A MULTI-LEVEL PORE-WATER SAMPLER FOR PERMEABLE SEDIMENTS

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ABSTRACT: The construction and operation of a multi-level piezometer (multisampler) designed to collect pore water from permeable sediments up to 230 cm below the sediment–water interface is described. Multisamplers are constructed from 1½ inch schedule 80 PVC pipe. One-quarter-inch flexible PVC tubing leads from eight ports at variable depths to a 1½ inch tee fitting at the top of the PVC pipe. Multisamplers are driven into the sediment using standard fence-post drives. Water is pumped from the PVC tubing with a peristaltic pump. Field tests in Banana River Lagoon, Florida, demonstrate the utility of multisamplers. These tests include collection of multiple samples from the permeable sediments and reveal mixing between shallow pore water and underlying lagoon water.

INTRODUCTION

The diffuse discharge of ground water to estuaries and the coastal oceans may represent a flow path for solutes to the overlying water column (Johannes 1980; Simmons 1992; Bokuniewicz 1980; Capone and Bautista 1985; Gallagher et al. 1996; Robinson et al. 1998; Moore 1999; Robinson and Gallagher 1999). Although ground-water discharge can originate from a variety of sources, in part it includes water discharging from onshore fresh-water aquifers that flows offshore under pressure from hydrostatic head (Cooper 1959; Glover 1959; Church 1996; Li et al. 1999). Direct measurements of the volumes of ground-water discharge can be orders of magnitude larger than available on the basis of aquifer recharge, however, which has led to the suggestion that physical and biological mixing of marine waters through shallow sediment also may be included in the total ground-water discharge (Aller 1980; Emerson et al. 1984; Li et al. 1999; Mu et al. 1999; Sandnes et al. 2000; Burnett et al. 2002). Although these processes may mix pore water with the water column over short time periods (e.g., days or weeks), sufficient time exists for diagenesis to alter reactive chemical components, such as nutrients and metals, and thereby provide important fluxes of these constituents to the overlying water column (Johannes 1980; Emerson et al. 1984; Capone and Bautista 1985; Sansone et al. 1988).

The rate of ground-water discharge to estuaries and coastal zones, and the resulting flux of mass from the sediment, can be difficult to measure because of its diffuse nature and slow flow rates. Methods of study have included direct measurements using Lee-type seepage meters (Lee 1977), measurements of sediment-sourced solutes and isotopes in the water column (Cable et al. 1996a; Cable et al. 1996b; Bagnas et al. 1996; Moore 1996), and modeling of gradients in the chemical compositions of pore waters (Emerson et al. 1984; Sandnes et al. 2000). Combining several different techniques provides the most robust measurement of ground-water discharge (e.g., Burnett et al. 2002). In addition to modeling flow rates from pore-water profiles, the chemical composition of pore water is important to solute fluxes because of changes in composition following diagenetic reactions. Pore-water samples can be difficult to obtain in estuaries and coastal zones using standard sampling devices, however, because of their commonly coarse-grained nature and high permeability.

This paper describes the construction and operation of a tool designed to sample pore water from permeable sediments. An example of use of the tool is provided by profiles of pore-water solutes in sediments from Banana River Lagoon, Florida. The tool is referred to as a multisampler, and as described here is inexpensive, easily constructed, simple to deploy and sample, and capable of collecting up to eight pore-water samples during a single deployment from depths as great as 230 cm below the sediment–water interface. The ability to collect multiple samples from a single location is an important attribute because large changes in the chemical composition of the pore water could occur over short lateral distances in permeable sediments (e.g., Boudreau et al. 2001), unlike pore water in fine-grained marine sediments, which may have large changes vertically in composition, but only small changes laterally (Berner 1980). Obtaining all samples from a single device also simplifies the field protocols and shortens the time required for sampling and installation of the tools.

Previous Pore-Water Sampling Techniques

The multisampler design described here is a modification of multilevel samplers that have a long history of development and use for terrestrial hydrogeologic sampling (e.g., Hansen and Harris 1974; Pickens et al. 1978; Cherry and Johnson 1982). These modifications leave many useful features of earlier models in the multisamplers, including the ability to sample over multiple depths at a single location, inexpensive and simple construction, quick sampling time, and the fact that only small volumes of water are needed to flush the sampling tubes prior to collection of pristine samples (e.g., Pickens et al. 1978). Many examples exist of the use of terrestrial multilevel samples (e.g., Pickens 1981; Pickens and Grisak 1981; McClain et al. 1992), but the method used to install these samplers precludes their use in the estuarine or marine environment. Terrestrial samplers require well bores for their installation, but wells in unconsolidated submarine sands would collapse before multi-level samplers could be installed. Multisamplers are designed to be driven into the sediment without first drilling a well.

Although numerous methods have been developed to sample pore waters of estuarine and marine sediments, none are applicable to frequent sampling of sandy and permeable sediment. Water can be extracted from fine-grained sediment cores by compaction of the sediment in mechanical vises (so-called Rheeburg squeezers) and with centrifugation. Because sands are largely incompressible, neither of these techniques produce sufficient volumes of water from permeable sandy sediments for chemical and isotopic measurements. Pore water can be collected using peepers, which consist of polycarbonate plates with ports 1 cm deep (Hesslein 1976). The ports are filled with degassed and deionized water, and then covered with semipermeable membranes to allow diffusive mixing of pore-water solutes. Peepers typically require several weeks to equilibrate with the pore water, limiting their usefulness for studies of variations in pore-water compositions over short time intervals such as may occur in permeable sediment (Boudreau et al. 2001). Peepers are generally < 50 cm long, and the membrane may tear in coarse-grained sediment. Multilevel well points have been developed for work in unconsolidated reef sediments (Sansone et al. 1988; Falter and Sansone 2000). Reef well points were initially made of 3.2 cm diameter stainless steel tubing but subsequently used schedule 80 PVC (Falter and
Sansone 2000). The PVC well points are less expensive and have the capability of collecting more samples than the stainless steel well points, but they are limited in their depths to ~ 70 cm below the sediment–water interface.

DESCRIPTION OF CONSTRUCTION, DEPLOYMENT, AND SAMPLING OF MULTISAMPLERS

Construction

Multisamplers are constructed of standard 1 ½" (3.8 cm) ID schedule 80 PVC pipe (Table 1). The initial step in constructing the multisamplers is to build the sampling ports and lead the tubing through the length of the PVC pipe. The multisamplers described here have eight ports at various distances along the length of the pipe (Fig. 1). Spacing of the ports can be customized for any sampling program restricted only by the size of the port, which as described here is 5.7 cm long. The ports spiral around the outside of the pipe by being offset from the ports above and below by 90° (Fig. 1). This arrangement retains more strength of the PVC pipe and allows water to be extracted from different sections of the sediment column.

Each port is fabricated by first drilling a ¼" diameter hole into the sides of the pipe. The holes are then modified by tilting the drill to an angle of approximately 30° to the PVC pipe (Fig. 2). The angle increases the size of the opening in the tube, prevents the tubing from being kinked as it is led up the inside of the PVC pipe, and increases the surface area for the tubing to be glued to the PVC pipe. Two additional ¼" holes are drilled ~ 3 inches below the top of the pipe in order to install an extraction cable. Once all holes have been drilled, ⅜" OD (¼" ID) black (photo-resistive) flexible PVC tubing is fed through the ports. The tubing is pulled to the top of the pipe with a stiff wire attached to the tube and led out the top of the pipe (Fig. 1). The tubing is attached to the sides of the ports with standard PVC cleaner and glue. The tubing that extends from the port (several centimeters) is taped to the PVC pipe immediately after the glue is applied in order to apply pressure and to ensure a strong joint. After the glue dries (~ 10 minutes), the excess tubing is cut flush with the surface of the pipe with a sharp knife. With a good bond, the PVC glue is sufficiently strong that the tubing cannot be separated from the port.

After the tubing is glued to the PVC pipe, the size of the ports is increased to expand the surface area from which pore water can be extracted (Fig. 3). The holes are enlarged with a trim router and a ¼" carbide straight bit is used to rout grooves 2 mm deep into the sides of the PVC pipe in a pattern as shown in Figures 1 and 3. The grid of channels allows water to be collected from a surface area of ~ 13.3 cm² with water flowing across the horizontal channel to the port. The length of the grooves is 5.7 cm, although shorter and wider grooves could be used to decrease the spacing of the ports. The ports are covered with 210 μm polypropylene mesh screening material which is fastened to the pipe by a PVC patch (Fig. 3). The patch is fabricated from ½" diameter thin-walled PVC pipe with grooves cut with a trim router and a ⅛" carbide straight bit to match the port. The patch is glued to the PVC pipe with the screening material sandwiched between the pipe and patch. Small holes (~ ¼") are punched through all portions of the mesh covered by the patch to allow better adhesion of the pipe, patch, and screening material. The sandwich of PVC pipe, screening material, and patch is clamped using hose clamps until the glue dries. The screening material is sufficiently strong that none was torn during 28 deployments of multisamplers in Florida estuaries.

Once the ports have been constructed and the tubing installed, the remaining parts of the multisamplers can be attached to the PVC pipe (Fig.
1. The extraction cable consists of an ~ 14" length of ⅛" coated steel cable that is fastened in a loop with a standard aluminum ferrule (Fig. 2). Shrink tubing can be installed over the crimped connection to reduce corrosion of the cable with exposure to salt water. The bottom of the multisamplers consists of a solid PVC tip, which is beveled to a point (Fig. 1).

Deployment

Multisamplers are driven into the sediment with a standard fence-post driver. The driver is a heavy metal tube with an inside diameter slightly larger than the outside diameter of the PVC pipe. Multisamplers can be installed in deep water by extending their length by taping couplers and additional sections of schedule 80 PVC to the top of the multisamplers. Prior to being driven into the sediment, all tubes are completely filled with lagoon water in order to remove air bubbles. Bubbles clog the tubes and prevent pore water from being pumped. Once the tubes are filled, they can be plugged with small plastic caps to prevent exchange with the pore water. The multisamplers are easily driven into unconsolidated sediment using this technique, but cannot be driven past consolidated material. At several locations in the Banana River Lagoon, the multisamplers could not be driven to their full lengths, because they encountered consolidated material, presumably the Anastasia Formation, a Pleistocene coquina, buried under only a few tens of centimeters of unconsolidated sediment.

While deploying the multisamplers, additional tubing is attached to the ends of the tubing that exit the Tee fitting (Fig. 1). The length of the additional tubing depends on water depth, but needs to be sufficiently long to allow the tubing to extend into the boat. The tubing is pumped with a peristaltic pump at rates up to ~1 ml/s. The flow rate is determined by the pump being used, and we found that any individual tube could provide water over the complete operational range of our pumps. The optimum pumping rate is rapid enough to collect and processes samples without having excess water drawn from the sample depth. The optimum pumping rate thus depends on the permeability of the sediment, the solute to be measured, and the method required for its sampling and preservation.

During sampling, pore water is pumped into a small plastic bucket and monitored continuously for oxygen concentration, conductivity, and temperature using portable field equipment. Once values stabilize, it is assumed that all lagoon water has been flushed from the tubing and pore water has reached the surface. Oxygen concentration is a particularly good indicator because of the low oxygen concentration in pore water, but temperature and conductivity also can be useful, depending on their differences in lagoon and pore water. Once the chemical parameters stabilize, samples are collected and preserved.

Examples of Pore-Water Profiles

Profiles of oxygen and Cl⁻ concentrations from sampling station BRL2 in the Banana River Lagoon, Florida, provide examples of solute concentration profiles that can be obtained from multisamplers (Fig. 4). The oxygen concentrations were measured in the field using a YSI model 55 portable field meter, and the Cl⁻ concentrations were measured in the laboratory using standard AgNO₃ titration. At BRL2, all eight ports yielded water when pumped. In other locations (not shown) some ports would not yield water during pumping. We suspect the ports that would not yield water were located in low-permeability layers, possibly in clay-rich zones.
With the exception of the upper sample in BRL2, the oxygen concentration of all samples is less than 1 mg/kg (Fig. 4). Although the nonzero concentrations of oxygen could indicate that there is not complete microbial reduction of the oxygen in the pore water, more likely the oxygen originates from atmospheric contamination during sampling because the sample bucket was open to air. Accurate measurements of oxygen concentrations will require measurements in a closed container. The uppermost sample has an oxygen concentration that is nearly an order of magnitude lower than the overlying water column, however, indicating that little to no estuary water is drawn into the tubing during sampling. This result suggests that sampled water flows horizontally along sediment bedding planes at the depth of the sampling port. Horizontal flow paths are more likely than vertical ones because lateral permeability commonly is greater than vertical permeability in unconsolidated sediment.

Chloride concentration of pore water from the uppermost port is identical to that in the overlying water column (Fig. 4). The concentration decreases from 412 to 359 mM at a depth of 50 cm below the sediment–water interface and then increases to 434 mM in the deepest sample collected. These variations in Cl⁻ concentrations with depth appear to relate to the hydrologic system in the region, including pressure-induced ground-water flow and mixing with the overlying water column (Martin et al. 2002). These variations, when compared with low but relatively uniform oxygen concentrations, further suggest that there is little mixing between the sample ports.

Although volumes of water pumped from each port were not measured, all ports that yielded water could be pumped until all sampling bottles were filled. Although the multisamplers can provide an essentially unlimited supply of water, it is important to limit the amount of extracted water to minimize vertical movement of the water. Nonetheless, the large amount of water allowed a full suite of additional solute concentrations and isotope ratios to be measured, including the major-element and minor-element concentrations, nutrient concentrations, δ¹⁸O and δD values, ⁸⁷Sr/⁸⁶Sr ratios, and activities of ²²²Rn and ²³³,²³⁴,²³⁶,²³⁸Ra (Martin et al. 2002). The ability to make a variety of measurements on pore-water samples is important to allow chemical modeling of the shallow pore waters and provide natural tracers to identify the origins of the water. Such origins could come from upward flow out of fresh-water aquifers or from downward mixing from the overlying water column (e.g., Bokuniewicz 1992; Burnett et al. 2002).

Multisamplers are inexpensive, versatile, and simply constructed tools for collecting pore water from shallow permeable sediments. Although they were developed to collect pore water from estuaries, they could also be used in fresh-water systems wherever sediment is sufficiently permeable, including possibly lakes and streams. The ease of construction and inexpensive nature allow adaptation of the tools to many different environments and to specific problems. For example, port spacing can easily be changed to collect samples at depths of interest. The surface areas and configurations of the ports can be altered to increase ease of extraction of water or to decrease the spacing between ports. Using multisamplers with other methods of collecting pore waters, such as cores and peepers, will provide the best control on concentration gradients.

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