Newsletter of

Coastal Ocean Processes

The CoOP Newsletter is intended to foster a vigorous exchange of ideas and to report on activities relevant to the study of continental margin systems, in an attempt to build a consensus regarding the importance of coastal zone research. These are exciting and successful times for continental margin research in general and for the CoOP Program in particular. Presently, CoOP is supporting four large interdisciplinary research programs, two in the Great Lakes (KITES and EEGLE) and two on the west coast continental margin (WEST and COAST). Information about these programs can be found in the last CoOP Newsletter and at the project web sites listed on page 2. Through these field programs, CoOP is presently providing support to over 75 P.I.s.

The next proposed area of CoOP-supported research will be the study of the physical, chemical and biological processes that control the cross-margin transport in coastal regions subjected to substantial freshwater inflow. To help focus this proposed research initiative, CoOP is also currently supporting the preparation of review papers on biogeochemical and transport processes in buoyancy-driven systems (listed on page 2).

Numerous coastal research activities are being conducted outside of the CoOP Program. In this issue of the newsletter, we highlight three of these activities: the RiOMar initiative and the newly formed SCOR working groups on pore water transport and reactions in permeable sediments and on groundwater discharge. In addition to these activities, there is continuing effort to develop and implement an Integrated Coastal Ocean Observing System. A workshop emphasizing the potential uses of such a system for operational issues, such as maritime operations and resource management, was held in May 1999. Links for the workshop report and related sites are included on page 2. The implementation of a coastal ocean observing system also has important implications for basic research in the coastal zone. Future planning efforts will need to focus on the potential contribution of such a system to basic research and the design criteria required to make such a contribution.

The CoOP Program is successful because of the efforts of many people: the researchers in the field, those scientists who have served on the Steering Committee, and our agency representatives. It has benefited especially from the initial guidance of Ken Brink, and for the last six years, from the insight of Mike Roman and the talented support of Jane Hawkey.

Rick Jahnke, Chair
CoOP Scientific Steering Committee

Table of Contents

Newsletter Issue No. 11 **August 2000**

CoOP Project Websites

Episodic Events - Great Lakes Experiment - EEGLE project: http://www.glerl.noaa.gov:80/eegle/

Keweenaw Interdisciplinary Transport in Superior - KITES project: http://chmac2.chem.mtu.edu/KITES/

Coastal Ocean Advances in Shelf Transport - COAST project: http://www.oce.orst.edu/po/COAST/

Wind Events in Shelf Transport - WEST project: http://ccs.ucsd.edu/coop/west/

CoOP website: http://www.skio.peachnet.edu/coop/

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Links for Coastal Ocean Observing Systems

"An Ocean Observing System for U.S. Coastal Waters, First Steps": http://www.hpl.umces.edu/projects/wrkrpt.pdf

"Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System": http://core.cast.msstate.edu/NOPPobsplan.html

Coastal Global Ocean Observing Systems (2000) Oceanography 13(1). For information on ordering the issue devoted to this subject, see http://www.tos.edu

Buoyancy-driven Transport Processes

The following four proposals were funded by ONR to support the preparation of review papers. The review papers are intended to clarify the current state of understanding about transport and transformation processes over continental shelves with significant freshwater inflows, and to provide background for a potential Announcement of Opportunity in the future.

Transport and transformation of dissolved and particulate materials on continental shelves influenced by large rivers: Plume processes. M. Dagg (LUMCON), R. Benner (U. So. Carolina), S. Lohrenz (U. So. Miss.) and J. O'Donnell (U. Conn.)

The transport and dispersal of sediment by buoyant plumes. R. Geyer (WHOI)

Transport and transformation of dissolved and particulate materials on continental shelves influenced by large rivers: Seabed and sediment-water interactions. B. McKee (Tulane), R. Aller (SUNY - Stony Brook), M. Allison (Tulane), T. Bianchi (Tulane), R. Geyer (WHOI) and G. Kineke (Boston College)

The Alaska coastal current: A buoyancy-driven current and its influence on chemical distributions and biota. P. Stabeno (PMEL, NOAA), J. Overland (PMEL, NOAA), N. Bond (UW), A. Hermann (UW) and C. Mordy (UW)

Buoyancy Workshop Report

The report from the October 1998 meeting is now available for distribution. PDF versions of the Executive Summary (5 p) and the Science Plan (39 p) may be downloaded from the CoOP website (http://www.skio.peachnet.edu/coop/). Complete copies of the report can be requested from the CoOP Office.

CoOP Steering Committee 2000

Sincere thanks for service are due to Nick Bond, Peter Franks, Susan Henrichs, Steve Lohrenz, Claire Reimers and Tom Royer, who rotated off the SSC in January 2000, and to Cheryl Ann Butman, who stepped down in May 2000.

Transport and reaction in permeable marine sediments

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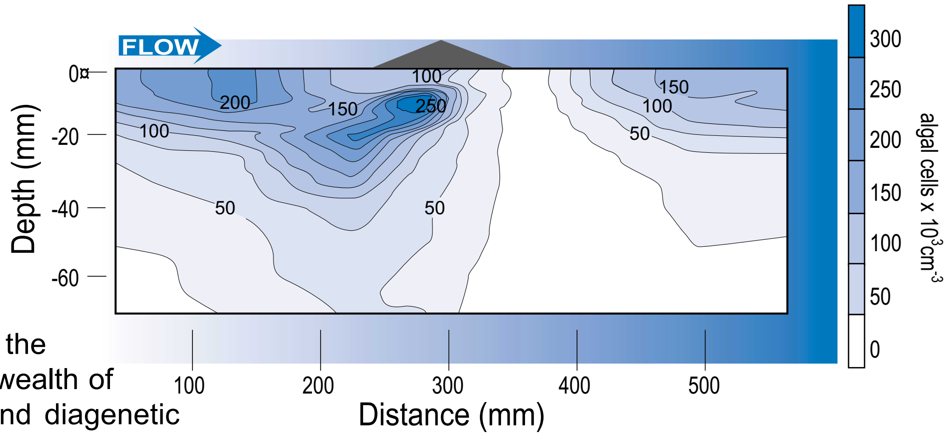

Fig. 2 Isoline diagrams generated from algal cell counts in subcores retrieved from a sediment core exposed to unidirectional boundary flow in a recirculating flume. The unicellular algae *Dunaliella sp*. was added to the flume water at the beginning of the experiment when no algae were present in the sediment. The advective pore water flows associated with the ripple on the sediment surface caused intrusion of water and suspended algae into the sand (adapted from Huettel and Rusch, 2000).

The Scientific Committee on Oceanic Research (SCOR) has established a new working group (WG 114) in order to promote the scientific investigation of transport processes and biogeochemical reactions in permeable marine sediments. During the last decades we have accumulated a wealth of information on the biogeochemistry and diagenetic processes in marine sediments. However, the vast majority of investigations were performed on the fine-grained and cohesive beds. Within this period, new insights gained by the development of new technologies (e.g. deep drilling, deep sea lander deployments, isotope measurements, microsensor and molecular probe developments) have forced us several times to fundamentally revise our view of the sedimentary environment and its biogeochemical processes. Likewise, we may have to revise our view of non-accumulating sandy shelf sediments that have attracted relatively little scientific attention, based on the belief that significant reactions and fluxes and a dynamic ecology require large standing stocks of reactants and organic matter.

In permeable sands, which cover more than half of the world's shelf areas, water can freely move through the interstices, providing a transport pathway with velocities exceeding that of diffusion by orders of magnitude (Fig. 1). The permeability tightly links the biogeochemistry of these sediments to the hydrodynamical conditions of their environment and turns sampling and investigation of these sands into a challenging task. However, the examination of these sediments may be rewarding; recent findings suggest that sandy beds play a significant role in the cycling of matter in the shelf.

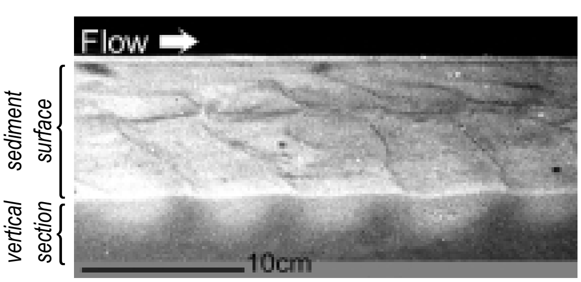

Fig. 1. Washout pattern in a sediment with ripples exposed to unidirectional boundary flow. The pore water of the sandy sediment was stained with Rhodamine dye. The cross section of the core shows dye washout under the ripple troughs caused by advective pore water flows generated by ripple-flow interaction (from Huettel and Webster, 2000).

Bacon *et al*. (1994) reported that in permeable Atlantic Bight shelf sediments (>90% sand), where no net accumulation of sediment and organic matter presently occurs, the excess ^{210}Pb inventories are nearly in balance with the atmospheric supply. Because ^{210}Pb only enters the sediment adsorbed to particles, these results imply that the sands efficiently retain fine particulate matter due to a trapping mechanism. Flume studies have shown that such sands can filter suspended particles and phytoplankton from the water column (Fig. 2 and 3; Huettel and Rusch 2000), supporting the hypothesis that permeable shelf beds may act as expansive filter systems (Shum and Sundby 1996). Seasonal resuspension of the upper sediment layers (e.g. during winter storm events) removes refractory material and fine minerals from the shelf sands, maintaining their high permeability and filtration capacity.

Because the organic carbon in sands is not diluted by accumulating aged material, the organic carbon in sandy shelf sediments has a higher average degradability than in most silty sediments. The degradability increases from 0.01-0.5 y^{-1} at grain sizes

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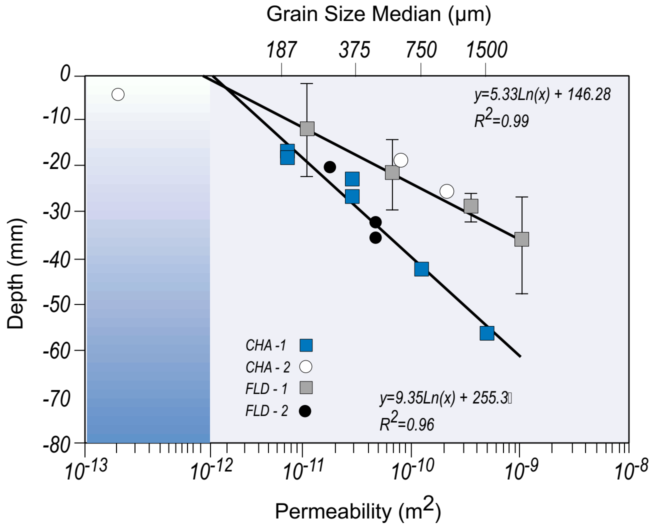

Fig. 3. Penetration depth of unicellular algae *Dunaliella sp.* into sandy sediments of different grain sizes. Advective pore water flows transport algal cells into sandy sediment depending on the permeability of the sand. Data from laboratory chamber experiments and in-situ experiments (Huettel and Rusch, 2000).

< 100 µm to 0.05-3.5 y^{-1} at grain sizes > 200 µm, depending on temperature (Dauwe 1999; Van Raaphorst, in prep.). The bottom water that carries the degradable particles into the upper layers of the bed also transports oxygen, nitrate and sulfate into the sand, providing electron acceptors for the decomposition of the trapped organic matter (Lohse *et al*. 1996; Ziebis *et al*. 1996). Pore water released from the bed in compensation for the intruding water removes metabolic end products that may inhibit bacterial decomposition activities (Marinelli *et al*. 1998). Sands on continental shelves, thus, may function as bio-catalytic converters, with a high turnover rate but negligible burial rate of organic matter.

The efficient mineralization of fresh organic matter and ensuing nutrient release is documented by high primary production in the organic-poor sands where light is available. Studies on the benthic primary production rates in photic continental shelf sands report mean values of 230 mg C m^{-2} d^{-1} with maximum rates exceeding 800 mg C m^{-2} d^{-1}. Roughly 30% of the continental shelf sea floor, an area of approximately $3.4x10^8$ km^2, receives sufficient light to support significant rates of benthic primary production which would result in an estimated production of $2.9x10^{14}$ g C y^{-1} (0.3 Gt C y^{-1}) (Jahnke *et al*. 2000; Nelson *et al*. 1999).

High filtration potential, rapid organic matter turnover and significant benthic primary production in shelf sands suggest that these sediments play an important role in the coastal biogeochemical cycles. Because approximately 30% of the marine primary production takes place in this nutrient-rich environment and up to 50% of this organic matter reaches the shelf sediments (Jørgensen 1996; Wollast 1991), the permeable beds may contribute significantly to the oceanic cycles of matter. Despite this potential importance, our knowledge of biogeochemical processes in permeable shelf sands is very limited, partly due to methodological difficulties. Virtually all of our present methods for estimating benthic mineralization rates and sea floor exchange are suspect in permeable sediments, and technological and methodological advances are required if future studies are to quantify the rates of processes in this environment.

In response to the potential importance of sandy shelf environments, SCOR established the new working group 114 in November 1999. The aim of this initiative is to investigate the importance of permeable sediments to local and global biogeochemical cycling and their influence on surrounding environments. To achieve this aim, this group will involve itself in the following activities:

• Identify reactions and transport phenomena that are important in permeable sediments, i.e. beach, inter-tidal, sub-tidal, reef and shelf environments.

• Suggest sampling schemes and devices for the measurement of both biogeochemical variables (e.g. solute and suspended matter concentrations and fluxes) and flow velocities and their patterns in permeable sediments from different environments.

• Promote the development of models for the description of reaction and transport in permeable sediments and their implementation into standardized "user-friendly" codes.

• Encourage the participation of the marine science community in research on permeable sediments by organizing a special meeting/symposium or a special session at one of the front-line international scientific conferences. Publish the best of the submitted papers, along with review articles by the working group members, in a broadly-read journal.

• Determine whether the study of reaction and transport in permeable sediments would be significantly enhanced by the development of a coordinated international research program (as has been done for carbon cycling with JGOFS), or if this goal would be better served by an enhanced presence in an existing program.

(continued on page 5

SCOR WG 114 welcomes input from all the marine community. Information contacts are:

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River-dominated ocean margins: Direct connections between terrestrial and oceanic environments

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A Dahlem Workshop Report published in 1991 (Ocean Margin Processes in Global Change. Editors: R.F.C. Mantoura, J.-M. Martin and R. Wollast) suggested that "Globally representative and socially relevant ocean margin systems…need to be typologically identified and investigated by coordinated multidisciplinary teams…". One important class of margin systems (in terms of oceanic processes and relevance to human activity) is river-dominated margins—environments in which coastal processes are strongly influenced by riverine inputs. Rivers are the major conduits for the transport of water, salt, organic matter, and mineral matter from land to sea. Large rivers may play a disproportionately important role in this terrestrial-marine linkage. The world's ten largest rivers transport approximately 40% of the fresh water and particulate materials entering the ocean (Milliman, 1991). Smaller rivers may quantitatively be very important to global biogeochemical cycles, yet function very differently in terms of material retention and transformation within the drainage basin and at the ocean margin interface.

RiOMar (River-dominated Ocean Margins) is a new research initiative that involves a broad spectrum of the geosciences community. This initiative specifically addresses the impact of rivers, and their associated ocean margins, on the global carbon cycle. The initial planning document of the U.S. Carbon Cycle Science Program ("A U.S. Carbon Cycle Science Plan") provides a comprehensive overview of global carbon cycle issues, and stresses the importance of examining both the terrestrial and oceanic sinks for organic carbon. In RiOMar, we seek to understand the influence of river-dominated ocean margins (the primary connection between terrestrial and oceanic environments) on global carbon cycle processes, and to better characterize the processes that govern: (a) the transport of organic carbon from terrestrial to oceanic environments via rivers; and, (b) the input, transformation and fate of organic carbon in associated ocean margin environments.

The RiOMar initiative grew out of a workshop held at Tulane University in November 1998, attended by a multi-disciplinary mix of 25 researchers with experience working in RiOMar environments globally. Specific workshop tasks were to assess the present state of

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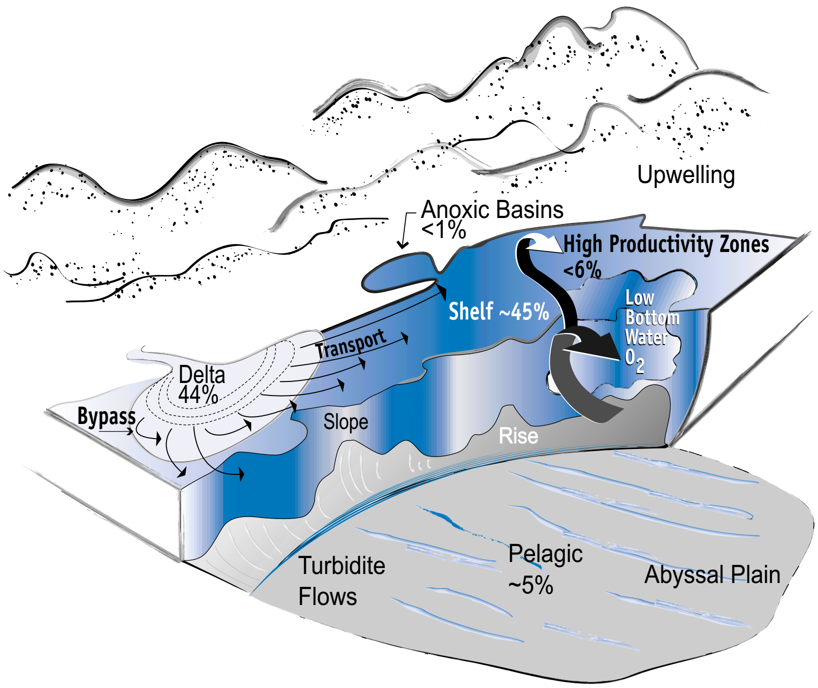

Fig. 4. Schematic of current estimates for the distribution of total organic carbon burial within various sediment types. Adapted from Hedges and Keil (1995).

knowledge regarding biogeochemical processes in river-dominated ocean margins; to evaluate the role of river-dominated ocean margins in the global biogeochemistry of the oceans; and to identify important research questions and innovative interdisciplinary approaches for future studies in river-dominated margins. Major conclusions of the workshop were: (1) a central, unifying research challenge is that of understanding how RiOMar environments affect global change—specifically through their role in the global carbon cycle; (2) research directed at understanding the influence of river-dominated ocean margins on global carbon cycle processes can most effectively be implemented by interdisciplinary teams (earth scientists and geological, chemical, biological and physical oceanographers) that are formed to address specific questions; and (3) the most effective research design is a combined intensive (high frequency, long-term sampling in one or more primary sites) and extensive (comparative studies of key processes in a few selected global RiOMar environments) approach.

There are many intriguing issues related to RiOMar environments and the global carbon cycle. The storage of terrestrial sediments in river basins may be much more important than previously recognized (Stallard, 1998), and is directly affected by human influences. This organic carbon reservoir is directly connected, through RiOMar environments, to the ocean. RiOMar environments receive large inputs of terrestrial (allochthonous) organic carbon via rivers, and marine (autochthonous) organic carbon resulting from high rates of coastal productivity. Greater than approximately 80% of global carbon burial occurs in continental margins, primarily in RiOMar environments (Fig. 4; Berner, 1982; Hedges and Keil, 1995). However, the total annual organic carbon burial in marine sediments is less than one-third of the riverine organic carbon discharge—indicating that riverine organic matter is rapidly mineralized and/or transported to deeper regions on the margin (Hedges and Keil, 1995). The preservation potential for organic carbon (allochthonous and autochthonous) is not as high in certain RiOMar environments as earlier thought (Aller, 1998; Keil *et al.* 1997). RiOMar sediments can provide a continuous integrated record of changes in land-use patterns and climate over expansive drainage basins. High sedimentation rates in RiOMar environments may provide a high-resolution record of changes within drainage basins and associated margins that covers a time span from the past 200 years, influenced by human activities, to 10,000-year glacial/interglacial cycles during which the role of RiOMar environments in global carbon cycles may switch dramatically.

To learn more about the RiOMar initiative and to stay abreast of future developments, visit the RiOMar web site: http://www.tulane.edu/~riomar

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Submarine groundwater discharge: An emerging coastal issue

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The most evident interface between terrestrial and ocean waters is the river mouth or estuary. Less obvious is the interface between terrestrial groundwater and ocean water. The direct flow of groundwater into the ocean and the recycling of sea water through coastal aquifers are processes that have been largely ignored in estimating material fluxes from the land to the sea. Now submarine groundwater discharge (SGD) is becoming recognized as an important process along many coasts. For example Moore (1996) estimated that SGD along the South Carolina coast was 40% of river flow; Cable *et al.* (1996) estimated that SGD to a 620 km^2 area was comparable to the discharge of the largest river in Florida.

There are two issues that must be considered: (1) What is the flux of fresh water due to SGD? (2) What are the material fluxes associated with chemical reactions of sea water and meteoric water with aquifer solids? Hydrologists are primarily concerned with the first question as it relates directly to the freshwater reserve in coastal aquifers and salinization of these aquifers. There may also be buoyancy effects on the coastal ocean associated with direct input of fresh water. Chemical, biological, and geological oceanographers are more concerned with the second question as it relates directly to alteration of coastal aquifers and nutrient, metal, and carbon inputs to the ocean. For example Krest *et al.* (2000) estimate that for South Carolina the flux of nutrients into salt marshes by SGD rivals the nutrient flux to the entire coast by rivers. To emphasize the importance of mixing and chemical reaction in coastal aquifers, Moore (1999) calls them subterranean estuaries.

Attempts to quantify SGD have focused on three approaches: (1) using seepage meters to directly measure discharge, (2) using tracer techniques to integrate SGD signals on a regional scale, and (3) groundwater modeling. Seepage meters are constructed from the top of a steel drum driven into the sediment. In the simplest application a small plastic bag collects the SGD.

More advanced seepage meters are being developed based on heat pulse and acoustic Doppler technologies. Tracer techniques utilize chemicals (often naturally occurring radionuclides, Figs. 5 and 6) that have high concentrations in groundwater relative to coastal waters and low reactivity in the coastal ocean.

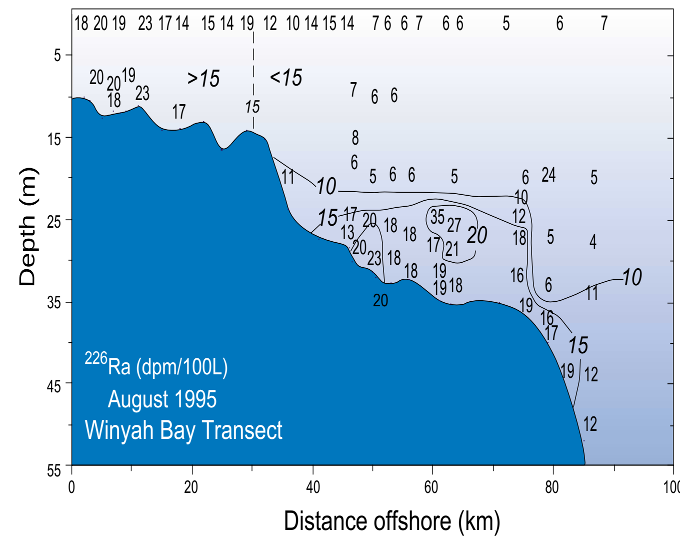

Figure 5. Cross-sectional distribution of ^{226}Ra along a transect of Winyah Bay in the U.S. South Atlantic Bight. Adapted from Moore (1999).

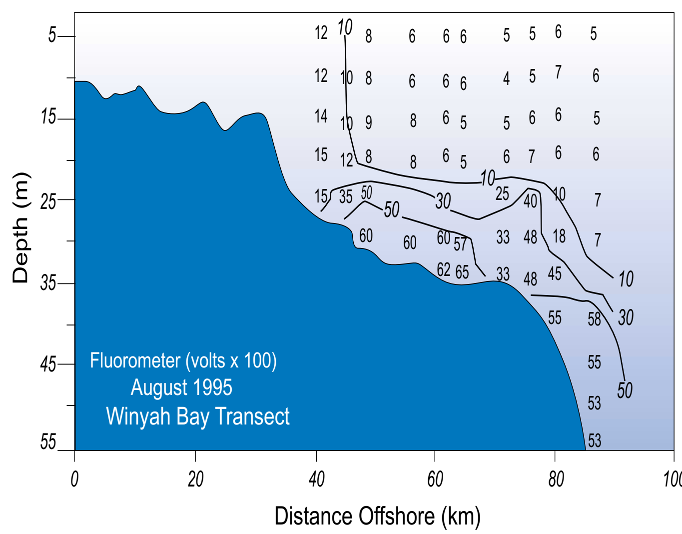

Fig 6. Cross section of chlorophyll-a fluorescence as determined at an emission wavelength of 685 nm along the Winyah Bay transect of Fig. 5. The values are plotted as volts x 100. Adapted from Moore and Shaw (1998).

These techniques require an assessment of the tracer concentration in the groundwater, evaluation of other sources of the tracer, and a measure of the residence time of the coastal water. With this information, an inventory of the tracer in coastal waters is converted to an offshore flux of the tracer. This tracer flux must be replaced by new inputs of the tracer from SGD.

(continued on page 8)

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Li et al. (1999) have attempted to reconcile groundwater flow models with tracer-derived estimates of SGD.

The Scientific Committee on Oceanic Research (SCOR) and Land-Ocean Interactions in the Coastal Zone (LOICZ) have established a working group to evaluate the magnitude of submarine groundwater discharge and its influence on coastal oceanographic processes. This working group is sponsoring intercomparison field experiments to test the most appropriate assessment techniques. For more information see http://www.jhu.edu/~scor/WG112.html.

This emerging field will require the expertise and viewpoints of a wide variety of coastal scientists. Some will try to understand the movement of water through anisotropic strata due to forcing by hydraulic gradients, tides, waves, and coastal freshwater demands. Others will investigate chemical reactions among the variable composition fluids and aquifer solids and the changes these reactions cause to both phases. The present effects of the discharge on the biology, chemistry, and physics of the coastal ocean must be understood; past effects of SGD, especially during altered sea level, must be considered as well. There is little doubt that important coastal management issues will derive from these studies.

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