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ORIGINS OF DEEP-SEA SEDIMENTS AND THEIR
VARIATIONS WITH TIME

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ABSTRACT

During this contract reporting period the emphasis was shifted from an analysis of deep-sea sediment characteristics and transport processes back through geologic time, to one of understanding the processes which presently affect the distribution of marine sediments. In particular this has meant studies of suspended particulate distributions and their relation to excess radon estimates of vertical mixing as a means of understanding the transport of sediments in the bottom boundary layer. A major effort in this regard was a study of temporal variations in bottom boundary layer phenomena in the western North American Basin. Work on sediment transport on the continental shelf was begun on a mini-leg of R/V KNORR between New York and Woods Hole on which excess radon, radium-226, -228, and suspended particulates were measured. SEM studies of suspended particulate samples taken on earlier cruises was begun. Several projects were begun or finished involving mineralogical and Rb/Sr, Sr-isotope provenance characteristics on air-borne particulates from the Equatorial Atlantic, on Sao Francisco River sediments and on Holocene sediments from the eastern Indian Ocean.

During this contract reporting period two papers resulting from previous work have come out in publication, seven have been accepted for publication and are in press, three are in preparation and four abstracts of papers given at meetings have been printed.

PROJECT GOALS

Research during this contract period saw a shift of emphasis from goals defined several years ago at the beginning of the project. Originally (as still reflected in the project title) the goal was to decipher the origins of deep-sea sediments from fine fraction characteristics, to deduce oceanographic and atmospheric transport mechanisms from their distributions and to look back in time in the deep-sea sediment record for evidence of variations in transport paths and mechanisms. We are now concentrating on understanding the nature and importance of some of these mechanisms, particularly bottom current transport in the nepheloid layer, as they exist in today's ocean, and their significance for today's sediment distributions. This has meant an increased emphasis on measurements of suspended sediments and associated parameters in the near-bottom water column. In particular the measurement of excess radon as a means of quantifying vertical mixing in the bottom boundary layer has been undertaken.

ACHIEVEMENTS

Accomplishments during the contract period are presented as Publications, Abstracts and Seminars, Progress in Analytical Equipment and brief summaries of several different Research Projects within the scope summarized above.

During the contract period the Principal Investigator devoted one third of his time to this research and will continue on that basis through the remainder of the contract period.

Publications

a. Papers actually published:

Assaf, G. and Biscaye, P. E., 1972, Lead-212 in the urban boundary layer of New York City: *Science*, v. 175, p. 890-894.

Krinsley, D., Biscaye, P. E. and Turekian, K. K., 1973, Argentine Basin sediment sources as indicated by quartz surface textures: *Jour. Sed. Petrology*, v. 43, p. 251-257.

b. Papers in press:

Biscaye, P. E., 1972, Strontium isotope composition and sediment transport in the Rio de la Plata Estuary: in *Symposium on Estuaries*, ed. B. W. Nelson; Geol. Soc. Amer. Memoir 133.

Biscaye, P. E. and Dasch, E. J., Rubidium-strontium "apparent ages" in deep-sea sediments: *Atlantic Ocean: Earth and Planet. Sci. Letters*.

Biscaye, P. E., Ryan, W.B.F. and Wezel, F. C., Age and nature of the Pan-Mediterranean subbottom reflector μ : in *Symposium on Sedimentation in the Mediterranean Sea*, ed. D. J. Stanley: Dowden, Hutchinson and Ross Publ.

Venkatarathnam, K., Biscaye, P. E. and Ryan, W.B.F.,
Origin and dispersal of Holocene sediments in the
eastern Mediterranean Sea: in Symposium on Sedimen-
tation in the Mediterranean Sea, ed. D. J. Stanley,
Dowden, Hutchinson and Ross, Publ.

Venkatarathnam, K. and Biscaye, P. E., Clay mineralogy and
sedimentation in the eastern Indian Ocean: Deep-Sea
Research.

Eittreim, S., Biscaye, P. E., and Gordon, A. C., Comments on
paper by T. Ichiye, N. J. Bassin and J. E. Harris,
"Diffusivity of Suspended Matter in the Caribbean Sea":
J. Geophys. Res.

Venkatarathnam, K. and Biscaye, P. E., Deep-sea zeolites:
Variations in space and time in the sediments of the
Indian Ocean: Marine Geology.

c. Papers in preparation:

Biscaye, P. E. and Burckle, L., A second deep-water passage
through the Rio Grande Rise; South Atlantic Ocean.

Assaf, G., Biscaye, P. E. and Amos, A. F., The oceanic
bottom boundary layer and excess radon profiles.

Biscaye, P. E. and Eittreim, S., Temporal variations in
bottom boundary layer phenomena: Nepheloid layer,
North American Basin.

d. Abstracts, Papers Presented and Seminars:

Venkatarathnam, K. and Biscaye, P. E., 1972, Clay mineralogy and sedimentation in the eastern Indian Ocean (abs.):

Paper given at Annual Clay Minerals Society Meeting, Woods Hole, Mass.

Eittreim, S. and Biscaye, P. E., 1973, Time variations in turbidity profiles in the western North Atlantic: Paper given at O.N.R.-sponsored Symposium on Suspended Particulates in the Ocean, Santa Barbara, Calif.

Biscaye, P. E. and Eittreim, S., 1973, Short-term variability of bottom boundary layer phenomena; North American Basin: Paper given at Annual Meeting of American Geophysical Union, Washington, D.C.

Eittreim, S., Biscaye, P. E. and Amos, A. F., 1973, Time variations in the nepheloid layer of the North American Basin: Paper given at Annual Meeting of American Geophysical Union, Washington, D.C.

In addition to the above formal papers given at meetings, seminars based on work under this contract were given at Bryn Mawr College in January 1972, at Rutgers University (Newark) in March 1973, several at Lamont and several talks to grammar school and high school students in local school districts.

PROGRESS IN ANALYTICAL EQUIPMENT

Because of the increased emphasis on radon measurements in this as well as other projects at Lamont-Doherty Geological Observatory, it was necessary to construct additional radon extraction boards. Rather than reproducing additional GEOSecs-type boards the Principal Investigator designed a new board which, although utilizing the same physical principle, incorporates several improvements, is easier and cheaper to construct, and is smaller, weighs less and is, therefore, easier to transport and to find space to use on the ship. The improvements include a more reproducible method of transferring the radon gas into the sample counting cell; a reduction in the amount and complexity of valving; the ability to flush a sample cell during extraction of another sample; use of nylon vs. stainless steel tubing for reduced cost and ease of construction, cleaning and replacement.

Two of these boards were constructed and used successfully during August-September 1972 on R/V R. D. CONRAD (see below) and have been since used in the laboratory for radium analysis of the same samples.

RESEARCH PROJECTS

The projects described briefly below represent both work under the new emphasis of this project as well as that begun previously.

A. Short-term variability study of bottom boundary layer phenomena.

Excess radon near the ocean bottom has been used for several years to estimate eddy diffusivity, principally by the Lamont group. Three years ago the P. I. began to try to correlate these estimates of vertical mixing with measurements of the concentration of suspended particulates in the nepheloid layer as a means of understanding the physical mechanisms responsible for this widespread layer of relatively turbid water. The results of these measurements made on two traverses across the western basins of both the North and South Atlantic indicated no first order relationship between the two phenomena. This could mean that either maintenance of the nepheloid layer is not dependent upon near-bottom turbulence or that variations in the near-bottom distributions of radon and of suspended particulates occur on sufficiently different time scales that a single cast (sampling) does not adequately characterize them or their possible interrelationship. Because, on an oceanic scale, the distribution of the nepheloid layer and bottom boundary currents renders the former option unlikely, a time variability study was designed to test the latter option.

Use of I-DGO's research vessel R. D. CONRAD was obtained for this study on the Bermuda to Jamaica leg (RC16-1) last summer. The P. I. was Co-Chief Scientist with Dr. Steve Eittreim who is also a student of the nepheloid layer principally from the viewpoint of optical oceanography. The experiment was designed, 1) to measure on at least a daily basis, the variability in as many parameters in the bottom boundary layer as possible at three separate locations, and 2) to show that this type of ships program is not necessarily mutually exclusive of Lamont-style geophysics by doing detailed geophysical work while steaming back and forth between locations. Two of the locations (called hereafter "E" and "F") were chosen on the lower eastern slope of the Blake-Bahama Outer Ridge (BBOR) to be, as much as possible, directly in the path of the Western Boundary Under Current (WBUC) to provide a high turbidity, high turbulence, high current velocity situation in an area of gentle local relief and bottom roughness. E and F were located along strike of the BBOR contours and separated from each other by about 100 km. The third location ("G") was chosen a couple hundred kilometers eastward on the Hatteras Abyssal Plain (HAP) to provide a lower turbidity, lower turbulence, lower current velocity situation in a different water mass (the Antarctic Bottom Water - AABW) and far removed from any influence of topographic relief and bottom roughness. Stations E and F were occupied and casts made at least once a day on alternate

days for ten days during which time a pop-up current meter was emplaced 1 m above the bottom at E and which was successfully recovered. (The data were also successfully processed and recovered from Geodyne which apparently has a success record in this regard comparable to some people's unhappy record in recovering their current meters.) Occupation of a station generally consisted of two casts; 1) STD with a string of eight 30 l Niskin sampling bottles for excess radon, suspended particulates, in vitro turbidity, salinity, temperature (reversing thermometers); 2) a standard L-DGO two-wire cast with the bottom camera - photo-optical nephelometer on the hydro wire and a standard piston core being taken on the trawl or core wire. On several occasions the 30 liter Niskin cast was made on the hydro wire with the camera-nephelometer.

After ten days at E and F, Station G on the HAP was occupied at least daily for the same array of samplings and measurements over a period of six days during which time the Geodyne current meter was also emplaced 1 m above the bottom. The current meter was successfully recovered but had flooded due to a ruptured O-ring and no data were recorded. After six days at G, two more days of available station time were utilized by three occupations of Station F, the more southerly BBOR station.

The results of this experiment have been presented in three different papers given at the A.G.U. in Washington,

and at an O.N.R.-sponsored Symposium on Suspended Particulates in Santa Barbara. A formal paper on the experiment is now in preparation (listed above under c.) and will be published in a volume of all the papers from the O.N.R. Symposium. The important results of this experiment are summarized as follows:

1) A real, apparently regular variation in several bottom boundary layer phenomena was measured at the two BBOR stations during the 18 day duration of the experiment. Values of turbidity (in situ and in vitro light scattering) and of suspended particulate concentrations (in $\mu\text{g/l}$) at fixed heights above the bottom and values of particulate standing crops (concentrations integrated in a column of water through the height of the nepheloid layer, in $\mu\text{g/cm}^2$) varied by up to a factor of five over the course of several days and with an apparent cyclicity of something on the order of 1-2 weeks. Current velocity and direction at Station E changed regularly with something like the same apparent cyclicity. (Obviously measurements of less than three week duration cannot confirm the regularity, i.e., periodicity, of variations with an apparent cyclicity on the order of two weeks.) The standing crop of radon also varied but neither the reality of the variation (above measurement error) nor its regularity was as noticeable as for the particulate parameters.

2) Variations in suspended particulate concentrations, light scattering and particulate standing crops were in phase at E and F despite their separation by about 100 km. Variation in radon standing crops was less in phase than those of the particulate-related parameters.

3) On a single cast basis there was, again, no first order correlation between the vertical distributions of excess radon and of suspended particulates. As may be expected for two parameters with bottom sources, however, (one, radon, with a limited source rate function and the other, particulates, with an unlimited source function) there were indications that increases in particulate standing crops at E and F were accompanied by decreases in excess radon concentration immediately above the bottom.

4) Comparing all results from stations E and F on the BBOR with those at Station G on the HAP several conclusions that would have been suggested by single casts at each station were confirmed by making replicate casts. First, at the BBOR stations the particulate concentrations, standing crops, and light scattering were much higher and more variable; were transported much higher in the water column; the excess radon distributions were more variable and excess radon carried higher in the water column; eddy diffusivities calculated on all data taken together at E and F were more than an order of magnitude higher than at Station G on the HAP. These differences correlate with a significantly

greater bottom roughness and local relief at E and F than at G. Based on the current meter data at E and current velocity measurements by other workers on the HAP these variations also correlate with a presumed greater current velocity at E and F than at G.

5) Correlation between in situ light scattering measurements made with the L-DGO photo-optical nephelometer and suspended particulate concentrations provide a sufficiently good working curve that all future nephelometer data and much of the vast number of previous L-DGO nephelometer stations can be calibrated in absolute mass per unit volume units permitting calculation of nepheloid layer standing crops for the entire world ocean.

B. Continental shelf measurements of excess radon and suspended particulate concentrations on KNORR 30-10.

Instead of proceeding directly to Woods Hole at the end of Leg 9 of the GEOSecs Atlantic cruise, R/V KNORR put in at New York to provide members of the U. N. Committee on regulation of the oceans to visit a modern research vessel. Rather than simply deadheading from New York to Woods Hole we obtained permission to make measurements underway and to make several stations. The P. I. was Chief Scientist on this mini-leg and measurements, with the exception of salinities, were made by six L-DGO personnel. All data have not yet been reduced or even measurements completed

but sampling was accomplished (and most measurements made) for excess radon, radium-226, radium-228, thorium-228, salinity, nutrients, and suspended particulates. The principal objective of this study was to significantly add to our fund of data on these parameters on the continental shelf in preparation for a concentration of effort on the continental shelf in the coming contract year.

C. Analysis of suspended particulate samples from LYNCH-33, ATLANTIS II-60, and CONRAD-16 by scanning electron microscopy.

As of the first of the year the P.I. and a technician began learning preparation techniques and use of the Scanning Electron Microscope (SEM) at Lamont with a view to extracting more information on the origin and physical basis of the nepheloid layer. In particular we are looking for 1) obvious differences between the nature of the suspended particulates and underlying sediments, and 2) obvious variations in the composition and size-frequency distribution of particles as a function of height above the bottom in individual casts. Results so far are qualitative and very preliminary but indicate that this will in future be a profitable source of understanding about the nepheloid layer in particular and suspended particulates in general (continental shelf and deep sea). This effort will soon be aided by the acquisition (under another contract) of an energy dispersive X-ray fluorescence system for use with the SEM.

D. Provenance studies on airborne particulates.

An important part of the work under the present goals for this contract is the ability to discern sediments from different source areas, i.e., the ability to discern sediment provenance. Although in future we will be concentrating these provenance studies on the continental shelf, much work remains to be done on understanding the geological and geochemical basis for, particularly, the Rb/Sr apparent-age technique. The last three projects reported here involve different aspects of our continuing study of sediment provenance on a larger scale.

In some parts of the world ocean wind-borne continental detritus is an important constituent. The problem of being able to discern the aeolian component (or any other component) in a multi-component sediment is a difficult, but almost always necessary one, i.e., almost no marine sediment, whether shelf or deep sea, has a single provenance. Solution of this "inverse problem" involves a knowledge of the characteristics of the source area sediments. In cooperation with Dr. Joe Prospero of University of Miami and Dr. Roger Chesselet of Paris, we have obtained samples of wind-borne dust filtered from air in the Equatorial Atlantic. Some initial work has been done on samples from Barbados which, from mineralogical characteristics previously published by Prospero and others, almost certainly come from Africa.

Rb/Sr, Sr-isotope and apparent-age characteristics of some of these samples tend to confirm this conclusion. Five samples collected over a two year period are extremely constant in their Rb/Sr, Sr-isotope characteristics and resemble more closely the characteristics of deep-sea sediments in, say, the Cape Verde Basin than those in deep-sea sediments adjacent to Barbados. We have begun processing for mineralogical, SEM-X-ray and Sr-isotopic analysis other air dust filters from east-west and north-south transects across the Equatorial Atlantic.

E. Rb/Sr apparent age studies on Sao Francisco River sediments.

Another important aspect of the sediment provenance part of this contract is an understanding of why a given fluvial source of sediments to the continental shelf or deep sea should have such well-defined Rb/Sr-apparent age characteristics. We have indications from several different rivers that in fact these parameters are usefully characteristic but at this point it is not clear why this should be so. In an attempt to study this problem the P.I. obtained from a Brazilian geologist, Dr. Almeida, a suite of samples from the Sao Francisco River which debouches into the Brazil Basin, on whose sediments we had begun a provenance study. We have completed the analyses of the suite of 15 samples and, in fact, the results yield a characteristic apparent

age parameter for the basin. We are presently corresponding with Almeida for more geological information with which to interpret our results.

F. Mineralogical provenance studies: Eastern Indian Ocean.

With the availability of an automated X-ray diffraction apparatus, acquired under support from a different contract, the extremely time consuming donkey work of doing fine fraction mineralogy is significantly reduced. We have therefore undertaken a mineralogy study in the eastern Indian Ocean with Kolla Venkatarathnam, an I-DGO colleague, (reported under Publications, above) as a minor effort. This area had received some previous work by American and Russian investigators but with very low sample densities. Because of the low sampling densities we suspected some of the previous workers' conclusions which suspicions were in fact borne out. We regard this type of study as a necessary adjunct to improving our understanding of techniques for discerning sediment provenance and our understanding of the processes of transport of continental sediments to and across continental shelves and into the deep sea.