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U.S. Energy Research and Development Administration

ORIGINS OF DEEP-SEA SEDIMENTS AND
THEIR VARIATIONS WITH TIME

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ABSTRACT

A brief review is given of the first and second three years of support under this contract during which the emphasis has shifted from provenance of deep-sea sediments and variations in geological time to processes of sediment transport in the benthic boundary layer of the deep sea. During the last two years the emphasis has shifted to an application of techniques for studying water mass mixing and sediment transport to the understanding of these processes on the continental shelf specifically in the New York Bight.

Progress during the past year is reported in terms of papers published, presented and in preparation and in terms of improvements in analytical techniques. These have been chiefly concerned with the radon method.

Results are presented of the first major combined geochemistry-physical oceanography cruise in the New York Bight on R/V VEMA during October 1974. Two areas in which radon was measured show important potential for understanding mixing in the Bight. On the shelf the Hudson Shelf Channel constitutes a strong local source of bottom radon and thus represents a known locus of injection of a natural radioactive tracer into the lower water column. The dispersion of this radon plume on the shelf can yield estimates of horizontal diffusivity. The second area is beyond the shelf break and is an area in which the bottom sediments are an equally strong source of excess

radon but in which little or no excess radon exists in the lower water column. This zone, which approximately corresponds with the upper component of the NADW (based on T-S relationships) and which is also characterized by relatively low near-bottom concentrations of suspended particulates, must represent a zone of high horizontal diffusivity in which excess radon and particulate concentrations are being rapidly diluted by exchange with open ocean water. This is important to the exchange of water on the shelf because this low-radon water flows into the upper Hudson Canyon which represents a potential conduit for movement of slope water onto the shelf.

Data on the nature of bottom sediments are presented principally in the context of their potential as sources of both radon and methane in the lower water column.

Preliminary data on the nature and composition of suspended particulates indicate that several characteristics have great potential for tracing the mechanisms of the dispersal of solids in the Bight. These characteristics are coatings of Fe and Ti on all types of particles, concentrations of other trace metals exclusively on organic particles and different types of aluminosilicates.

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1.0. HISTORICAL SUMMARY

The year ending 31 July 1975 is the sixth year of this contract AT(11-1)3132 which began as AT(30-1)4055 and which in the coming year will be merged with AT(11-1)2185. In light of this juncture, and the way in which the directions of research have evolved over the six years, a brief review is appropriate.

1.1. 1969-1972: First Three Years

As implied by the title, which has remained the same, this contract was originally funded to study processes of deep-sea sedimentation and how these have varied as a function of geologic time. The approach was principally to be able to characterize any particular deep-sea sediment using any means by which one could determine its origin and, if detrital, its provenance thereby permitting conclusions, or at least inferences, as to the processes by which it arrived at the place sampled. Efforts consisted primarily of developing and exploiting the use of the Rb-Sr-Sr isotope system as a complement to fine-fraction mineralogy in determining sediment provenance.

About midway through this period an attempt was begun to relate coefficients of vertical mixing to quantities of suspended particulates in the benthic boundary layer (BBL) using the excess radon method. From the mineralogical and isotopic provenance studies it was obvious that, in the western basins of the Atlantic at least, transport of sediment in the nepheloid benthic boundary layer/^(BBL) was an important process.

It was hoped that one could learn about the mechanisms of suspension and transport by being able to relate suspended particulates to some measure of the mixing energy. The P. I. participated in two cruises to make simultaneous radon and suspended particulates measurements - on R/V LYNCH in 1970 in a transect across the western boundary basin at about the latitude of Barbados and on R/V ATLANTIS in 1971 in a leg across the northern Argentine Basin and Cape Basin in the South Atlantic. During the first three years the emphasis was on sediment provenance studies but work on present processes in the BBL was begun.

1.2. 1972-1975: Second Three Years

During the second three years of support some aspects of the work on sediment provenance were continued but this was generally subordinated to work on mixing and sediment transport in the BBL. This focus on sedimentary processes was also shifted during this period from the deep sea to the continental shelf. In late 1972 an entire leg on the Lamont ship R/V CONRAD was devoted to a study of temporal variations in the BBL in three locations in the North American Basin by making repeated measurements of excess radon, turbidity (using the L.D.G.O. nephelometer), suspended particulates, hydrographic characteristics using an STD, bottom photography, and current velocity and direction. Besides characterizing two different geographic regimes with respect to the BBL (lower continental

slope and abyssal plain), the results of this study demonstrated large variations in time at a given location under the western boundary undercurrent (WBUC). Such variations suggest significant lateral shifting back and forth of the core of the WBUC on the time scale of weeks or even days. Results of this study also suggested that advective pumping of heat downslope into the WBUC may be an important mechanism in maintaining its vertical mixing characteristics.

During 1973 and 1974 we began trying to apply these techniques for studying processes in the BBL to the continental shelf. Specifically we made several short (one to four day) cruises and took samples for radon and suspended particulates in the New York Bight. Since access to ships working in the Bight was exclusively on a short term and guest basis, we regarded these early attempts as a matter of getting an idea of the levels of these parameters and whether or not they had potential for helping to elucidate water and sediment movement in the Bight. The conclusions from this early work on the shelf were, 1) that the combination of scanning electron microscopy (SEM) and energy dispersive x-ray fluorescence (EDXRF) had great potential for studying dispersion paths and mechanisms for heavy metal pollutants in the Bight; 2) that without a more extensive framework of measurements it was difficult to conclude exactly how the excess radon method was going to be useful, although the variation in profiles over time and space suggested a likely utility; 3) that short cruises on a guest

basis were not very productive and were almost as much work to mount as a major cruise.

Those working on the physical oceanography and other aspects of geochemistry in the Bight under the other ERDA contract at L.D.G.O., AT(11-1)2185, had also concluded that a major combined effort was required. During the last contract year we obtained R/V VEMA for a combined geochemical-physical oceanographic cruise during the last two weeks of October 1974. The cruise report gives a brief summary of the kinds of measurements made and is included as Appendix A. Some of the results of the radon, bottom sediment and suspended particulate analyses under this contract are given below under section 5.0 FIELD PROGRAM IN NEW YORK BIGHT. These results, taken over a two week period, form the framework into which the previous measurements, scattered in space and time now fit, and indicate at least two regimes in which the radon method has the potential for providing data on the rates of horizontal movement and exchange of water masses in the Bight. Preliminary attempts to model the data have been made and are given under section 5.0. Establishing a relationship between radon flux and bottom sediment type was begun on samples taken on the VEMA cruise and it is the variability in this flux which provides the potential for measuring horizontal water mass diffusion or advection. Relationships between bottom sediment type, suspended particulate concentrations and water masses also have been observed and form the basis for future work on

understanding the mechanisms of the dispersal of solids in the Bight.

As a result of the very successful combination of the efforts under this contract with those geochemical and physical oceanographic studies under contract AT(11-1)2185 and in light of the similar goals of the two projects it was decided to merge this contract (3132) into the larger one (2185) for the coming year. This is therefore the last year a separate report will be written for the radon, bottom sediment and suspended particulates work under EEDA support at Lamont-Doherty.

In summary of accomplishments of the second three-years of support under AT(11-1)3132 a list of papers published during this period is given in Appendix B.

2.0. PROJECT GOALS DURING THE PRESENT CONTRACT YEAR

Goals of this project for the present contract year have been:

- 1) To integrate the field efforts of AT-3132 with those of AT-2185 in two major cruises in the Bight to take place under different seasonal regimes. (Because of changes in ship scheduling the second of these cruises will not take place until July 1975, the final month of AT-3132 and the first month of the new contract year of AT-2185.)
- 2) To evaluate the utility of excess radon in measuring mixing in near-bottom waters on the shelf.

- 3) To establish levels of suspended particulates in the water column during the season(s) sampled and to relate spatial variability to bottom sediment types.
- 4) To continue examining samples of suspended particulates filtered from Bight water by combined SEM-EDXRF to learn the mechanisms whereby some industrial (or otherwise anthropogenic) pollutants are dispersed throughout the Bight.
- 5) To continue work on other techniques for characterization of sediment provenance such as x-ray diffraction mineralogy and Rb, Sr, Sr-isotope system.

3.0 PUBLICATIONS

In the three parts of this section are listed the papers actually published since the last annual report, the papers in preparation at this date and the papers presented at meetings since the last report.

3.1. Papers Published

Biscaye, Pierre E., 1974, Deep sea sedimentation: Environmental Health Perspectives, v. 9, p. 177-178. (This is the edited transcript of a talk given at a conference on Asbestos in the Environment in Durham, North Carolina in 1973.)

Biscaye, P. E., Chesselet, R., Prospero, J. M., 1974, Rb-Sr, $^{87}\text{Sr}/^{86}\text{Sr}$ isotope system as an index of provenance of continental dusts in the open Atlantic Ocean: Jour. de Recherches Atmospheriques; juillet-decembre 1974, Numero

Special; "Symp. Int. sur les Echanges Ocean/Atmosphere de Matiere a l'Etat Particulaire", Nice, France, 1973 (in press).

3.2. Papers in Preparation

Mathieu, G., Biscaye, P. E., and Hammond, D., Extraction of radon from natural water systems using activated charcoal.

Eittreim, S., Biscaye, P. E., and Amos, A. F., Benthic nepheloid layers and the Ekman thermal pump. (A preprint of this paper is included as Appendix C.)

Biscaye, P. E., Millford, N., and Mathieu, G., Excess radon and horizontal diffusion on the continental shelf, New York Bight.

Biscaye, et al. (order of other authors not yet decided), Relationships between excess radon and suspended particulates in near bottom waters of the New York Bight.

Biscaye, P. E. and Dasch, E. J., Rubidium-strontium "apparent ages" in deep-sea sediments; Atlantic Ocean.

3.3. Papers Presented at Meetings

Biscaye, P. E., Mathieu, G., Hesslein, R., Hammond, D., and Olsen, C., 1975, Geochemical studies of mixing on the shelf and upper continental slope: New York Bight (abs.). Paper presented at 7th Long Island Sound Conf. sponsored by the University Inst. of Oceanog., C.U.N.Y., 11 January 1975, New York City.

Biscaye, P. E., Feely, H., Mathieu, G. and Olsen, J., 1975, Geochemical studies of mixing in waters of the continental shelf (abs.): Paper presented at American Chemical Society Special Symposium on Marine Chemistry in the Coastal Environment, 8-10 April 1975, Philadelphia, Pa.

Biscaye, P. E., Feely, H. W., and Mathieu, G., 1975, Geochemical techniques applied to problems of continental shelf dynamics (abs.): Paper presented at International Liege Seventh Colloquium on Ocean Hydrodynamics; Continental Shelf Dynamics, 5-9 May 1975, Liege, Belgium.

In addition, a report on our work in the New York Bight was presented at the Brookhaven National Laboratory Workshop on the Mid-Atlantic Bight on 10 and 11 March 1975.

4.0. PROGRESS IN ANALYTICAL TECHNIQUES

Efforts toward improved analytical techniques have continued principally in connection with the extraction of radon from water samples and with the chemical and granulometric characterization of filtered suspended particulates. Digitization of the solid source mass spectrometer projected in last year's report has not yet been completed although all components are now in hand. / ^{Sr-isotope} analysis of the initial series of New York Bight bottom samples has been deferred both in anticipation of completion of this upgrading and in favor of other aspects of the work on VEMA 32-01 results and samples.

4.1. Radon Extraction and Counting

The principal achievement has been completion of several of the charcoal-trap radon extraction systems and their use on the VEMA 32-01 cruise last October. Besides decreased cost per sample and operator attention during extraction, the charcoal systems on VEMA prevented the premature termination of the radon program when we ran out of liquid nitrogen for the older systems. Faulty dispensing valving on two out of three rented LN_2 tanks caused the loss of $\sim 2/6$ of our nitrogen about three quarters of the way through the cruise. Three of the LN_2 -extraction boards were immediately modified for use in the charcoal-dry ice mode and radon profiles were taken, albeit at a reduction in samples per profile, for the remainder of the cruise. Details of the charcoal system are given in the pre-print of a paper now ready for submission which is included as Appendix D.

Other efforts on radon analytical techniques involve the continuing effort to improve overall analytical precision and the as yet unresolved problem of discrepancies between analyses in the three laboratories participating in radium-226 analyses on GEOSECS samples. Since the radium-226 parent of radon-222 is present dissolved in sea water, ^{it} contributes to the total radon dissolved in near-bottom samples, must be subtracted by subsequent analysis, and is measured by the same technique as radon, the problem of analytical precision is most obvious in conjunction with the laboratory radium analyses. The possi-

bility of radon leakage through various types of flexible tubing used in the extraction bottles was checked. Comparisons of loss from amber latex, butyl rubber and clear vinyl tubing were made and butyl rubber was found to have the lowest rate of leakage. It cannot, however, be used in all portions of the extraction bottle and substitute materials for those portions are being sought.

Tests were run to quantify the memory effect on the old (GEOSECS, LN_2) boards which, because we have not been able to completely convert to charcoal-dry ice, we are still forced to use at sea. These tests showed that, for samples up to about 10 dpm Rn/100 l the memory effect (0.22 ± 0.08 dpm) on the extraction of the next sample is indistinguishable from blank runs (0.16 ± 0.04 dpm). The memory effect for extractions following standards (174 dpm) or hot samples is perceptably higher (0.51 ± 0.15 dpm) and must be borne in mind during high-production rate periods in selecting which boards to use in the extraction of samples expected to contain either high or low activities.

Another source of error investigated during the past year is the apparent drift in certain sample cell counting efficiencies. We have over the years used four different types of alpha phosphors and these have been found to plateau at significantly different high voltages. We have found that these differences can account for some of the discrepancies between interlaboratory and shipboard versus shore based checks.

Other efforts on radon technique involved analysis of variations in overall extraction efficiency, of operator error and the effects of contamination of the phosphor sample cell. We feel that these efforts will contribute to improve analytical precision in the lab and on future cruises although we have not yet solved all the radium (radon) analytical puzzles.

4.2. SEM-EDXRF Analysis of Filtered Particulates

One of the promising techniques for studying sediment and pollutant dispersal in the New York Bight mentioned in last year's report is the combination of Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Fluorescence (EDXRF). Particles down to about 0.2 μm in diameter can be observed directly on the SEM for morphology and inter-particle relationships and each particle can be analyzed (semi-quantitatively with our equipment) for elemental composition ($Z \geq 9$). Curtis Olsen, a student, has done considerable preliminary work on filters obtained on VEMA 32-01 and previously, and has observed some significant patterns and relationships which are described below under 5.0. Although very revealing, however, as to the relationships between, for example, trace metals and particle types, the process of particle by particle examination is a slow and tedious one. Certain aspects of this type of analysis are capable of automation and have been done in the laboratory of Dr. Eugene White at Penn State Univ. We have visited his laboratory and applied his CESEMI system equipment (Computer Evaluation of Scanning Electron Microscope

Images) to a sampling of filtered deep sea particulates. We are still evaluating our results but we believe this system has potential application to the study of sediment and pollutant dispersal in New York Bight.

5.0. FIELD PROGRAM IN NEW YORK BIGHT

The principal field effort in this contract year was the cruise on R/V VEMA (V32-01) during the last two weeks of October 1974. This had been originally scheduled to coincide with the beginning of the fall-winter breakup of the seasonal thermocline but an unusually prolonged, hot summer resulted in a program during a well-formed summer thermocline regime. A second cruise planned for this spring has been delayed until late July.

All aspects of the geochemical and hydrographic work under this contract and contract AT(11-1)2185 were integrated and the track chosen with all programs in mind. The plan was to make three transects across the shelf - one along the Hudson Shelf Channel and Hudson Canyon and one each to the northeast and southwest of it (Fig. 1). After an initial coverage of the three transects the plan was to then reoccupy as many stations as possible in order to make the initial survey as synoptic as possible and then obtain some data on temporal variability. Data on the results of work done under AT-2185 are given in the annual report of that contract.

A summary of the results of measurements made during this cruise and subsequently on samples taken on the cruise is given below. Many aspects of these results are inter-related but, for the sake of organization, they are presented in three sections - dissolved species, bottom sediments and suspended particulates.

5.1. Dissolved Species

Measurements of three dissolved species were made on samples taken on V32-01 - dissolved oxygen, methane and radon. The first two measurements were made by students and these data have not been completely worked up and integrated with other results but brief summaries are given below. Most of the effort in this section both on the cruise and subsequently went into the measurements of excess radon and the interpretation of these data since an evaluation of the potential of radon as a tool in shelf water studies was a primary goal of this year's work.

5.1.1 Oxygen. Oxygen analyses were done on every STD calibration sample by Ray Hesslein using the Carpenter modification of the Winkler titration. Two oxygen minima appear as the striking features of the oxygen data. First is a zone of < 3 ml/l water covering a wide zone on the middle shelf between the base of the thermocline and the bottom (Fig. 2). In the center of the study area this zone roughly coincides with that portion of the Inner Shelf on which the Hudson Shelf Channel

has distinct topographic expression (delineated approximately by the 50 m contour in Fig. 2). It is terminated on the shoreward side by shallow water in which vertical mixing from surface to bottom is fairly strong as seen in both STD and radon profiles. That is, the near-bottom oxygen minimum zone roughly coincides with that portion of the inner shelf which coincides with both the zone of fine-grained, organic-rich sediments (and that is restricted laterally to the Hudson Shelf Channel) and the overlying formation of a strong thermocline. We interpret this as a zone of biological and chemical oxygen utilization which takes place largely in the waters overlying the Hudson Shelf Channel but which by horizontal diffusion is seen as a minimum extending roughly parallel to the coast to the northeast and southwest.

The second oxygen minimum is seen in Fig. 2 as a band of < 3 ml/l near-bottom water just beyond the shelf break approximately between the 100 m and 300 m isobaths. In vertical section this zone is seen to extend as a minimum from its intersection with the upper slope beyond the deepest station occupied on V32-01. This zone is completely separated from the inner shelf oxygen minimum and coincides with the water mass underlying the strong salinity maximum from about 100 to 300 m deep. (See section of AT(11-1)2185 report by Arnold L. Gordon, "STD Profiles in the New York Bight; Preliminary Evaluation of Thermocline Stratification.") Gordon attributes

the characteristics of this water to the introduction of warm, salty water by anticyclonic eddies broken off the northern side of the Gulf Stream. The minimum in oxygen, representing relatively old water, is consistent with this interpretation.

5.1.2 Methane. Samples for methane analysis were collected from about 125 STD calibration bottles, stored upside down in the reefer and analyzed chromatographically by Doug Hammond at L.D.G.O. The analytical error on these measurements is ± 0.3 nmol/l or $\pm 8\%$, whichever is greater.

Several aspects of the behavior of methane in the ocean are yet to be clarified. However, a survey of the available literature indicates that several sources may exist: 1) production in reducing sediments and diffusion into overlying waters; 2) production in reducing sediments, formation of a gas phase, and bubble transport into overlying waters; 3) production in the water column by degradation of organic matter. Sources 1) and 2) should dominate inputs in shallow waters and source 3) is probably the most important in the surface layer of the open ocean. The sinks for methane are evasion to the atmosphere and oxidation within the water column at a very slow rate.

Several types of water at these stations were described in the physical oceanography discussion on the basis of T-S characteristics. These can be classed in three groups on the basis of the methane data: 1) slope waters, 2) outer shelf waters, including the "winter water" remnant, and 3) inner

shelf waters. Each of these will be discussed in the following paragraphs.

1) Slope waters (STD sta. nos. 66, 67, 68, 69); surface waters are in equilibrium with the atmosphere (~ 2 nmol/l). At three of the four stations, a spike in the methane versus depth plot was observed. These spikes occur near the top of the oxygen minimum zone and near, but not necessarily at, the salinity maximum. Such spikes have been observed by previous workers. The association with the salinity maximum indicates this is not shelf water advected horizontally, but the association with the oxygen minimum indicates that the spikes are probably related to a biological process in the water column. This process is apparently restricted to a narrow zone and is not uniform throughout the oxygen consumption region as indicated by Fig. 3 which shows no consistent correlation between methane and salinity.

Deep waters have methane concentrations below atmospheric equilibrium indicating some methane consumption since they were last exposed to the atmosphere. One might expect an increase in near-bottom methane at STD station 67, located near the mouth of the Hudson Canyon, because the fine-grained sediments of the Canyon are a likely source of methane, but only a slight increase was observed.

2) Outer shelf waters (STD sta. nos. 70, 72); as is the case on the slope, surface waters on the outer shelf are in equilibrium with the atmosphere. Deeper waters show much

higher concentrations than do deep waters on the slope. The source of this methane is apparently sediments in the Hudson Canyon. This argument is supported by the correlation between the presence of excess radon and high methane in deep water at STD station no. 70.

A positive correlation exists between methane and oxygen at these two stations, in contrast to stations on the inner shelf (Fig. 4). The significance of this is not clear. It might indicate methane accumulation in "winter water" of high oxygen and long residence time on the shelf. Alternatively, it may indicate accumulation in oxygenated water in the process of moving up-canyon. The methane-salinity relationship indicates some support for the latter hypothesis, as methane production seems to occur over a rather broad range of salinities.

3) Inner shelf waters (STD sta. nos. 53,54,56,57,59,60, 61,62,63,64,65); surface water concentrations are close to atmospheric equilibrium. Only the innermost station (65) shows evidence of being influenced by river transport of methane. Figure 5 is a plot of methane versus depth for samples in the Hudson Channel axis which shows increasing concentrations in the landward direction. This relationship is probably due to landward increase in methane source strength as the stations approach the dump sites. Except for STD station 65 which shows the effect of river runoff the high methane in most of these inner shelf stations is restricted to water below the thermo-

cline. Apparently vertical mixing homogenizes this water with respect to methane but is hindered at the thermocline.

In summary, although some relationships between methane and other parameters seem to hold consistently in the V32-01 data, others are considerably less obvious. The relationship between high near-bottom methane and the fine-grained sediments of the Hudson Shelf Channel confirms our hope to be able to use methane as a natural tracer of shelf water movement. Some of the less obvious relationships between methane and other water mass characteristics like oxygen and salinity elsewhere on the shelf and slope, however, indicate the need for more understanding of methane sources and sinks. We hope to increase this understanding from the CONRAD cruise samples taken in July.

5.1.3 Radon. Use of excess radon-222 in near-bottom waters has heretofore been restricted to estimating vertical mixing in the deep sea. This one dimensional interpretation has appeared justified in that regime of minimal topographic variations because horizontal gradients in the radon source function are probably small on the scales considered. Additionally in the deep sea this zone of radon excess is separated by several kilometers of water from the surface zone in which there may be a deficiency of radon because of evasion to the atmosphere. As water depth gets shallower on the upper continental slope and on the shelf these zones of radon excess and deficiency approach each other one runs the risk that these zones overlap causing gradients in both zones to appear steeper than they are and resulting in an underestimation of vertical mixing in both zones. (Fig. 6) Our purpose on the V32-01 cruise was to test the applicability of this technique to studying mixing on the shelf by delineating those areas or conditions in which these problems did and did not obtain. We thought, for example, that, despite the shallowness of the shelf water the seasonal thermocline might help by acting as a barrier to diffusion between the zones of excess and deficiency.

The radon results indicate a great potential utility on the shelf and upper slope, but not primarily in estimating vertical mixing. Two regimes were encountered on V32-01 in which excess radon may be useful for estimating horizontal diffusion. The first is on the shelf where a sharp textural

pattern of bottom sediment types creates a relatively restricted point or line source of radon in near-bottom waters. The second is beyond the shelf break in a zone between about 1000 to 2000 m depth in which, despite strong source potential for excess radon in terms of bottom sediment type, a band of water intersects the upper slope and contains little or no excess radon adjacent to the bottom. Samples of vertical profiles from each of these regimes are seen in Fig. 7.

The strong radon excesses seen in the two shallow profiles of Figure 7 pretty much characterize most of the profiles taken on the shelf: little or no excess above the seasonal thermocline and strong gradients below with fairly large excesses immediately adjacent to the bottom. In the deep sea it is generally not a problem to measure the entire standing crop of excess radon by integrating the excess up the profile to the level at which equilibrium with parent radium-226 is reached, if one has been prescient enough to take samples that high. One can thus compare the total radon excess from one area to another and, for example, test the assumption of relatively uniform horizontal source function. This is not as easy to do in shallow water because of the possibility of exchange across the thermocline or, if no thermocline exists, the possibility of direct evasion to the atmosphere. Mostly, however, the problem is that one is attempting to compare stations over a wide range of depth intervals. Therefore rather than portray the variation in radon excesses on the

shelf in terms of spatial variation in standing crop, the variation in concentration of excess radon 10 m above bottom (MAB) is shown in Fig. 8. The biggest excesses are seen in the water approximately overlying the Hudson Shelf Channel.

A more complete discussion of the distribution of bottom sediment types is given below under section 5.2, but, briefly, sediments of the Hudson Shelf Channel constitute a band of fine-grained sediments cutting across the shelf otherwise covered by coarse-grained, sandy sediments. Grab samples of bottom sediment have been analyzed directly for their potential radon productivity. Samples of sediment (on the order of 100 g) are put as a slurry in "kettles" fit with inlet and outflow valves similar to the arrangement on our normal 20 l water bottles. After a suitable period for radon ingrowth the radon is extracted from these kettles during agitation of the slurry by a recirculating stream of helium. After several measurements the sediment is removed from the kettle, dried and weighed to yield dpm of radon per gram dry weight of sediment. The distribution of these results on bottom sediments is plotted in Fig. 9. The highest values of dpm/g dry sediment are found in the fine-grained sediments of the Hudson Shelf Channel and the Hudson Canyon. We have not completed the kettle analysis of all V32-01 bottom grab samples but Fig. 10 is a plot of productivity in dpm/g dry sediment versus a simple parameter indicative of grain size, the weight percent $< 63 \mu\text{m}$ in diameter. The correlation coefficient of all measurements thus far

is $r = 0.98$ indicating that we can expect the radon productivity distribution to closely parallel the distribution of sediment grain size.

It is the near-coincidence of the strongest near-bottom excess radon anomalies (Fig. 8) with the Hudson Shelf Channel radon source (Fig. 9) that indicates the potential for calculating horizontal diffusivities of bottom water on the shelf. The data obtained during V32-01 are not overwhelmingly numerous nor, lacking prescience, were the stations ideally distributed with respect to the Hudson Shelf Channel source for optimal use of the data in model calculations. A start at such calculations however, has been made by S. Nevil Milford who spent the last six months of his sabbatical from Brisbane, Australia, with us. We felt it important, despite the paucity of radon data, to make some preliminary calculations in order to both get an idea of the diffusivities one might obtain and to point out a more optimal sampling program for the July 1975 cruise in the Bight on CONRAD.

In brief, some of the conclusions from these early attempts at modeling the V32-01 data are as follows.

- 1) Although it is useful to consider the band of fine-grained sediments filling the Hudson Shelf Channel as a line source of radon, it is far from an ideal source in that it is not infinitely thin in either the x or y dimension. Its

actual dimensions in terms of radon productivity must be better known than we do from the few samples collected on V32-01. We have begun acquiring additional samples in profiles across the Hudson Shelf Channel with the help of the MESA project's ship R/V KELEZ.

2) Because the line source is not infinitely thin with respect to the horizontal scale over which radon from this source might be detected it will be necessary to space profiles at future stations for radon profiling over greater distances (tens of kilometers) from it than was done on V32-01 in order to distinguish line-source from background radon.

3) Even with the few data available from V32-01 a three dimensional model is necessary for any reasonable estimations of horizontal diffusivity because one and two dimensional models do not account for diffusion of the radon source spike in the y and z dimensions.

A more complete presentation of the modeling of the Hudson Shelf Channel radon data had been intended in this report but at this writing Nevil Milford is enroute back to Australia having apparently taken with him the only complete manuscript. His treatment of the V32-01 radon data is being included in the paper now in preparation (see 3.2) for the Liege Symposium Proceedings.

In summary concerning the Hudson Shelf Channel radon source and plume, it appears from the data presently in hand,

1) that there is a strong, rather linear natural bottom source of radon on the shelf in the New York Bight; 2) that this bottom source is injecting radon tracer into the water column; 3) that the radon from this source is detectable and distinguishable from background radon adjacent to the Hudson Shelf Channel and possibly tens of kilometers away; 4) that there was possibly a diffusive and/or advective displacement of radon away from the source in October 1974 (Fig. 8); 5) that, within certain limitations, excess radon in the water column has a potential, modelable utility in making estimates of horizontal mixing on the shelf.

The second area in which the V32-01 radon data provide useful insights into mixing processes is in the water in contact with the upper continental slope and the upper Hudson Canyon. In Figure 8 the concentration of excess radon 10 MAB is seen to go through a minimum in transects from the shelf break seaward approximately between the 1000 and 2000 m isobaths. At several stations in this interval there is no detectable excess radon 10 MAB and a similar map of concentrations 5 MAB shows the same lack of excess. This zero-to-low excess radon water to some degree fills the upper Hudson Canyon at both 10 and 5 MAB and two examples of profiles in the Canyon are seen in Fig. 7.

This lack of near-bottom excess radon is particularly striking in comparison with the Hudson Shelf Channel source and strong near-bottom plume in shallower water. There we

see a correspondence between excess radon in the water column and a potential bottom source. Seaward of the shelf break the data on bottom sediments (Figs. 9 and 10 as well as 12 and 13, discussed below) suggest that these are as good or better a source of excess radon than are the sediments of the Hudson Shelf Channel.

The number of data points is too small to precisely delineate the depth interval over which the water adjacent to the upper slope contains anomalously low excess radon but it appears to lie between about 1000 and 2000 m except in the upper Hudson Canyon where near-bottom profiles in water somewhat shallower than 1000 m show no excess. Examination of T-S diagrams of water in this depth range reveal a small but characteristic departure from the general trend of the North Atlantic Deep Water which approximately coincides with the anomaly in excess radon. This is shown for three stations in Fig. 11. In their discussion of the water mass relationships seen in the STD profiles taken on V32-01 Gordon and Gerard refer to this water mass as a component of upper North Atlantic Deep Water (NADW) which is influenced toward slightly higher salinity by the Mediterranean outflow water (see Annual Report of Contract AT(11-1)2185).

There appears to be in contact with the upper continental slope and partially filling the upper Hudson Canyon a water mass with somewhat distinctive T-S characteristics and strikingly anomalous in its near-bottom radon distribution.

In that the Hudson Canyon represents a potential conduit for exchange of water between the upper slope and the shelf, this is a potentially important observation in understanding the interaction of shelf water with open ocean water across the interface between them.

At present the qualitative explanation offered for the anomalously low excess radon adjacent to the bottom where this upper component of NADW abuts the upper slope is that horizontal diffusivity in this water must be very high. Despite the potentially high flux of radon suggested by the grain size of bottom sediments, the excess radon must be rapidly diluted to levels below the limit of detection by horizontal mixing. This qualitative conclusion accords with an observation reported to us verbally by Pearn Miller of Oregon State (but not yet located in the literature) that someone at Woods Hole has observed a peak in the spectrum of energy from current meter data in water adjacent to the upper continental slope. It is generally thought that the net drift of slope water (NADW) along the continental slope is to the southwest and the radon data in waters down to about 1000 m and below 2000 m are not inconsistent with this, i.e., the water has recently been in contact with the bottom. The net drift of this distinctive component of NADW between about 1000 and 2000 m may also be to the southwest but it must also have an additional component of horizontal diffusivity which mixes away the excess radon which is surely being injected into that water at the sediment-

water interface.

We have some evidence that this anomalously low excess radon was not a transitory phenomenon which we happened to observe last October. Two radon profiles taken in the upper Hudson Canyon in April 1974 also showed an almost complete lack of excess radon. We shall attempt to further delineate this phenomenon during late July 1975 on the CONRAD cruise.

5.2. Bottom Sediments

Reference has been made above to bottom sediments in the context of variability of radon source strength as a function of sediment grain size (Fig. 10). The grain size data for the abscissa of that plot are presented with additional samples in map form in Fig. 12. This simple division at $63\ \mu\text{m}$ shows the prominent features of the sediment distributions that pertain to radon sources: 1) most sediments covering the shelf are sandy, consisting mostly of less than 10% finer than $63\ \mu\text{m}$; 2) the Hudson Shelf Channel is overlain with much finer sediments ($> 20\%$ finer than $63\ \mu\text{m}$) in the inner part of the shelf where it has some topographic expression; 3) in the outer part of the shelf where there is little or no topographic expression of the Channel the sediments are again almost completely sandy; 4) beyond the continental shelf break along the upper slope (seaward of $\sim 100\text{-}200\ \text{m}$) the bottom sediments are increasingly fine-grained; 5) the finest sediments of all are those in the Hudson Canyon with some containing more than 95% silts and clays $< 63\ \mu\text{m}$.

Essentially the same information is conveyed by Fig. 13 on which is plotted the size in microns of the mode of the sand-sized ($> 63 \mu\text{m}$) sediments. The shelf samples have coarse modes ($> 200 \mu\text{m}$) and the upper slope, Hudson Shelf Channel and Canyon finer modes ($< 100 \mu\text{m}$). In addition several samples show a slightly bimodal distribution and these are plotted using a different symbol. These sand size frequency data were obtained using a vacuum sieving apparatus which grades the sediment into up to 32 classes. A number of workers (Friedman, Visher and others) have used this type of data to interpret provenance and sediment transport mechanisms from sediments on the shelf. We have not yet attempted to make such interpretations from our data both because of a lack of time and because I am not yet convinced of the validity of such interpretations from size frequency curves in the absence of other data. We shall use the actual sieved size classes in conjunction with mineralogical and Sr-isotope studies and defer interpretation of the slopes of cumulative size frequency distributions until later.

Work on the fiber fraction ($< 63 \mu\text{m}$) will also include mineralogy and Sr-isotope analysis as well as SEM-EDXRF comparison of bottom sediments with filtered suspended particulates (see 5.3.2 below).

5.3. Suspended Particulates

Three methods were used during V32-01 to measure the concentration of suspended particulates in the water: 1) The L.D.G.O. photographic nephelometer which measures light scattering in situ. Use of this instrument is limited in shallow water work to nighttime stations. We will not refer to these data in this report as they are not yet in digital form. The analog traces, however, reveal the same features as do the other methods. 2) The Neph Turbidimeter which is a light scattering method but is done in vitro with water samples brought on deck. The value of this is that it is the quickest way to get some quantitative measure of particulate concentrations aboard ship. 3) Gravimetric analysis of filtered particulates. Water from the 30 l Niskin bottles taken for radon analysis is sucked through preweighed 0.4 μ pore size (47 mm dia.) Nucleopore filters which are washed to remove salt, dried and reweighed for weight of particulates. These gravimetric data are those discussed in 5.3.1 and the data on suspended particulate composition discussed in 5.3.2 are also derived from analysis of these filters.

A fourth type of information on suspended particulates was attempted unsuccessfully on V32-01. We attempted to run the water samples on a Coulter Counter to measure the size frequency distribution of fine suspended particulates. Shortly after the start of the cruise, however, the instrument malfunctioned and the operator (who was the P.I. of this contract

and Chief Scientist of the cruise) was too inexperienced and otherwise busy to repair the instrument for the rest of the cruise. We will rectify that problem on the July CONRAD cruise by having as operator a grad student with previous experience using the Coulter Counter and with no other duties on the cruise.

5.3.1 Concentrations. Two figures are included to show the distribution of suspended particulates in near-bottom waters of the Bight during October 1974. In Fig. 14 is plotted the concentration in $\mu\text{g/l}$ of suspended particulates at 10 MAB and in Fig. 15 the standing crop of suspended particulates (in $\mu\text{g/cm}^2$) integrated up to 50 m. Although the standing crop presentation has the advantage of smoothing over small vertical variations, both figures show approximately the same features of the particulate distribution. These are, 1) concentrations on the shelf which are generally an order of magnitude greater than those encountered in the deep sea; 2) a general decrease in near-bottom concentrations from the coast seaward toward deeper water; 3) superimposed on this general trend are two zones of extremely high suspended particulate concentrations which correspond to two major topographic features - the Hudson Shelf Channel and the Upper Hudson Canyon - and which correspond to the areas of finest bottom sediment (Figs. 12 and 13); 4) an anomaly in the previous statement with respect to the Hudson Canyon deeper than about 1000 m. That is, below

around 1000 m the topographic expression of the Canyon is just as great as from one or two hundred to 1000 m and the sediments in this part of the Canyon are just as fine grained as in the upper Canyon. The extremely high suspended particulate concentrations ($> 400 \mu\text{g/l}$) and standing crops ($> 800 \mu\text{g/cm}^2$) terminate at around the 1000 m isobath. It is in this zone that the upper component of the NADW contains anomalously low near-bottom excess radon and, from the deepest 3 stations in Fig. 12 it looks as though the suspended particulates may also go through a minimum and increase in value below 2000 m. It thus appears that the high horizontal diffusivities in this water mass which mix excess radon to vanishingly small concentrations seaward also dilutes the concentrations of suspended particulates with "cleaner" open sea water. This explanation, at least qualitatively, appears to be consistent with the high energy in this layer being diffusive rather than advective in that advective energy might be expected to increase near-bottom suspended particulate concentrations by suspension of bottom fines. By this model one expects that the water in the upper Canyon has some advective component which is in fact consistent with data from the bottom moored current meter which is discussed by Amos et al. in the AT(11-1)2185 Annual Report. This combination meter and nephelometer moored 5 and 10 MAB respectively in the axis of the Canyon at 800 m water depth in fact recorded back and forth advective flow with diurnal and semidiurnal frequencies but in which there was a

net component of flow up canyon of 2.7 cm/sec. The turbidities recorded by the in situ nephelometer moored 5 m above the current meter were high but variable with a diurnal frequency.

It appears that one should be able to model horizontal mixing in this upper layer of the NADW from both the radon and suspended particulate data as well as possibly the rate of exchange of this water in the upper Canyon from both the anomalous excess radon data and estimates of the radon flux in those fine grained sediments. Such models will be constructed in the coming year and used with both VEMA and CONRAD data.

5.3.2 Composition. Because of the time-consuming nature of the microscopic-x-ray (SEM-EDXRF) work on filtered particulates, we have only analyzed a small portion of the available filters. From the thirty-six filters so far analyzed by Curtis Olsen (vertical profiles from seven stations) the following relationships appear to be true: 1) In the apex of the Bight, in and around the dredge spoils and sewage sludge dump sites the filtered particulates consist of a high percentage of organics which generally appear as aggregates of particles. Organics are indicated on the EDXRF by either the complete absence of an x-ray spectrum indicating a composition entirely of elements of $Z < 9$, or the presence, along with other elements, of peaks of sulfur, phosphorus and/or chlorine in any possible combinations and proportions. 2) In the Bight Apex we note the presence of a large number of

particles - always organics and always containing P - in or on which trace metals (Cu, Zn, Cr, Ni, Sn, Pb, As) can be found throughout the water column. These metals do not appear on organic particles filtered from inner shelf waters laterally removed from the apex of the Bight but do appear in organic particles from surface and intermediate waters only (not bottom waters) of the outer shelf. 3) In the Bight Apex we note a coating of Fe on all particles and Ti on ~60% of the particles in the region of the dump sites. We know they are coatings rather than in the crystal lattice because they occur on particles whose identity and composition are otherwise recognizable and known such as diatoms which, elsewhere in the Bight show the expected pure Si x-ray spectrum. We have looked at enough filters to begin to see a gradient in these Fe and Ti coatings away from the Bight so coatings of these two elements appear to represent good potential tracers of anthropogenic (dumped) wastes in at least the inner Bight. 4) In the Bight Apex the dominant aluminosilicates are K-aluminosilicate (probably illite but possibly K-spar) which appear at all depths. 5) In waters of the outer shelf near the shelf break the aluminosilicates in the upper waters are also K-aluminosilicates but those in the lower waters are Ca-Mg-aluminosilicates.

These relationships suggest that we have great potential in the SEM-EDXRF studies of suspended particulates for understanding the mechanisms of transport of solids in the Bight.

From the data in hand we appear to be getting anthropogenic signals (Fe and Ti coatings on all particles plus other trace metals in or on organics) as well as natural sediment tracer signals (aluminosilicates). More filters will be taken on the CONRAD cruise in July and more of these as well as previously taken filters will be examined by SEM-EDXRF. We expect x-ray diffraction work on these filters to contribute to our understanding of the aluminosilicate tracers.

From the present data it appears that there is a transport of suspended particulates (both organics and aluminosilicates) seaward from the Bight Apex in surface waters. Out near the shelf break, however, it appears that material from a different source (the Ca-Mg-aluminosilicates) is being transported in the bottom waters. The source(s) may be elsewhere (probably northeast) along the shelf and transported parallel to the shelf or it (they) may be from down the continental slope and transported upslope and onto the outer shelf in bottom waters. In the latter case the Hudson Canyon would likely play some role but we must examine many more filters to determine what that might be.

FIGURE CAPTIONS

Fig.
No.

1. VEMA 32-01 cruise track and station locations.
2. Concentration of oxygen (ml/l) in near-bottom waters.
3. Methane vs. oxygen in slope waters.
4. Methane vs. oxygen and methane vs. salinity in outer shelf waters.
5. Methane vs. depth in inner shelf waters along the Hudson Shelf Channel.
6. Schematic diagram of radon in the deep sea and on the continental shelf. In the deep sea the near-bottom radon excess (vertical hashed area added to curve of radium-supported radon) is well separated from the near-surface radon deficiency (diagonally hashed area subtracted from radium-supported radon). On the shelf these two zones may be separated from each other by a strong thermocline and be useful as at A. Or they may overlap as shown at B such that radon concentrations measured at any depth are completely ambiguous as to the amount of excess or deficiency.
7. Representative vertical profiles of radon from the area of the Hudson Shelf Channel (showing strong bottom source) and from the Hudson Canyon (showing the anomalous effect of no excess radon despite a strong bottom source because of horizontal mixing with open ocean NADW).

8. Concentration of excess radon in water 10 meters above bottom in dpm/100 l.
9. Potential radon production (in dpm/g dry sediment) in bottom sediments. Lacking actual radon flux measurements we take these potential radon productivities to be linearly related to excess radon flux and therefore representative of different source strengths in different sediments.
10. Potential radon productivity (dpm/g dry sediment) vs. sediment grain size (% less than $63\ \mu\text{m}$).
11. T-S diagram of upper slope waters showing relationship of upper component of NADW to zone of no excess radon in near-bottom waters between ~1000-2000 m deep.
12. Distribution of fines (silts and clays - % < $63\ \mu\text{m}$) in bottom sediments.
13. Modal grain size (in μm) of sand fraction (> $63\ \mu\text{m}$) of bottom sediments.
14. Concentration of suspended particulates (in $\mu\text{g/l}$) in water 10 meters above the bottom.
15. Standing crop of suspended particulates (in $\mu\text{g/cm}^2$) in water integrated from bottom up to 30 meters above the bottom.

CH₄ (mmol/l)O₂ (mmol/l)O₂ (mmol/l)SLOPE STATIONS, OXYGEN vs. METHANE
OCTOBER, 1974

OUTER SHELF, METHANE VS. OXYGEN AND SALINITY OCTOBER, 1974

STD #
70
72

K&E 10 X 10 TO THE CENTIMETER 19 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

title & stop

HUDSON CHANNEL STATIONS
METHANE VS. DEPTH,
OCTOBER 1974

RN-222 PRODUCTION, DPM / GRAM DRY SEDIMENT

PERCENT FRACTION <63 μ IN BOTTOM SEDIMENTS