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Hydrogeology and geochemistry of near-shore submarine groundwater discharge at Flamengo Bay, Ubatuba, Brazil

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Abstract

Near-shore discharge of fresh groundwater from the fractured granitic rock at Flamengo Bay, Ubatuba, Brazil, is strongly controlled by the local geology. Freshwater flows primarily through a zone of weathered granite to a distance of 24 m offshore. In the nearshore environment this weathered granite is covered by about 0.5 m of well-sorted, coarse sands containing pore water with sea water salinity, with an abrupt transition to much lower salinity once the weathered granite is penetrated. Further offshore, low-permeability marine sediments contain saline porewater, marking the limit of offshore migration of freshwater. Freshwater flux rates based on tidal signal and hydraulic gradient analysis indicate a fresh submarine groundwater discharge of 0.17–1.6 m^3/day per m of shoreline. Dissolved inorganic nitrogen and silicate are elevated in the porewater relative to seawater, and appeared to be a net source of nutrients to the overlying water column. The major ion concentrations suggest that the freshwater within the aquifer has a short residence time. Major element concentrations do not reflect in situ alteration of the granitic rocks, possibly because the alteration occurred prior to development of the current discharge zones, or because of large volumes of water discharge in this high rainfall region.

Keywords: submarine groundwater discharge; porewater geochemistry; nutrient fluxes

1. Introduction

While there has been growing interest over the last two decades in quantifying the discharge of groundwater to the coastal zone, the majority of studies have been carried out in aquifers consisting of unlithified sediments or in karst environments. This study is part of an intercomparison experiment that examines a range of techniques used to quantify submarine groundwater discharge (SGD) in a fractured-rock aquifer environment. This is a difficult environment to evaluate due to the spatial variability in aquifer properties resulting from the variability in the spacing, aperture, and interconnectedness of the fractures. While the intercomparison experiment examines SGD on a variety of scales, the work reported on here quantifies SGD on the small scale of a beach transect in the near-shore region where much of the discharge is expected to take place. Previous SGD studies (for example, Harvey and Odum, 1990; Vanek, 1993; Nuttle and Harvey, 1995; Staver and Brinsfield, 1996; Robinson, 1996) have been carried out on a small scale (tens to hundreds of meters), while previous SGD intercomparison experiments (Burnett et al., 2002; Burnett et al., 2006; Martin et al., 2007) have examined SGD on multiple scales, including the local scale.

The granitic rocks of the study area are representative of the extensive Pre-Cambrian shield region of eastern Brazil.

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Groundwater occurs in fractures in the granitic and metamorphic rocks of the area. Not a great deal is known about the groundwater in the fractured bedrock since it is not used to a significant degree as a resource. There is some utilization of localized springs related to major fractures. The region is one of the highest rainfall (2000–4000 mm/year) regions of Brazil (Rebouças, 2002) which means recharge is likely to occur readily. Rainfall was relatively light (13 mm in 7 days, based on local weather station data) during the period of this study which was conducted towards the beginning of the rainy season. SGD would most likely be greater towards the end of the rainy season.

Understanding SGD on this small scale should provide insight into scaling effects when compared to data collected on the much larger scale of some of the geochemical tracer studies (Burnett et al., 2006; this issue) that were being carried out at the same time. This study also documents groundwater discharge in a geologic environment that was poorly documented previously. The location of the field area is given in Fig. 1. Enseada de Flamengo (Flamengo Bay), near Ubatuba, São Paulo state, is the location of the marine laboratory of the University of São Paulo. The beach at the marine laboratory was selected for in-depth studies because of the presence of weathered bedrock and sediment above the fractured granite; this granular material permitted the installation of wells and equipment that would not have been possible to install in fresh, fractured bedrock.

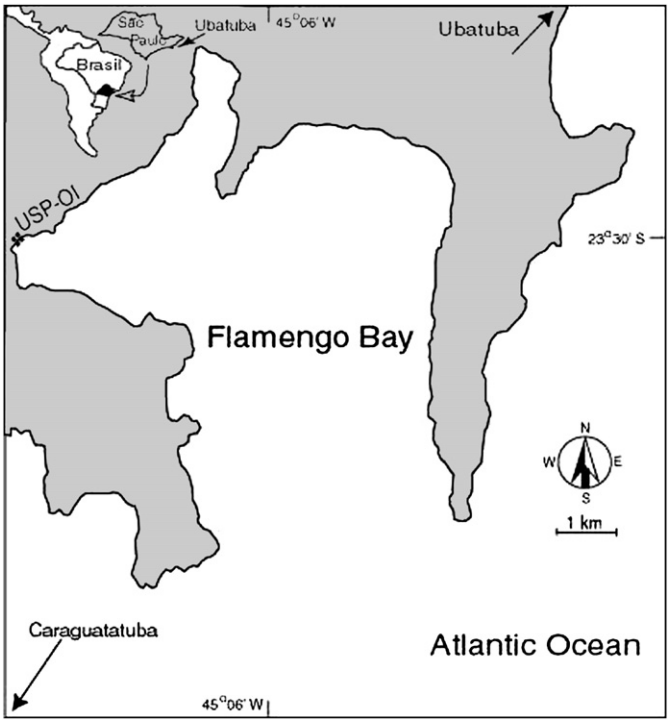

Fig. 1. Map showing location of field site at the University of São Paulo Oceanographic Institute (USP-OI).

2. Methods

2.1. Piezometer installation

Within this nearshore beach site, wells were installed in two stages. Nine small-diameter (5 cm), shallow wells were installed by a Brazilian consulting company (Gea) in October 2001. In November 2003, during our intercomparison experiment, eight temporary piezometers were installed for the purpose of collecting pore waters for (bio)geochemical analysis: four multi-level piezometers capable of providing access to discrete pore water depths down to 2.3 m (MS-2, -3, -4, -5) and two very small diameter (1-cm) vapor-probe wells (WH-1, -2). These wells are described in more detail in Section 2.7.

Wells installed in 2001 are labeled well 0, A1, A2, A3, B1, B2, B3. Two of the wells installed in the inter-tidal zone were subsequently destroyed prior to the start of the 2003 intercomparison experiment. The locations of the remaining seven wells are shown in Fig. 2. Well 0 was completed at a depth of 5.0 m below ground surface (bgs), while the depth of completion of the remaining wells ranged from 0.7 to 2.1 m bgs. During the installation of well 0, 3 m of saturated, weathered granite were encountered; most of the groundwater is expected to flow through this sandy, decomposed granite since it is expected to be more permeable than the underlying fresher granite. These wells were hand-augered and completed with perforated PVC pipe with plastic screen clamped around the perforated section to minimize seepage of sediment into the wells. During installation of the onshore wells (wells 0, A1 and B1), augering had to stop when geologic materials too hard to auger through by hand were encountered. For the wells completed offshore, all well-casings extended well above the high tide level.

2.2. Coring

Sediment cores were collected near the two vapor-probe wells (WH1 and WH2; see Fig. 2 for locations relative to other

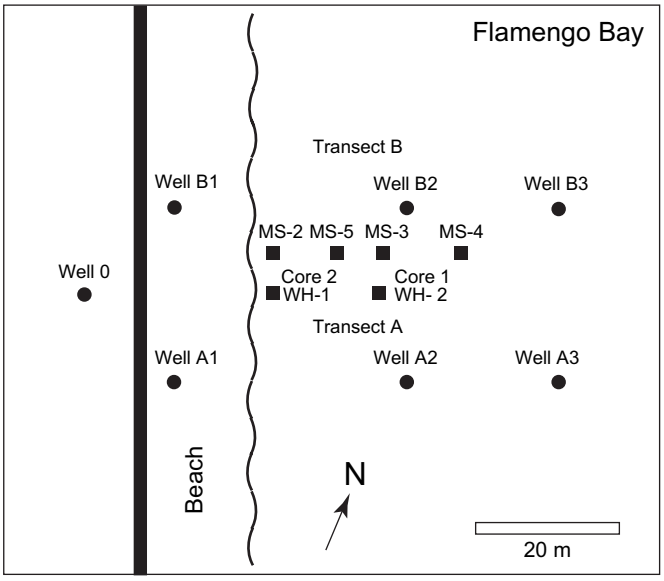

Fig. 2. Location map for field installations (Transect A with A-wells, Transect B with B-wells, piezometer and coring sites) at USP-OI at Flamengo Bay.