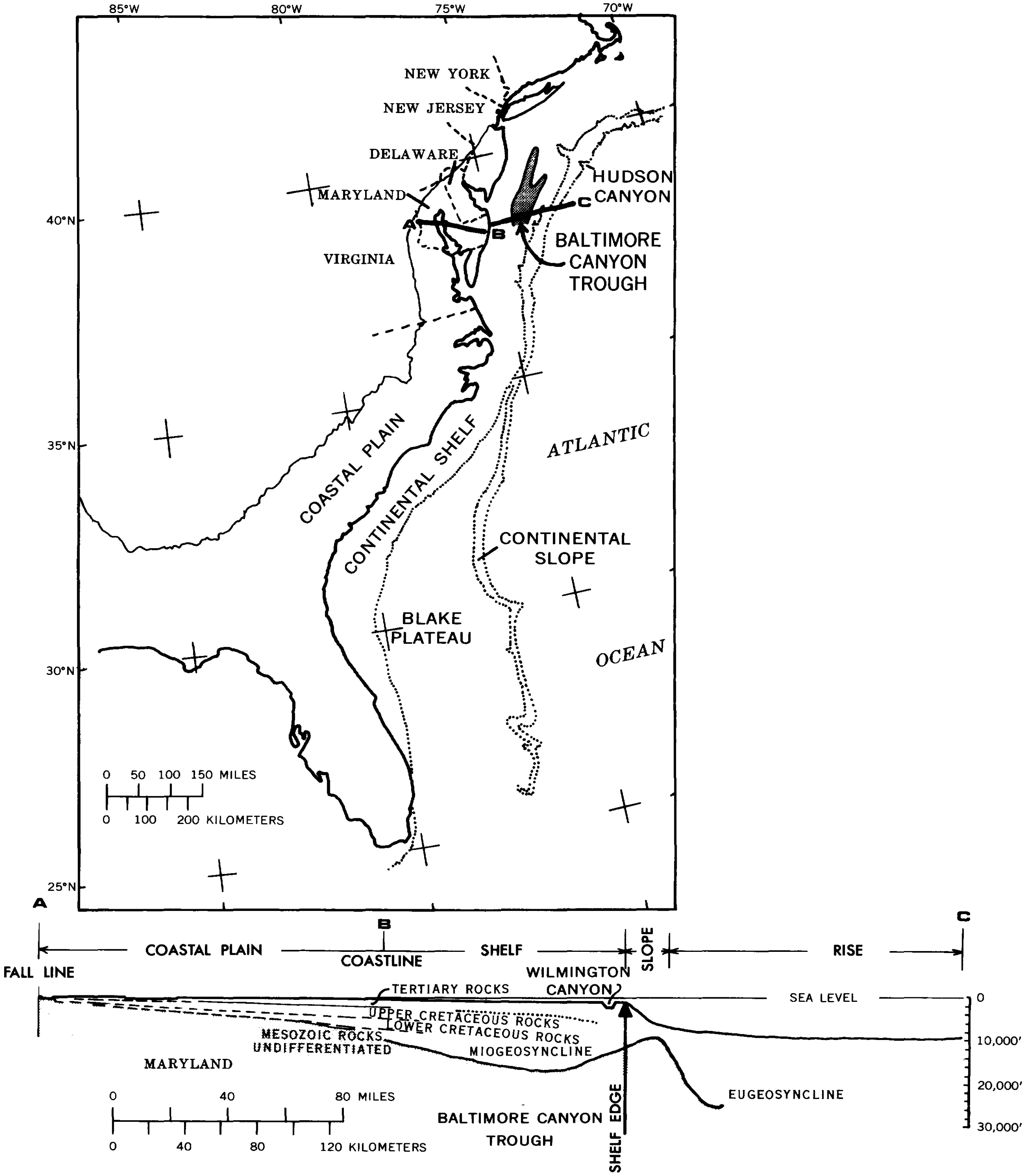

FIGURE 1.—Location map and cross section of the Baltimore Canyon Trough. Modified from figure 6 and plate 5 in Maher and Applin (1971).

rounding region as well. The inclusion of this peripheral area in the study area was necessary because the boundary conditions for the currents and the winds must be known.

The purposes of this paper are to outline a deductive approach for assessing the movement and effects of oil that may be spilled over the Outer Continental Shelf, to deduce the adequacy of the existent data for the Baltimore Canyon Trough area, and to determine what implications this evaluation may have for future research either within or outside the area.

I greatly appreciate the helpful criticism of Dr. Donald V. Hansen, National Oceanic and Atmospheric Administration, Miami, Fla., and Dr. Robert H. Meade, U.S. Geological Survey, Woods Hole, Mass.

APPROACH

A deductive approach to the problem of determining the movement and effect of spilled

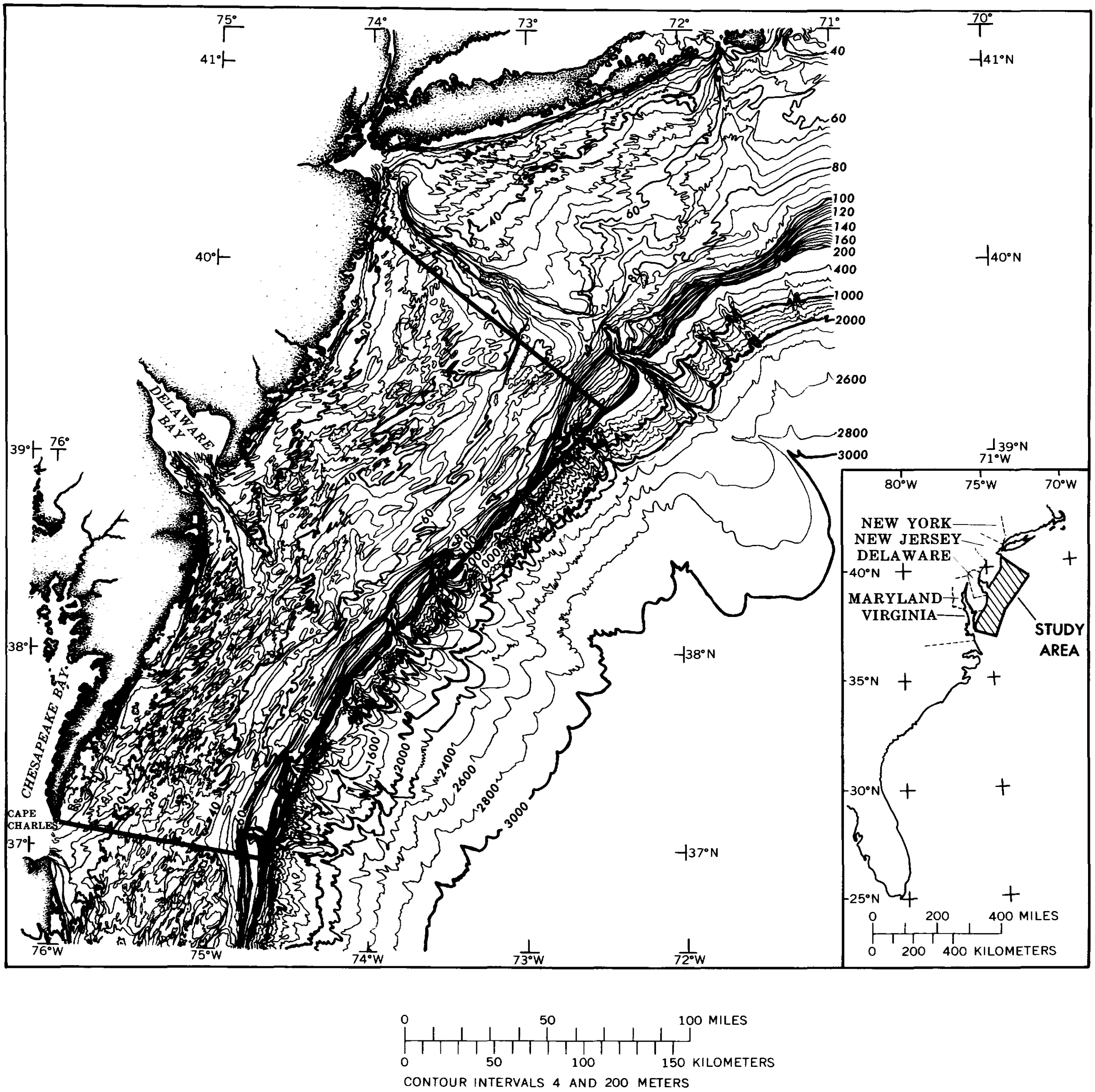

FIGURE 2.—Limits and location of the Baltimore Canyon Trough area as defined for this study. The coastline, exclusive of Delaware Bay, delimits the western boundary of the area. Bathymetry from Uchupi (1970).

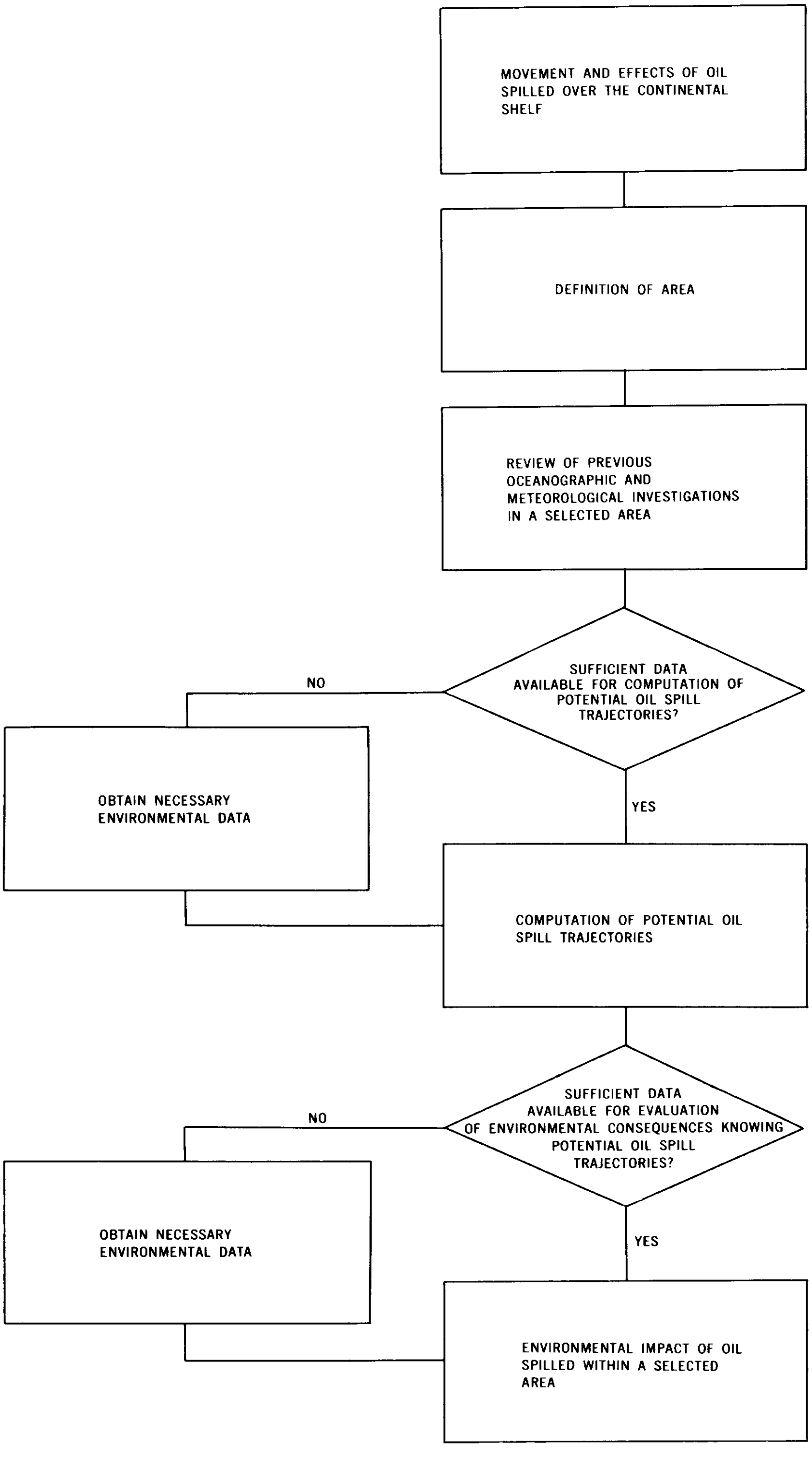

FIGURE 3.—Outline of deductive approach to the problem of determining the movement and effects of spilled oil over the Outer Continental Shelf. Each step is summarized within either a rectangle or a parallelogram, and the progression is from top to bottom along lines that connect adjacent steps. Rectangles indicate explicit steps, whereas those that involve decisions are enclosed in parallelograms. Mutually exclusive paths proceed from those steps which involve decisions because of the two possible outcomes.

oil over the Outer Continental Shelf is outlined in figure 3. The paths of the oil must be determined first, in order that critical subareas may be defined for later study. Subsequent baseline studies within explicit subareas should focus on the environmental aspects that might be affected by the oil. If, at any stage of the investigation, the existent data proves to be inadequate, then new information will have to be obtained before either the paths or the effects of the oil can be determined (fig. 3). Thus, for any subarea of the Outer Continental Shelf, the first step in an evaluation of the adequacy of existent data is to find out whether or not the potential paths of spilled oil can be reliably predicted.

Over the outer shelf, the paths of spilled oil depend on the following dispersive processes: dissolution, evaporation, emulsification, spreading, drifting, and sinking (Zobell, 1964; Pilpel, 1968). The degrees of dissolution, evaporation, and emulsification are determined primarily by the kind of spilled oil and its physical state; water temperature, wind, and surface mixing are secondary factors. The processes of spreading and drifting, on the other hand, depend largely on the quantity of spilled oil, the horizontal and vertical water movements, and the duration and velocity of the winds. Moreover, oil sinks after its density is increased by the loss of the volatile and light fractions or by the inclusion of suspended solids; the rate and the depth of descent may be affected by the thermohaline structure of the water. Thus, aside from the chemical composition and the quantity of spilled oil, the dispersive processes depend on the temporal and spatial variability of (1) the thermohaline structure of the waters, (2) the circulation of the water, (3) the winds, and (4) the distribution of suspended matter. These aspects must be considered, initially, for the Baltimore Canyon Trough area.

PREVIOUS WORK

Thermohaline structure

Short-term measurements of temperature and salinity from the Baltimore Canyon Trough area are found in reports that deal either with isolated aspects of the thermohaline circulation or with routine observations. Hydrographic measurements that were made to evaluate the surface coastal circulation during the change from spring to summer conditions were reported by Miller (1952a, b). Temperature and salinity data that were obtained during the summer and early winter months were used by Howe (1962) to evaluate the density-induced surface drift over the central and outer parts of the shelf. Daily determinations of temperature and salinity that were made during the years 1956 to 1970 at lightship stations over the inner shelf (fig. 4) have been tabulated by Bumpus (1957b), Day (1959a and b, 1960, 1963), and Chase (1964, 1965, 1966, 1967, 1969a and b, 1971a–c, 1972). Observations from eight inner-shelf traverses north of Cape Charles have been reported by Nichols and Lynch (1964). Nearly synoptic charts of the surface temperature of shelf waters have been drawn monthly since 1966 from data collected on temperature-measuring flights by aircraft; they are available from the U.S. Coast Guard Oceanographic Unit, Washington, D.C.

Compilations of thermohaline measurements, on the other hand, have been used to describe and explain the variability of waters within the area. Comprehensive descriptions of the annual cycles of temperature and salinity have been presented by Bigelow (1933) and Bigelow and Sears (1935), respectively. Charts, diagrams, and tables that show temperature or salinity statistics of surface and subsurface waters by month, season, or year can be found in Fuglister (1947), Bumpus (1957a), Pyle (1962), Stearns (1964, 1965), Emery (1966), Schroeder (1966), Walford and Wicklund (1968), and Emery and Uchupi (1972, p. 259–269). Some effects of runoff and winds on the hydrography of shelf waters have been discussed by Ketchum (1953), Ketchum and Keen (1955), Chase (1959, 1969c), Bumpus and Chase (1965), and Harrison and others (1967).

Circulation of water

Tidal currents are the horizontal movements of water that are produced by the periodic motion of the tidal cycle. Tidal currents within the Baltimore Canyon Trough area have been discussed in reports by Haight (1942), McClennen (1973), and Redfield (1958). Tide and tidal-current tables are published annually for the east coast of North America (for example, U.S. Department of Commerce, 1973a, b) and can be used to determine the tidal characteristics at any desired location near the coast.

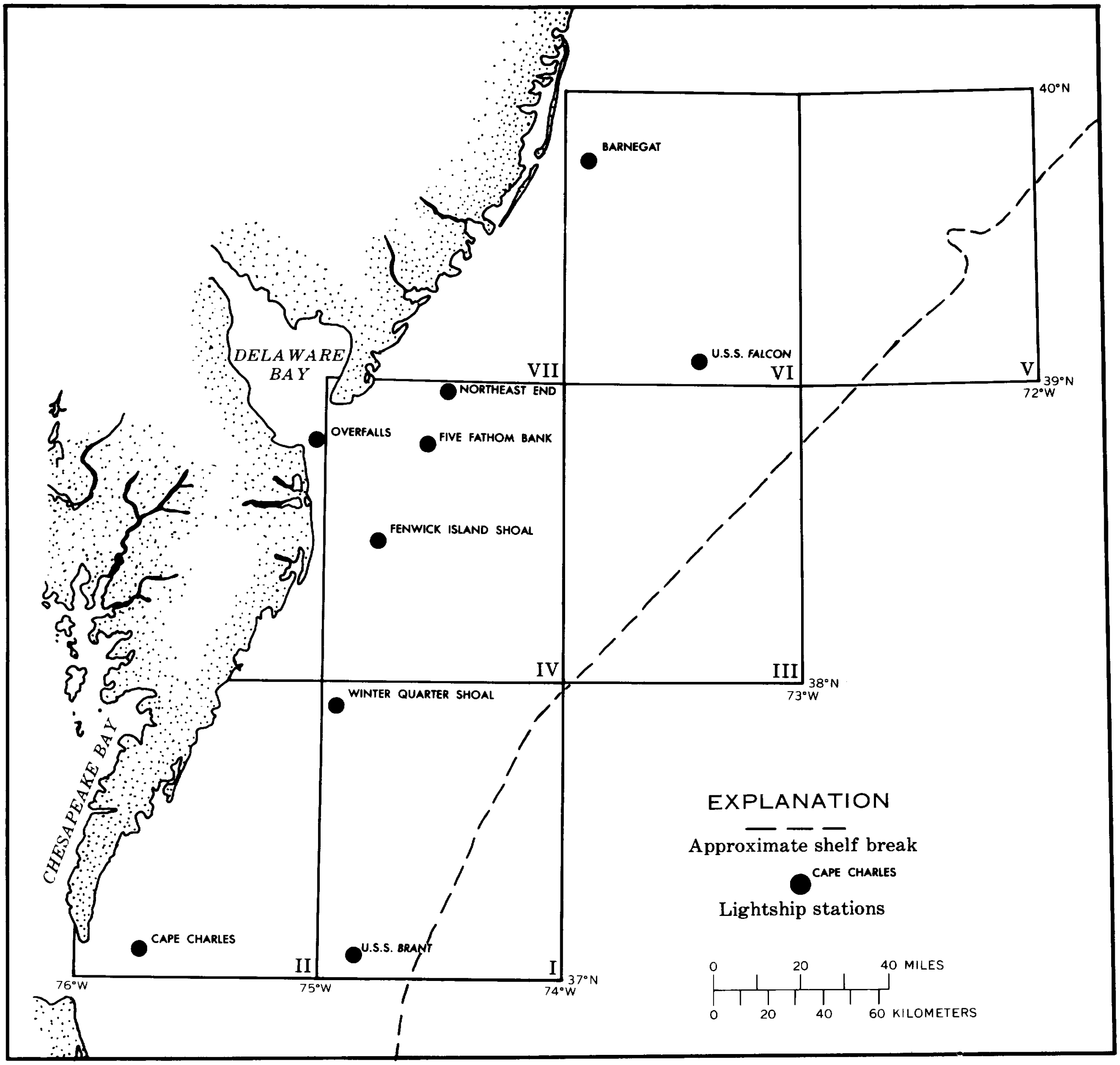

FIGURE 4.—Sketch map showing the Baltimore Canyon Trough area with locations of lightship stations from Haight (1942) and the definition of one-degree quadrangles (Roman numerals) of latitude and longitude from Bumpus (1974) for the surface and seabed drifter census presented in table 2.

The nontidal residual drift over the Baltimore Canyon Trough area has been studied by following the movement of waters with time (Lagrangian measurements), by determining the flow at fixed locations (Eulerian measurements), and by examining the effects of various environmental factors. Lagrangian measurements within the surface waters include those made by means of drift bottles (Bumpus, 1963, 1969a and b, 1974; Bumpus and Chase, 1965; Bumpus and Lauzier, 1965; Bumpus and others, 1973; Harrison and others, 1967; Ketchum, 1953; and Miller, 1952a) and drogued transponder buoys (Howe, 1962). Eulerian measurements that were made at lightship stations near the coast have been reported by Haight (1942). The effects of winds, runoff, and the density distribution on the surface circulation pattern have been discussed by Bumpus (1969a and b, 1974), Bumpus and Chase (1965), Bumpus and others (1973), Emery and Uchupi (1972), Haight (1942), Harrison and others (1967), Howe (1962), Ketchum (1953), Miller (1952a), and Schroeder (1966).

The residual drift of subsurface waters in this area has been investigated primarily with the aid of sea-bed drifters (Bumpus, 1964, 1965, 1974; Bumpus and others, 1973; Harrison and others, 1967). McClennen (1973), however, recently measured the near-bottom drift at several locations over the central and outer shelf by means of moored current meters. Bumpus (1965, 1974), Bumpus and others (1973), Chase (1959), Harrison and others (1967), and McClennen (1973) discussed some changes in the subsurface circulation that were due to the winds and the thermohaline structure of the waters.

Winds

Wind data from the Baltimore Canyon Trough area can be found in publications that deal with the interaction between the sea and the atmosphere as well as in reports of weather statistics. Papers by Chase (1959), Emery (1965), Haight (1942), Harrison and others (1967), Miller (1957), and Redfield and Miller (1957) are included in the first category of publications, whereas wind statistics have been reported by the Chief of Naval Operations (1955), U.S. Department of Commerce (1959), U.S. Naval Oecanographic Office (1963), and the U.S. Naval Weather Service Command (1970). In addition to these reports, wind records from coastal weather stations and from ships in the area are available from the National Climatic Center in Asheville, N.C.

Suspended matter

The suspended matter within the water column over the Baltimore Canyon Trough area has been measured during two seasons. Manheim and others (1970) reported measurements that were obtained during the spring, whereas Meade and others (1970, 1974) discussed measurements that were obtained during the early part of the fall. Meade (1972) considered the sources and fate of suspended matter over this part of the Atlantic continental shelf.

ADEQUACY OF EXISTENT DATA

Thermohaline structure

Knowledge of the monthly or seasonal thermohaline structure is probably most useful for predicting the movement and effects of spilled oil. Within the water column, the sinking rate and the concentration of oily debris may be controlled by pronounced pycnoclines, the locations of which, in turn, can be estimated from the mean thermohaline structure of the waters. In the Baltimore Canyon Trough area, the thermohaline structure is determined primarily by seasonal changes in solar insolation, winds, runoff, and indrafts of slope water (Bigelow, 1933; Bigelow and Sears, 1935).

In the Baltimore Canyon Trough area, the monthly and seasonal variability of the thermohaline structure of waters is known from existent hydrographic data. Bigelow (1933), for example, in his classic description of the cycle of temperature, used most of the data that were available before 1933. For the Baltimore Canyon Trough area, these data were largely serial observations that were made by the U.S. Bureau of Fisheries and the Woods Hole Oceanographic Institution while studying various fisheries problems. As a result, observations were available for all seasons and over several years. Moreover, the serial measurements were made on samples that were obtained across the entire shelf and throughout the water column to 200 meters.

Monthly isothermal charts and diagrams for waters over the Baltimore Canyon Trough area can be found in Fuglister (1947), Pyle (1962), Schroeder (1966), and Walford and Wicklund (1968). The marine environment atlas folio by Walford and Wicklund (1968) is especially informative because it is based on a comprehensive collection of observations that span a 50-year period (1914–64) and it outlines the mean-temperature structure of both the surface and subsurface waters. The quantity and distribution of observations were such that averages for 15-minute squares were used to position the isotherms.

The annual cycle of salinity in this area is best described by Bigelow and Sears (1935) and Chase (1969c). The account by Bigelow and Sears (1935) is a sequel to the description of the temperature cycle by Bigelow (1933) and, like its predecessor, is based primarily on serial observations that were made throughout the year over many years (1913–32). It considers the water column over the entire Baltimore Canyon Trough area. Chase (1969c), on the other hand, discussed only the surface salinity over the inner part of the shelf. This study is significant, however, because it used daily salinity determinations that were made at lightship locations over a period of 12 years. From these data, Chase (1969c) was able to relate the coastal salinity distribution to the discharge and proximity of rivers.

Circulation of water

Tidal currents are relatively unimportant in determining the net drift of spilled oil within the Baltimore Canyon Trough area. Over this part of the shelf, tidal currents are semidiurnal and generally attain speeds no greater than 13 centimeters per second (Redfield, 1958). Maximum speeds develop about 3 hours before high and low water and, at these times, the flow is directed approximately normal to the trend of the shelf (Haight, 1942; Redfield, 1958). During the remainder of the tidal cycle, the components of motion parallel to the coast are small (Redfield, 1958). Thus, because of their oscillatory nature, low speed, and limited net transport, these currents are probably secondary to nontidal currents in the movement of waterborne oil. It should be remembered, however, that tidal currents may aid in the spreading and in the continued suspension of oil within tidal excursion limits and that they may be important agents in the resuspension of oily debris from the bottom.

The nontidal residual drift over the Baltimore Canyon Trough area is controlled by the winds, the pressure gradient induced by the runoff, and the geostrophic effects of the temperature and salinity distributions (Bumpus and others, 1973). In order to predict the potential paths of spilled oil in this area, therefore, one must know the correlations between these factors and the net drift.

The only direct current measurements that have been reported from this region are the drift-pole observations of Haight (1942), the parachute-drogue experiments of Howe (1962), and the current-meter records of McClennen (1973). Haight (1942) computed the nontidal component of the observed surface currents that were measured at nine lightship stations over the inner and central parts of the shelf (fig. 4). At four of the inner-shelf stations, from which a year's or more than a year's record of hourly data were available, he compared the nontidal currents to estimates (made simultaneously) of the directions and speeds of the winds. The average relationships that were derived from the exercise are shown in table 1.

The attempt by Haight (1942) to deduce the effect of the winds on the residual drift is recognized, but other nontidal effects are included as well in his current-velocity data. In fact, the capricious and negative deviations of currents to the right of the winds (table 1) show that other factors had an effect on the flow. The utility of these data in understanding the circulation over the Baltimore Canyon Trough area therefore is limited not only because the driving forces were not resolved but because (1) only the surface currents were measured, (2) data from the outer shelf are lacking, and (3) the observations at many of the stations were sporadic, discontinuous, and short-term (3–5 months).

Howe (1962) compared nontidal-drift velocities over the central and outer parts of the shelf to density gradients that were determined from nearby hydrographic sections; from data that were obtained during calm periods in summer and autumn, he discerned a high degree of correlation between the two parameters. Regression equations were derived, consequently, from which the residual drift could be estimated from differences in the mean density between stations.

The observations and equations of Howe (1962) may be useful for predicting, under limited conditions, the movements of spilled oil within the Baltimore Canyon Trough area. Most notably, the results are applicable only to the eastern part of the area because no measurements were made over the inner part of the shelf. Moreover, the correlations pertain only to two seasons of the year; data are lacking for the winter and spring when wind mixing and runoff are likely to have the greatest effects on the density structure of the waters.

Table 1.—*Average relationship between the observed currents and winds at Atlantic coast lightship stations (from Haight, 1942)*

	AVERAGE RATIO OF CURRENT VELOCITY IN KNOTS TO WIND VELOCITY IN STATUTE MILES PER HOUR					AVERAGE DEVIATION OF CURRENT DIRECTION TO RIGHT OF WIND DIRECTION IN DEGREES				
WIND FROM—	BARNEGAT	NORTHEAST END	OVERFALLS	WINTER-QUARTER SHOAL	AVERAGE	BARNEGAT	NORTHEAST END	OVERFALLS	WINTER-QUARTER SHOAL	AVERAGE
N	0.010	0.021	0.015	0.015	0.015	6	30	31	18	21
NNE	.011	.022	.016	.018	.017	5	14	-23	-1	-1
NE	.009	.021	.016	.022	.017	-13	-3	-1	-5	-6
ENE	.010	.024	.026	.016	.019	-9	-11	14	-21	-7
E	.006	.016	.015	.013	.013	-16	-20	-58	-27	-30
ESE	.003	.013	.016	.012	.011	-7	-31	-58	-35	-33
SE	.004	.013	.012	.005	.009	33	-42	-61	-19	-22
SSE	.007	.012	.024	.009	.013	54	-28	-18	31	10
S	.008	.010	.011	.010	.010	55	37	51	23	41
SSW	.011	.008	.008	.013	.010	30	44	11	20	26
SW	.010	.016	.010	.015	.013	14	25	18	4	15
WSW	.008	.015	.019	.015	.014	8	18	51	14	23
W	.008	.011	.004	.011	.009	0	7	17	9	8
WNW	.005	.014	.019	.010	.010	-5	16	28	8	12
NW	.005	.009	.006	.012	.008	21	25	15	28	22
NNW	.008	.013	.008	.014	.011	29	18	56	27	33
AVERAGE	.008	.015	.014	.013		13	6	5	5	

McClennen (1973) measured the currents at four locations across the shelf off southern New Jersey with instruments that were set within 2 meters of the sea floor. Data on bottom currents were obtained over periods of 9–11 days at each station during the late spring of either 1970 or 1971 in water depths of 30, 59, 74, and 143 meters. For each station, the energy spectrum of the currents was examined for tidal effects, and the periodicity and timing of the tides and winds were compared to the net drift as determined from progressive vector plots.

Off New Jersey, McClennen (1973) compared the 7:00 a.m. coastal winds (measured at shore stations) to the daily net drift that was determined from his current-meter data. He found that the coastal winds seemed to be correlated with the near-bottom water movement that occurred over the inner and central parts of the shelf but that the winds did not necessarily correspond with the bottom drift over the outer shelf. These qualitative comparisons were made because insufficient wind data were taken at sea near the current-meter stations. Although the comparisons indicate that wind effects may or may not be recognized within the bottom flow across this part of the shelf, they are no substitutes for a quantitative correlation that can be used to estimate the effects of local winds on the bottom drift. The lack of such a correlation limits the usefulness of the current-meter data of McClennen (1973) in predicting the net movement of oil-tainted material along the bottom.

Most of what has been published about the nontidal drift over the Baltimore Canyon Trough area has been inferred from indirect current measurements involving surface and seabed drifters. The most comprehensive reports that deal with such measurements are those by Bumpus and Lauzier (1965) and Bumpus (1974). Bumpus and Lauzier (1965) described the surface drift in this area on the basis of all drift bottle data that were available from 1948 through 1962. Included in their folio are monthly charts that show, on a 30-minute rectangular grid, where the drift bottles were released, the percentage of recovery on the North American seaboard from each rectangle, and the drift velocities through those rectangles from which the bottles originated. The seasonal circulation patterns were portrayed on four summary charts.

Bumpus (1974) subsequently reviewed the surface circulation pattern in this area in light of drift-bottle data that were obtained from 1961 to 1970 and also described the bottom flow from coeval seabed-drifter data. His report included charts of the general surface and bottom drift (averaged for each month) over the 10-year period as well as month-by-month charts of surface drift for the years 1968 and 1969. Charts of the surface drift on a month-to-month basis for the years 1960 to 1967 had already been published by Bumpus (1969b). All the charts show the locations at which the drifters were released and the directions of inferred drift; speeds were estimated only for the surface flow. General flow patterns were determined by averaging the azimuths between launch positions and the recovery sites.

The essence of the drifter data reported for the Middle Atlantic Bight by Bumpus and Lauzier (1965), Bumpus (1974), and others can be summarized by the following passage from Bumpus and others (1973). They report:

> . . . we see the circulation over the continental shelf of the Middle Atlantic Bight as a surface drift with the land on the right at speeds on the order of 10 miles per day. There may be a shoreward component of this drift during the warm half of the year and an offshore component during the cold half carrying a flux of fresh water away from the estuaries. The surface drift, fundamentally the result of the temperature-salinity distribution, may be modified by the wind. A persistent bottom drift, at speeds of tenths of miles per day, extends from just beyond mid-shelf toward the coast and eventually into the estuaries, providing a flux of salt. Along the outer edge of the shelf, the bottom drift is less well defined.

This summary by Bumpus and others exemplifies the dubious as well as the more substantial aspects of the drifter data that were obtained over and around the Baltimore Canyon Trough area. Although the general nature and causes of the residual flow have been inferred from drifters, specific predictions of water movements cannot be made with any degree of confidence. This vagueness is due, in part, to the difficulty in inferring trajectories from a knowledge of only the launch and recovery locations, from a biased estimate of the travel time between these locations, and from the small percentage of drifters that are ultimately recovered, especially those from the outer shelf and during the fall and winter (table 2; fig. 4). Moreover, drifters probably could never fully define (even with statistical models) the nontidal circulation over this part of the shelf because the temporal and spatial scales of the velocity field are, in general, small compared to the times of drift and the distances travelled (Bumpus, 1974; Bumpus and others, 1973; Haight, 1942; Howe, 1962; McClennen, 1973). Also, the relationship of drifter data to the flow at middepth is uncertain.

Winds

In order to forecast the movement and dispersal of spilled oil over the Baltimore Canyon Trough area, one must know that, in the event of a spill, wind stress would not only modify the water circulation but would act on the surface oil film directly. Thus, two sets of wind data are required. One set must be obtained along with simultaneous accurate measurements of water currents in order to establish the correlation between the winds and the nontidal drift. The second set, which may be derived from past observations, must define the variability (direction, magnitude, and duration) of the wind stress. The adequacy of the existent information should be evaluated in terms of the requirements of the latter set.

The definition of the variability of the wind velocity (hence wind stress) over the Baltimore Canyon Trough area depends on data that outline both the temporal and spatial scales of the velocity field. Measurements of short duration or over limited parts of the area, such as those included in reports listed earlier that deal with sea-air interaction, clearly do not meet these criteria. Likewise, wind statistics, such as those published by the Chief of Naval Operations (1955), the U.S. Department of Commerce (1959) and the U.S. Naval Oceanographic Office (1963), describe only average conditions whereas modeling the winds requires data that can characterize the random behavior of the wind, particularly the deviations from the mean, over the entire region.

The compendium by the U.S. Naval Weather Service Command (1970) comes closest to meeting the requirements for wind data. This compendium summarizes the surface-wind observations that have been made aboard vessels since the late 1800's within discrete areas off the North American coast. Volume 2, in particular, treats those observations for a subarea bounded by latitudes 38° and 40°N., by longitude 72°W., and by the coast (fig. 2), a subarea which includes most of the Baltimore Canyon Trough area. For this subarea (and others as well), the percentage frequency of wind direction by speed and by hour are given on a monthly basis. Thus, wind direction, wind magnitude, and time are correlated. As a result, one can determine the probability of observing a wind from a given direction, within a specified speed range, at a specified hour during a particular month.

The compendium by the U.S. Naval Weather Service Command (1970), however, has several shortcomings. First, the basic wind observations are probably biased toward lower values; whenever possible, ships in transit avoid bad weather, the result being that fewer wind observations are made within storm areas than in areas with more clement conditions. Second, the compendium does not give statistics on the frequency, size, and history of storms; during storms, the movement of oil on the sea surface is likely to be the greatest. Finally, the duration of the winds cannot be evaluated from these data. Because oil spills are likely to last for days (and even weeks), any evaluation of surface motion is incomplete without estimates of the persistence of winds from different directions and of the turning of the winds with time.

Suspended Matter

The movement and dispersal of spilled oil may be aided by the inclusion of suspended matter; the density of oil may be increased by the incorporation of particles at sea surface, and, consequently, oily debris may sink to intermediate water depths or to the sea floor. Whether or not suspended matter is a viable dispersive agent wihin a particular area depends on its concentrations and composition within the surface waters.

Over most of the Baltimore Canyon Trough area the concentrations of suspended matter are rather low. Manheim and others (1970) studied the distribution of suspended solids

TABLE 2.—*Number of drifters released on the shelf of the Middle Atlantic Bight (column A) and percentage recovered from North American shores (column B), 1961–70 (from Bumpus, 1974)*

QUADRANGLE	LOCATION		JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
	LAT°N	LONG°W	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
DRIFT BOTTLES																										
I	37–38	74–75	115	0	137	0	115	2	145	2	178	1	193	2	245	8	82	10	202	3	124	2	138	0	90	0
II	37–38	75–76	233	9	227	6	234	10	318	8	276	12	353	8	359	11	228	29	366	17	199	18	259	2	181	0
III	38–39	73–74	95	0	156	0	185	0	85	0	171	3	85	1	171	5	169	8	195	1	244	0	125	0	125	0
IV	38–39	74–75	1050	0	1050	1	1335	4	1165	11	1360	22	1154	11	1160	13	1279	23	1304	19	1285	2	1251	1	1091	0
V	39–40	72–73	177	0	230	0	346	0	168	3	196	2	175	1	294	2	274	4	331	0	299	0	221	0	163	0
VI	39–40	73–74	711	1	639	1	859	5	554	23	644	12	615	15	866	13	823	18	896	14	511	5	784	1	703	0
VII	39–40	74–75	65	0	50	0	125	4	40	15	70	39	65	14	66	29	131	24	160	22	120	13	127	8	80	0
SEABED DRIFTERS																										
I	37–38	74–75	125	13	95	7	85	7	142	6	70	1	120	3	135	7	67	15	179	11	110	6	100	22	85	13
II	37–38	75–76	155	25	160	17	130	26	161	11	115	17	185	11	220	15	207	14	253	18	200	28	135	33	95	38
III	38–39	73–74	95	4	95	4	159	6	85	5	185	2	180	4	100	5	260	5	258	6	135	9	85	11	65	15
IV	38–39	74–75	165	18	125	14	296	21	85	24	210	21	170	21	165	35	311	24	280	23	243	39	155	35	75	31
V	39–40	72–73	70	17	140	12	140	4	94	5	96	4	90	2	205	5	225	9	215	9	160	10	160	8	120	10
VI	39–40	73–74	160	3	135	2	265	25	125	6	150	27	135	36	185	30	245	40	310	36	220	31	165	28	85	40
VII	39–40	74–75	70	29	40	30	149	26	40	25	70	43	65	54	65	60	125	50	160	46	110	53	70	50	40	30

along three well-sampled longitudinal lines over the inner, central, and outer parts of the shelf in this area. They found (for May and June) that areas having appreciable amounts of suspended matter in the surface waters were restricted to within a few kilometers of the coast. The total concentrations over the inner shelf ranged between 0.125 and 1.00 mg/l (milligram per liter), whereas those over the central and outer shelf were less than 0.125 mg/l. Similar concentrations were found across the area during September (Meade and others, 1970, 1974).

The particulate matter in this area is dominated by biogenic detritus produced by shelf organisms (Meade, 1972). During the May-June sampling period, combustible organic matter accounted for 40 to 60 percent (by weight) of the suspensate in the surface waters over the inner shelf, whereas the proportion of organic matter was even greater (60 to 90 percent) further offshore (Manheim and others, 1970). Meade and others (1974) observed a similar change across the shelf during September, although the combustible organic fraction in the surface waters over the inner shelf at that time was usually between 60 and 80 percent. Microscopic examination of samples that were obtained in the spring revealed that mineral grains coarser than 4 micrometers constituted less than 3 percent of the total suspended matter in the surface waters seaward of the longshore zone (Manheim and others, 1970).

The concentrations and compositions that have been observed indicate that suspended matter is not likely to have an appreciable effect on the movement and dispersion of oil that may be spilled over the Baltimore Canyon Trough area. The measurements by Manheim and others (1970), in particular, show that low concentrations prevail throughout the area even during the spring phytoplankton bloom. The small terrigenous component within the suspensate throughout the year is due to the nearshore-estuarine circulation which transports the small amount of fine-grained river sediments that escapes the estuaries back into the estuaries and coastal wetlands; only a small percentage of the total river sediment input crosses this part of the shelf into the deep sea (Meade, 1972). Moreover, because of the lack of terrigenous sediments and the predominance of biogenic detritus, the average density of the suspended matter in this area is probably quite low. Thus, even with greater concentrations, the suspended matter would probably not have a pronounced effect on the sinking rate of spilled oil. No measurements of suspended matter, however, have been made in this area after the passage of large storms or hurricanes. Such measurements have been made for the surface waters across the shelf off Cape Lookout, N.C.; the concentrations of the suspended matter over the inner shelf were increased significantly, whereas changes over the central and outer shelf were small (Rodolfo and others, 1971). A similar condition can be expected within the Baltimore Canyon Trough area.

SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

The adequacy of the existent data differs for each of the factors that have been considered for the Baltimore Canyon Trough area. The mean thermohaline structure is perhaps the most accurately defined factor because of the adequate number of temperature and salinity observations in time as well as over areal extent. Across this part of the shelf both the monthly and seasonal variations are known from existent data. In view of the rather long time required for pronounced changes, a determination of the average thermohaline structure for shorter periods of time seems unwarranted.

The circulation of the water, on the other hand, is poorly known. Drifter data have provided general estimates of the surface and near-bottom flow across the Baltimore Canyon Trough area but without due regard to small-scale changes in the velocity field. Only a few direct current measurements have been made within this area, and these are restricted with regard to time, location over the shelf, and position within the water column. The greatest deficiency, however, is the lack of quantitative understanding of the relationship between the nontidal drift and its basic driving mechanisms. Studies by Haight (1942), Howe (1962), and McClennen (1973) have shown that the effects of the winds and the pressure gradient (due to the runoff and the thermohaline structure) can be recognized within the measured flow, but the exact contribution of each force to the net drift has not been determined.

Quantitative correlations are possible only if accurate measurements of the nontidal drift and its basic driving mechanisms can be made simultaneously and in such a way that the spatial and temporal scales of the velocity field are included. In order to determine such correlations, the net flow throughout the water column should be measured at strategic locations across the shelf during all seasons and under storm as well as calm conditions. Presently, Eulerian methods (possibly moored current-meter arrays) can be used to measure subsurface drift, whereas both Eulerian and Lagrangian methods (possibly transmitting or responding drogues) can be employed to determine the surface flow. Concurrently, the temperature and salinity should be determined in sections across the shelf near where direct current measurements are being made, in order to assess the flux of fresh and saline water. With simultaneous observations of the ambient weather conditions, the wind-induced component of the net drift can be defined (and subsequently estimated).

The variations in the winds and the wind stress are also inadequately known for the Baltimore Canyon Trough area. The compendium by the U.S. Naval Weather Service Command (1970) outlines the relationships between wind direction, wind magnitude, and time, but it does not give statistics on the frequency, magnitude, and history of storms or the persistence of the winds from various directions. Moreover, the basic wind observations that were used in this study are probably biased towards lower values because reporting ships usually try to avoid storms.

The necessary information on wind patterns within the Baltimore Canyon Trough area may be obtained by reexamining the historical data. The records that should be used in this case (because of the spatial and temporal coverage) are all the ship weather reports that have been made for this area since the 1800's and that have been archived at the National Climatic Center in Asheville, N.C. These observations, which can be purchased on reels of magnetic tape, should be edited for gross errors, corrected for bias toward fair weather, and then sorted by subarea and time. After this process, statistical parameters that might characterize the variability of the winds and wind stress (including time series) could be computed.

Suspended matter is probably not an important dispersive agent for spilled oil in the Baltimore Canyon Trough area because of its low concentrations and biogenic composition (characterized by low density) within the surface waters. The characteristics of the suspended solids change very little throughout the year, especially over the central and outer parts of the shelf, because of the nearshore-estuarine circulation along this stretch of the coast. Although the suspended matter after the passage of large storms has not been studied in this area, the resultant changes are likely to be small and localized.

Of those factors that may effect or influence the movement and dispersal of spilled oil, the winds and the circulation of the water are inadequately defined by the existent data. Therefore the movement of potential oil spills in this area cannot be reliably predicted. According to the deductive approach outlined earlier (fig. 3), this deficiency, in turn, means that subareas for intensive (baseline) studies cannot now be delineated. Although one might argue that baseline studies should not be so restricted and should encompass the entire area, the size of this region renders this argument impractical.

The main result of this study is to point out that inadequacies exist in the data even for those sections of the Continental Shelf toward which a relatively great deal of previous research has been directed. The inadequacies of the existent data in the Baltimore Canyon Trough area are partly caused by a previous lack of technology, the complexity and variability of the shelf circulation and its driving mechanisms, and the tremendous amounts of time, money, and effort that are required for the collection and synthesis of this type of data. Above all, we are now addressing ourselves to a new problem resulting from man's interaction with his environment. As the data indicate, most of the previous studies in this area were directed toward different goals; thus, it would have been fortuitous if the existent data had fulfilled the new requirements.

These inadequacies are not likely to be either quickly or easily rectified. Direct current measurements in the Baltimore Canyon Trough area, for example, should be made, at the very least, for a full year and during times of inclement weather conditions when the chances of obtaining reliable data are uncertain. Lead times to obtain the necessary data for decisions on petroleum exploration and production on the Outer Continental Shelf should be anticipated.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974— 543–586/ 148