IODP Proposal Cover Sheet

☐ **New** ☐ **Revised** ☐ **Addendum**

Please fill out information in all gray boxes

Above For Official Use Only

Please check if this is Mission proposal ☐

Title:	A Shallow Drilling Campaign to Assess the Pleistocene Hydrogeology, Geomicrobiology, Nutrient Fluxes, and Fresh Water Resources of the Atlantic Continental Shelf, New England		
Proponent(s):	M. Person, B. Dugan, R. Evans, D. Lizarralde, D. Hutchinson, H. Kooi, J.K. Groen, B. van Breukelen, W.F.M Röling, J. McIntosh, P. Sauer, K. Licht		
Keywords: *(5 or less)*	Pleistocene, Hydrogeology, Submarine Groundwater Discharge	Area:	New England Continental Shelf

Contact Information:

Contact Person:	Mark Person		
Department:	Earth and Environmental Science		
Organization:	New Mexico Tech		
Address	801 Leroy Place, Socorro, NM 87801 USA		
Tel.:	+1 575 835 6506	Fax:	+1 575 835 6436
E-mail:	mperson@nmt.edu		

Permission to post abstract on IODP Web site: ■ Yes ☐ No

Abstract: (*400 words or less)*

In many coastal settings worldwide, the distribution of freshwater within continental shelf sediments is far out of equilibrium with modern sea-level. One of the most remarkable examples is found on the Atlantic continental shelf off New England where groundwater within shallow Pliocene-Pleistocene sand aquifers over 100 km offshore has low salinity (3000 mg/l or less). On Nantucket Island, a 514m deep borehole penetrating the entire Cretaceous-Tertiary sedimentary package shows considerable variations in salinity with extremely fresh (<1000 mg/l) water in sand aquifers, higher salinity (30-70% of seawater) in thick clay/silt layers, and intermediate-to-low salinity in thin confining units. IODP Exp. 313 also showed abrupt freshwater-saltwater boundaries linked to lithology. This demonstrates the disequilibrium nature of such systems; diffusion tends to eliminate such patterns. Pore fluid within Pleistocene to upper Cretaceous sands beneath Nantucket Island is also found to be modestly overpressured, ~4m relative to the local water table.

We hypothesize that the rapid incursion of freshwater on the continental shelf in New England could have been caused by one or more of the following mechanisms: (1) meteoric recharge during Pleistocene sea-level lowstands including vertical infiltration of freshwater associated with local flow cells on the shelf; (2) sub-ice-sheet recharge during the last glacial maximum; and (3) recharge from pro-glacial lakes. We further hypothesize that the overpressures could be due to: (1) Pleistocene sediment loading; or (2) fluid density differences associated with emplacement of a thick freshwater lens over saltwater (analogous to excess pressures in the gas legs of petroleum reservoirs). We argue these different recharge mechanisms and overpressure models can be distinguished through drilling, coring, logging, and fluid sampling. Noble gas and environmental isotope data will be necessary to completely evaluate recharge models.

This work will extend our understanding of the current and past states of fluid composition, pressure, and temperature in continental shelf environments. It will help better constrain rates, directions, and mechanisms of groundwater flow and chemical fluxes in continental shelf systems. It will contribute to the development of new tools for measuring freshwater resources in marine environments. The apparent transient nature of continental shelf salinity patterns could have important implications for microbial processes and long-term fluxes of carbon, nitrogen, and other nutrients to the ocean. Successful drilling will test process-based models for shelf freshwater off New England. These models can then be applied to other shelf freshwater systems around the world.

Scientific Objectives: (*250 words or less*)

We argue that targeted drilling and coring including hydrogeochemical, microbiological, isotopic, and noble gas analysis and measurement of hydraulic properties and fluid pressures will permit us to develop a process-based understanding for the origin and volumes of offshore freshwater, how these fluids could influence local and global biogeochemical cycles, and how they record climate cycles.

We propose a four site, shallow-water drilling campaign on the Atlantic continental shelf off Martha's Vineyard, MA, USA to test our hypotheses and map the distribution of freshwater resources. Our transect takes advantage of existing boreholes on Martha's Vineyard (ENW-05) and Nantucket (6001) and builds on previous AMCOR and IODP analyses. Our transect will provide samples from the freshwater, freshwater-saltwater transition, and saltwater zones allowing complete characterization of the system. Based on paleohydrologic reconstructions, we have a 2D model of the freshwater distribution and predict the freshwater-saltwater transition is approximately 50km offshore. Drilling will directly test this model and provide additional constraints for future 3D transport models.

Our planned drilling campaign will require one MSP. We propose a drilling program similar to IODP Exp. 313 to increase recovery in unconsolidated sand units and a casing/screening program to facilitate collection of pristine pore fluid samples for geochemical and microbiological analyses. Post-expedition numerical models will include simulation of groundwater residence time and noble gas transport for comparison with field measurements. This highly interdisciplinary work will be one of the first focused hydrogeological-biogeochemical-microbiological studies of shelf systems.

Please describe below any non-standard measurements technology needed to achieve the proposed scientific objectives.

LWD, well tests in cased/screened sites, collection of noble gas samples

Proposed Sites:

Site Name	Position	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
MV-01B (Alternate)	41.3033 N 70.5673 W	21	350		350	Characterize freshwater-dominated zone
MV-02B (Primary)	41.1171 N 70.3953 W	37	550		550	Characterize freshwater-dominated zone
MV-03C (Primary)	40.8746 N 70.2697 W	42	650		650	Characterize freshwater-saltwater transition
MV-04B (Primary)	40.6206 N 70.1381 W	52	750		750	Characterize freshwater-saltwater transition
MV-05B (Primary)	40.3771 N 70.0119 W	79	775		775	Characterize saltwater zone

IODP 637-Add3 Proponents

Proponent	Affiliation	Email	Expertise
Mark Person	Hydrology Program, New Mexico Tech, USA	mperson@nmt.edu	hydrogeology, basin-scale flow modeling
Brandon Dugan	Dept. of Earth Science, Rice University, USA	dugan@rice.edu	physical hydrogeology, marine geology
Robert Evans	Dept. of Geology & Geophysics, Woods Hole Oceanographic Institution, USA	revans@whoi.edu	electromagnetic methods
Daniel Lizarralde	Dept. of Geology & Geophysics, Woods Hole Oceanographic Institution, USA	danl@whoi.edu	marine geophysics, margin processes
Deborah Hutchinson	Coastal and Marine Geology Program, Woods Hole Science Center, U.S. Geological Survey, USA	dhutchinson@usgs.gov	marine geology and geophysics
Henk Kooi	Dept. of Hydrology & Geo-Environmental Sciences, VU University Amsterdam, The Netherlands	henk.kooi@falw.vu.nl	hydrogeology, offshore freshwater
J. Koos Groen	Dept. of Hydrology & Geo-Environmental Sciences, VU University Amsterdam, The Netherlands	j.groen@acaciainstitute.nl	groundwater exploration, coastal zone hydrology
Boris van Breukelen	Dept. of Hydrology & Geo-Environmental Sciences, VU University Amsterdam, The Netherlands	boris.van.breukelen@falw.vu.nl	contaminant hydrology, biogeochemistry
Wilfred Röling	Dept. of Hydrology & Geo-Environmental Sciences, VU University Amsterdam, The Netherlands	wilfred.roling@falw.vu.nl	groundwater ecosystems, geomicrobiology
Jennifer McIntosh	Dept. of Hydrology and Water Resources, University of Arizone, USA	mcintosh@hwr.arizona.edu	aqueous geochemistry, isotope geochemsitry
Peter Sauer	Dept. of Geological Sciences, Indiana University, USA	pesauer@indiana.edu	biogeochemistry, paleoclimatology
Kathy Licht	Dept. of Earth Sciences, Indiana University-Purdue University, USA	klicht@iupui.edu	glacial geology, quaternary geology

IODP 637-Full2 Updates

This addendum to IODP 637-Full2 (New England Margin Hydrogeology) includes three primary advancements supporting our proposal to characterize and to understand the distribution and emplacement mechanisms of submarine freshwater resources, and associated nutrient and biogeochemical cycles, along the New England continental shelf: (1) we completed a high resolution seismic survey of the study region allowing more detailed characterization of the stratigraphic architecture and providing site survey data; (2) IODP Expedition 313 documented separate advection- and diffusion-dominated freshwater-saltwater systems offshore New Jersey; and (3) IODP Expedition 313 established safe and viable drilling practices for unconsolidated shelf sediments. In addition, we provide an overview of the scientific goals and motivation for the program and an overview for each proposed site.

Introduction

In coastal settings worldwide, large freshwater volumes are sequestered in permeable continental shelf sediments. Freshwater storage and discharge have been documented off N. America, S. America, Europe, and Asia [*Hathaway et al.*, 1979; *Kooi and Groen*, 2000; *Taniguchi et al*., 2006; *Weinstein et al.*, 2007; *Mottl and Hayashi*, 2009]. In Europe, the PALAEAUX collaboration characterized coastal freshwater to evaluate climatic fluctuations and to develop management strategies [*Edmunds and Milne*, 2001]. In other studies, submarine groundwater discharge has been evaluated as it impacts nutrient fluxes to the ocean [*Moore*, 1996; *Li et al*., 1999; *Michael et al*., 2005] and as an agent of erosion [*Robb*, 1984]. We propose to study the Atlantic continental shelf off New England where freshwater extends up to 100 km offshore. Using high-resolution mathematical models and existing well data, we estimate that ~1300 km^3 of freshwater is sequestered from New York to Maine, and up to $3x10^5$ km^3 may be sequestered along passive margins worldwide [*Cohen et al.*, 2010]. These worldwide, vast quantities of freshwater represent a resource to urban coastal centers, if accurately characterized and managed [*Custodio et al*., 2001].

In IODP 637-Full2, we propose four primary sites (MV-02B, MV-03C, MV-04B, and MV-05B) off Martha's Vineyard (New England, USA) to determine source, volume, and emplacement of this freshwater. The emplacement hypotheses are: (1) meteoric recharge during sea-level lowstands; and (2) sub-ice sheet meltwater recharge during glaciations. These different mechanisms can be distinguished using environmental isotope and noble gas data. Our study builds on data from seismic and coring ventures from the 1970s. Site survey data collected in 2009 provide new, high-resolution constraints on the stratigraphic architecture of the study region. Our proposed sites will obtain focused hydrogeochemical and microbiological samples across the freshwater-saltwater zone and will characterize the hydrological properties of the shelf. These samples and data will help us define the hydrogeological, geochemical, and biological processes within the shelf and what drives them.

Preliminary Models

Dip models based on USGS Line 5 examine the impacts that aquiclude (silt) connectivity has on freshwater distribution. The models invoke two stratigraphic architectures that are not differentiable with the vintage seismic and well data (**Figs. 1a,b**) [*Kohout et al.*, 1977; *Hathaway et al.*, 1979; *Valentine*, 1981; *Poag*, 1982; *Schlee and Fritsch*, 1982; *Klitgord et al.*, 1994; *Person et al.*, 1998; *Person et al.*, 2003]. The differences between the models are the connectivity of the Cretaceous-Tertiary silt and the termination of the Cretaceous carbonate (**Figs. 1a,b**). We simulated sea-level variations for 1.8 million years using a 120-m amplitude, 100,000-year period and included one cycle of ice sheet loading (glaciation). Details of the modeling methods and sediment properties can be found in *Marksammer et al.* [2007], *Person et al.* [2007], and *Cohen et al.*, [2010].

These simulations show that freshwater volume is greatly affected by silt connectivity. When continuous silt aquicludes separate aquifers (**Fig. 1a**), we predict freshwater 50 km offshore to 200 m below seafloor (**Fig. 1c**). This freshwater is pervasive in the shallowest sediments and fingers into deeper sediments. When the silt is discontinuous (**Fig. 1b**), the freshwater volume decreases by 50%, but still exists far offshore (**Fig. 1d**). Recently acquired site survey data are being used to update the stratigraphic geometry and numerical model predictions of freshwater distribution. IODP *drilling will provide additional constraints on lithology and hydrogeological parameters and direct measurements of fluid composition* to test the models.

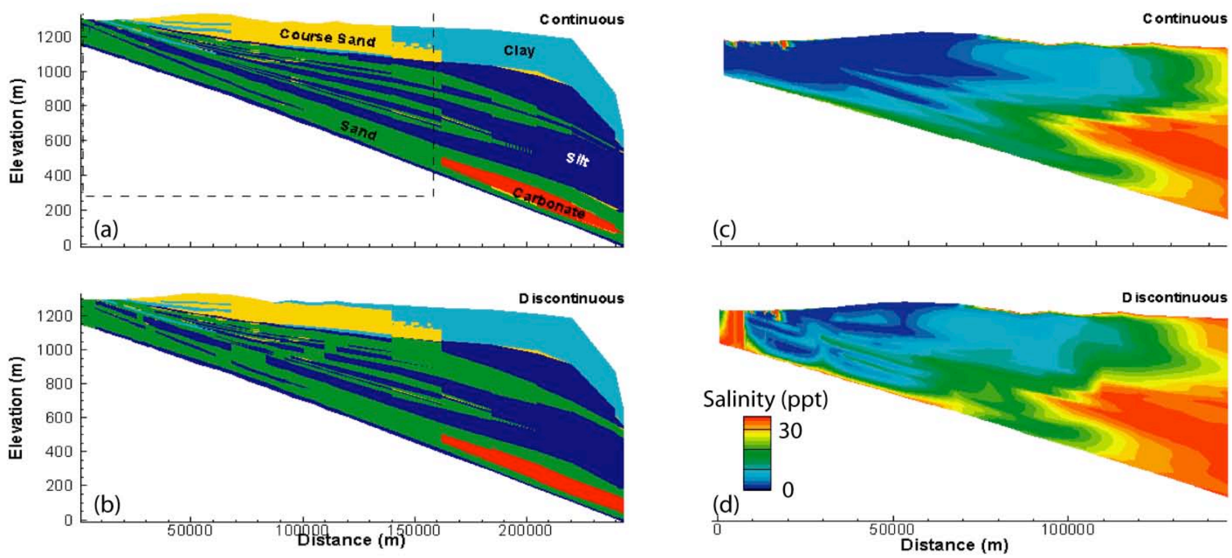

Fig. 1*. (a) Stratigraphic framework for the preliminary model with continuous silt aquicludes. (b) Stratigraphic framework for the preliminary model with discontinuous silt aquicludes. (c) Simulated salinity for the continuous-aquiclude model a. (d) Simulated salinity for the discontinuous-aquiclude model b.*

Recent drilling offshore New Jersey in IODP Expedition 313 provided new information on the freshwater-saltwater transition within the continental shelf. Drilling and porewater sampling documented a complex distribution of freshwater and saltwater 45-65 km offshore New Jersey [*Mountain et al.*, 2009]. The shallow sedimentary section had sharp freshwater-saltwater boundaries that were closely linked with stratigraphy; in the deeper section, and farther offshore, a gradual increase in salinity with depth was observed with salinity exceeding that of modern seawater [*Mottl and Hayashi*, 2009]. These distinct and different (sharp boundary vs. gradual transition) trends in porewater chemistry suggest that advective and diffusive systems are active along within the continental shelf. These systems operate at different spatial and temporal scales. With these data and the additional sample and data from the focused approach of IODP 637-Full2, we will enhance our knowledge of fluid and chemical fluxes and their variation in continental shelf sediments.

Successful drilling of IODP 637-Full2 combined with high-resolution stratigraphic data, two-dimensional electromagnetic surveys, and numerical modeling will provide process-based understanding of global, offshore freshwater. This project will have <u>*broad, interdisciplinary, scientific impact*</u> because of the role this freshwater plays in nutrient fluxes to the ocean, geochemical and deep-biosphere processes in shelf sediments, and long-term, episodic greenhouse gas emissions. A better understanding of these large freshwater reservoirs will have <u>*broad, societal impacts,*</u> as these waters are a potential source available for increasing global freshwater demands.

Site Survey

In August 2009, we completed an NSF-funded survey (NSF 0824263) that collected >1000 km of high-resolution, multi-channel seismic (MCS) data in the proposed study region (**Fig. 2**). The seismic data, including crossing lines at proposed sites MV-02B, MV-03C, MV-04B, and MV-05B, have been submitted to the IODP SSDB for evaluation by the SSP and EPSP. In addition, a complete environmental and safety report will be submitted to EPSP before their next meeting (~June 2010).

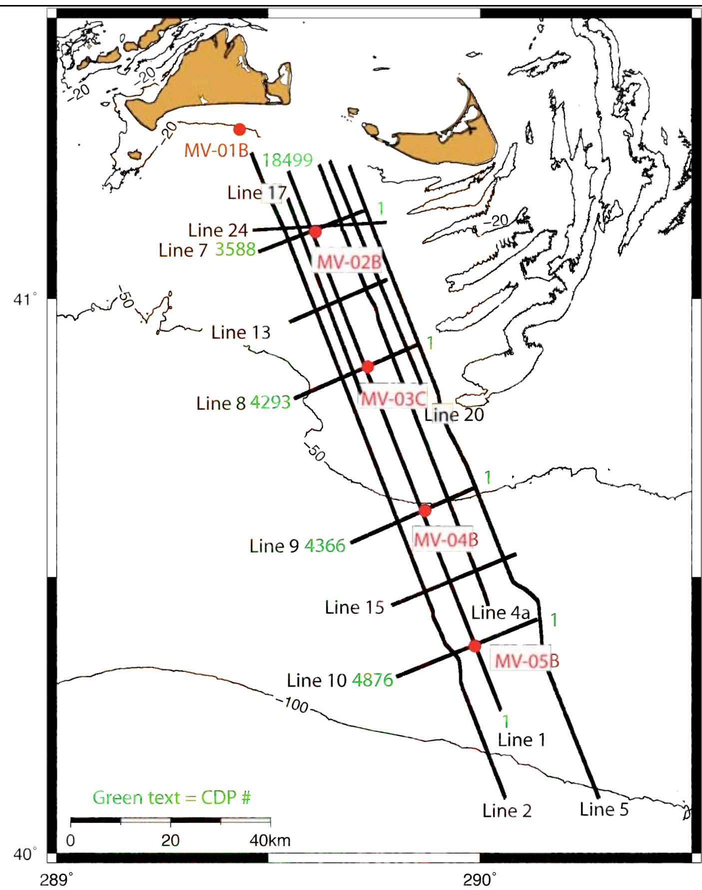

Fig. 2. *Trackmap for high-resolution MCS data (black lines) collected in August 2009 on the R/V Endeavor. Each line also has 3.5 kHz echosounder profiling. Proposed IODP sites are labeled in red. Primary sites are MV-02B, MV-03C, MV-04B, and MV-05B. MV-01B is an alternate site. Contours are water depth (20m, 50m, and 100m).*

We imaged the Cretaceous-Tertiary units using Scripps's high-resolution multi-channel streamer (48-channel, 600-m) with a 45/105 in^3 generator/injector (GI) gun source. For our shallow water shelf setting, the system provided ~6 m vertical resolution and allowed imaging to ~1 km (**Fig. 3**). Each seismic line (**Fig. 2**) also has 3.5 kHz echosounder data that were collected during the survey. The MCS seismic data are being used to map and characterize the details of the capping Plio-Pleistocene section. This thin Plio-Pleistocene section is where we speculate that recharge of freshwater may have occurred during sea-level lowstands and where submarine discharge of freshwater may be active today. Ongoing mapping and better seismic constraints on stratigraphy will increase the predictive capability of our modeling efforts.

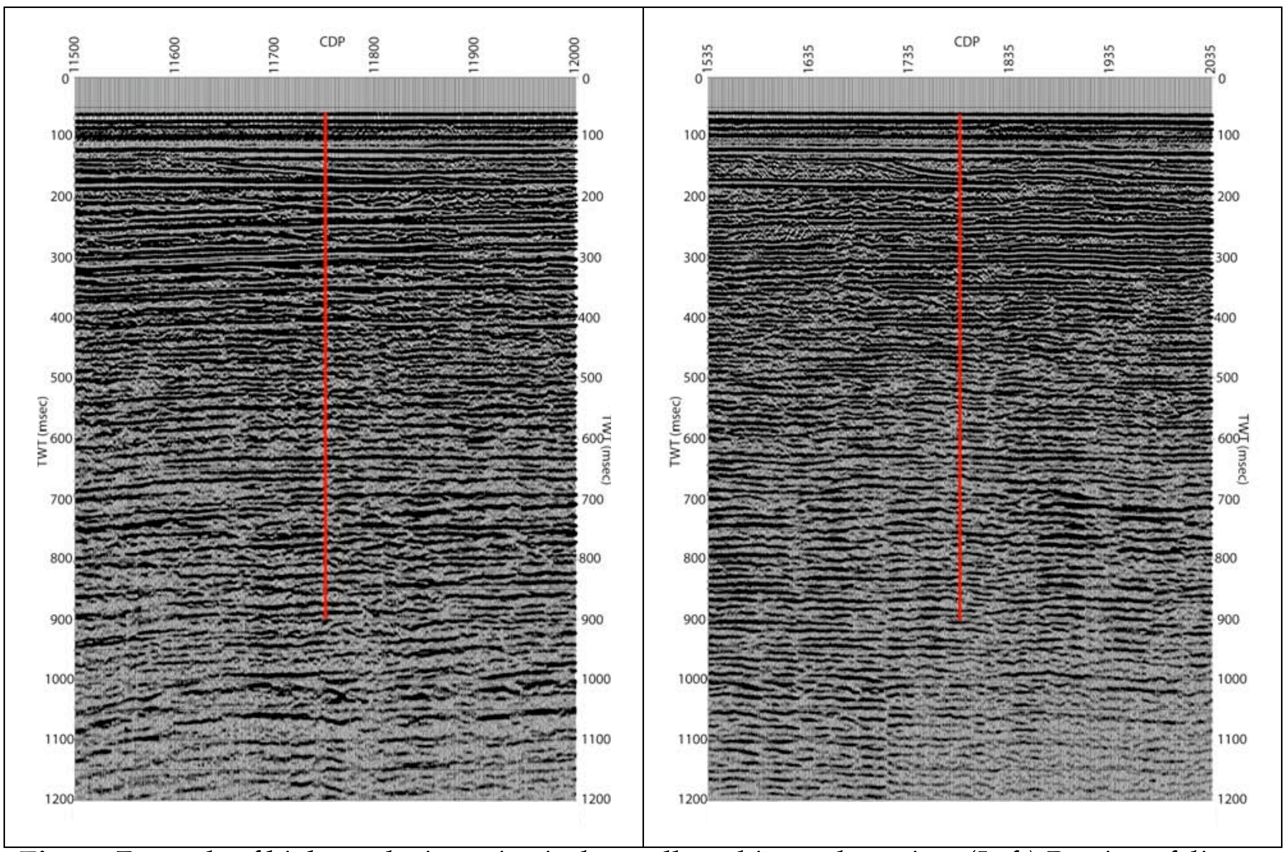

Fig. 3. *Example of high-resolution seismic data collected in study region. (Left) Portion of dip seismic line 1 (located in* ***Fig. 2****) crossing MV-03C (red line). (Right) Portion of strike seismic line 8 (located in Fig. 2) crossing line 1 at MV-03C (red line). CDP spacing is 6.25m.*

Initial processing of the seismic data included top and bottom mutes, bandpass filter (3-6-120-240 Hz), F-K filter, true amplitude recovery (7dB/s), normal moveout correction, and CDP stacking. This processing stream focused on imaging the shallow stratigraphy (**Fig. 3**). We continue to process and to interpret the data including detailed velocity analysis, mapping key stratigraphic horizons, and making isochron/isopach maps. Our advanced processing is focusing on multiple suppression for better near-seafloor imaging and velocity analysis for hazard assessment and depth migration of the profiles. Final stacked sections will be used to define the three-dimensional stratigraphic architecture for numerical models of the study area. These models will provide estimates of *in situ* fluid chemistry and fluid age that will be tested by the drilling proposed in 637-Full2. In addition to seismic data, we anticipate collecting towed electromagnetic (EM) data to image the two-dimensional resistivity structure of the shallow subsurface near each proposed site. The EM data will be combined with logging and pore fluid data to provide an image of freshwater distribution across the region, which will serve as additional tests for the numerical models.

Drilling and Sampling

We propose four primary sites (**Fig. 2**) to assess freshwater volumes, freshwater emplacement mechanisms, the freshwater-saltwater transition, and the impact of mixed fluids on nutrient cycling and biogeochemistry. Based on our models (**Fig. 1**), we are confident that the proposed sites will allow us to characterize the freshwater, transition, and saltwater zones. This will allow us to complete the science objectives with one mission specific platform (MSP) eliminating multi-platform costs.

Our drilling campaign will use IODP drilling for an MSP based on the success of IODP Expedition 313, which had 80% core recovery for New Jersey shelf sediments [*Mountain et al.*, 2009]. Based on similar lithology between the New Jersey shelf and the shelf offshore Martha’s Vineyard, MA, and similar target depths, we are confident that a similar drilling strategy will provide the data we need to achieve our science goals. In addition to drilling and coring, we propose an LWD program and detailed porewater sampling with hydrogeologic (e.g., packer) tests. The LWD data will provide high quality information on lithology and fluids through gamma ray, density, and resistivity imaging for core-log-seismic correlation and for characterizing any unrecovered intervals. It will also provide first-look data prior to coring so we can establish key horizons for hydrogeologic testing.

Hydrogeologic tests are required to collect formation fluids from permeable aquifers. These fluids are necessary to understand nutrient fluxes, fluid origin, and age. These tests also provide well-scale hydrogeologic properties (e.g., storativity, permeability) for input to numerical models and for comparison with shorebased tests on core samples. The tests are non-standard in IODP, but MSP flexibility and existing technology will facilitate these types of experiments. To assess technology options for casing and sampling shelf fluids, a project-scoping meeting was held between the proponents, IODP-MI, ESO, and Schlumberger (24 April 2007). From this meeting, we are confident that existing methods and tools (e.g., Westbay Multiport Sampler) on an MSP can overcome water/sediment sampling problems experienced by ODP and AMCOR in unconsolidated sections. Interpreted survey data will help decide which technology is best for our sites. We look forward to working with ESO to develop the best drilling and sampling strategy to maximize science with existing technology while managing operation costs.

Site Overviews

Site MV-02B (primary) is proposed for 550 m of penetration to characterize the freshwater-dominated zone of the system. We anticipate that we will sample Late Pleistocene glacial meltwater and meteoric water with increasing amounts of seawater. Salinity should be higher in fine-grained units. Drilling will penetrate Pleistocene-Upper Cretaceous unconsolidated to poorly consolidated sands, silts, and clays with thin (20 cm) coal stringers. Sample analysis will focus on pore fluid chemistry, noble gas, ^{18}O, ^{2}H, ^{14}C, ^{13}C, ^{81}Kr, ^{4}He, permeability, porosity, compressibility, and DNA/RNA analysis to assess fluid origin, flow behavior, and microbial activity. Crossing seismic lines (**Fig. 2**) exist for this site.

Site MV-03C (primary) is proposed for 650 m of penetration to characterize the freshwater-saltwater transition zone. We anticipate that we will sample Late Pleistocene glacial meltwater and meteoric water with increasing amounts of seawater relative to MV-02B and also with increasing depth. Salinity should be higher in fine-grained units. Drilling will penetrate Pleistocene-Upper Cretaceous unconsolidated to poorly consolidated sands, silts, and clays. Sample analysis will focus on pore fluid chemistry, noble gas, ^{18}O, ^{2}H, ^{14}C, ^{13}C, ^{81}Kr, ^{4}He, permeability, porosity, compressibility, and

DNA/RNA analysis to assess fluid origin, flow behavior, and microbial activity. Crossing seismic lines (**Fig. 2**) exist for this site.

Site MV-04B (primary) is proposed for 750 m of penetration to characterize the freshwater-saltwater transition zone. We anticipate that we will sample significant amounts of seawater with some freshening due to Late Pleistocene glacial meltwater and meteoric water. With increasing depth, salinity should increase and may exceed that of modern seawater such as observed in IODP Expedition 313 [*Mottl and Hayashi*, 2009]. Salinity should be higher in fine-grained units. Drilling will penetrate Pleistocene-Upper Cretaceous unconsolidated to poorly consolidated sands, silts, and clays. Sample analysis will focus on pore fluid chemistry, noble gas, ^{18}O, ^{2}H, ^{14}C, ^{13}C, ^{81}Kr, ^{4}He, permeability, porosity, compressibility, and DNA/RNA analysis to assess fluid origin, flow behavior, and microbial activity. Crossing seismic lines (**Fig. 2**) exist for this site.

Site MV-05B (primary) is proposed for 775 m of penetration to characterize the saltwater end member of the system. We anticipate that we will sample Pleistocene seawater in the shallow section, with salinity increasing above that of modern seawater with depth [e.g., *Mottl and Hayashi*, 2009]. Drilling will penetrate Pleistocene-Upper Cretaceous unconsolidated to poorly consolidated sands, silts, and clays. Carbonates may be encountered at the bottom of the site. Sample analysis will focus on pore fluid chemistry, noble gas, ^{18}O, ^{2}H, ^{14}C, ^{13}C, ^{81}Kr, ^{4}He, permeability, porosity, compressibility, and DNA/RNA analysis to assess fluid origin, flow behavior, and microbial activity. Crossing seismic lines (**Fig. 2**) exist for this site.

Site MV-01B (alternate to MV-02B) is proposed for 350 m of penetration to characterize the freshwater end member of system. We anticipate that we will sample Holocene meteoric water and/or Late Pleistocene glacial meltwater with minor amounts of seawater at depth >300 m. Drilling will penetrate Pleistocene-Upper Cretaceous unconsolidated to poorly consolidated sands, silts, and clays with thin (20 cm) coal stringers. Sample analysis will focus on pore fluid chemistry, noble gas, ^{18}O, ^{2}H, ^{14}C, ^{13}C, ^{81}Kr, ^{4}He, permeability, porosity, compressibility, and DNA/RNA analysis to assess fluid origin, flow behavior, and microbial activity. No high-resolution data were collected at this site due to shallow water conditions.

Societal Relevance

With increasing global demands for freshwater, sequestered continental shelf freshwater represents a large, untapped resource. These demands have led to local and regional coastal freshwater studies and management plans in Europe [*Custodio et al*., 2001; *Edmunds*, 2001]. In our study region, more than 1300 km^3 of freshwater may exist [*Cohen et al*., 2010], which would help coastal cities (e.g., New York City uses 1.5 km^3/yr), if efficiently managed. Globally these coastal freshwater resources will become more important with time; successful use rests upon a process-based understanding of their short-term and long-term behavior, which IODP 637-Full2 will help determine.

References

Cohen, D., Person, M., Wang, P., Gable, C.W., Hutchinson, D., Marksamer, A., Dugan, B., Kooi, H., Groen, K., Lizarralde, D., Evans, R.L., Day-Lewis, F.D., Lane Jr., J.W., 2010, Origin and Extent of Fresh Paleowaters Beneath the Atlantic Continental Shelf, New England, Ground Water, 48(1), 143-158, doi:10.1111/j.1745-6584.2009.00627.x.

Custodio, E., W.M. Edmunds, and Y. Travi, 2001, Management of coastal palaeowaters, Geological Society of London Special Publications, 189, 313-327.

Edmunds, W.M. and C.J. Milne (eds), 2001, Palaeowaters in coastal Europe: evolution of groundwater since the late Pleistocene, Geological Society of London, Special Publication, 189, 332 pp.

Grow, J.A., and J.S. Schlee, 1976, Interpretation and velocity analysis of U.S. Geological Survey multichannel reflection profiles 4, 5, and 6, Atlantic continental margin, U.S. Geological Survey Miscellaneous Field Series Map MF-808.

Hathaway, J.C., C.W. Poag, P.C. Valentine, R.E. Millerk, D.M. Schultz, F.T. Manheim, F.A. Kohout, M.H. Bothner, and D.A. Sangrey, 1979, U.S. Geological Survey core drilling on the Atlantic Shelf, Science, 206(4418), 515-527.

Hutchinson, D.R., K.D. Klitgord, and R.S. Detrick, 1986, Rift basins of the Long Island Platform, GSA Bull., 97, 688-702.

Klitgord, K.D., J.S. Schlee, and K. Hinz, 1982, Basement structure, sedimentation, and tectonic history of the Georges Bank Basin, in P.A. Scholle and C.R. Wenkam, eds., United States North Atlantic continental shelf; Geological studies of the COST Nos G-1 and G-2 wells, U.S. Geological Survey Circular 861, 160-186.

Klitgord, K.D., C.M. Schneider, and L. North, 1994, Geophysical database of the East Coast of the United States Northern Atlantic Margin: cross sections and gridded database (Georges Bank basin, Long Island platform, and Baltimore Canyon trough): U.S. Geological Survey Open-File Report OF94-637, 189 pp.

Kohout, F.A., J.C. Hathaway, D.W. Folger, M.H. Bothner, E.H. Walker, D.F. Delaney, M.H. Frimpter, E.G.A. Weed, and E.V.C. Rhodehamel, 1977, Fresh groundwater stored in aquifers under the continental shelf, Implications from a deep test, Nantucket Island, Massachusetts, Water Resources Bulletin, 13(2), 373-386.

Kooi, H. and J. Groen, 2000, Modes of seawater intrusion during transgressions, Water Resources Research, 36(12), 3581-3589.

Li, L., D.A. Barry, F. Sagnitti, and J.Y. Parlange, 1999, Submarine groundwater discharge and associated chemical input into the sea, Water Resources Research, 35(11), 3253-3259.

Marksamer, A.J., M.A. Person, F.D. Day-Lewis, J.W. Lane, Jr., D. Cohen, B. Dugan, H. Kooi, M. Willet, 2007, Integrating geophysical, hydrochemical, and hydrologic data to understand the freshwater resources on Nantucket Island, Massachusetts, in Hyndman, D.W., F.D. Day-Lewis, K. Singha (eds), AGU Geophysical Monograph 171 – Subsurface Hydrology: Data Integration for Properties and Process, doi:10.1029/171GM12.

Michael, H.A., A.E. Mulligan, C.F. Harvey, 2005, Seasonal oscillations in water exchange between aquifers and the coastal ocean, Nature, 436, doi:10.1038/nature03935.

Moore, W.S, 1996, Large groundwater inputs to coastal waters revealed by ^{226}Ra enrichments, Nature, 380, 612-614.

Mottl, M.J., Hayashi, T., 2009, Fresh and salty: chemistry of sediment pore water from the New Jersey shelf: IODP Exp. 313, Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract PP31A-1293.

Mountain, G.S., Proust, J., McInroy, D., Expedition 313 Science Party, 2009, Links between eustatic history, sequence architecture, and lithofacies associations put to the test: IODP Exp. 313 drilling on the NJ Margin, Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract PP31C-1362.

Person, M., McIntosh, J. Bense, V. and V.H. Remenda, 2007, Pleistocene Hydrology of North America: The Role of Ice Sheets in Reorganizing Groundwater Flow Systems, Reviews of Geophysics, 45, RG3007, doi:10.1029/2006RG000206.

Person, M., B. Dugan, J.B. Swenson, L. Urbano, C. Stott, J. Taylor, and M. Willett, 2003, Pleistocene hydrogeology of the Atlantic continental shelf, New England, GSA Bull., 115, 1324-1343.

Person, M., J. Taylor, and S. L. Dingman, 1998, Sharp-Interface Models of Salt Water Intrusion and Well Head Delineation on Nantucket Island, Massachusetts, Ground Water, 36, 731-742.

Poag, C.W., 1982, Stratigraphic reference section for Georges Bank Basin-Depositional model for New England Passive Margin, AAPG Bull., 66(8), 1021-1041.

Robb, J.M., 1984, Spring sapping on the lower continental slope, offshore New Jersey, Geology, 12, 278-282.

Schlee, J. S. and J. Fritsch, 1982, Seismic stratigraphy of the Georges Bank Basin complex offshore New England, AAPG Memoir 43, 223-251.

Taniguchi, M., T. Ishitobi, J. Shimada, 2006, Dynamics of submarine groundwater discharge and freshwater-seawater interface, J. Geophys. Res., 111, C01008, doi:10.1029/2005JC002924.

Valentine, P. C., 1981, Continental margin stratigraphy along the U.S. Geological Survey seismic Line 5 - Long Island platform and western Georges Bank basin: U.S. Geological Survey Miscellaneous Field Studies Map MF-857, 2 sheets.

Weinstein, Y., W.C. Burnett, P.W. Swarzenski, Y. Shalem, Y. Yechieli, B. Herut, 2007, Role of aquifer heterogeneity in fresh groundwater discharge and seawater recycling: an example from the Carmel coast, Israel, J. Geophys. Res., 112, C12016, doi:10.1029/2007JC004112.