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Characterization of the porosity distribution in the upper part of the karst Biscayne aquifer using common offset ground penetrating radar, Everglades National Park, Florida

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SUMMARY

The karst Biscayne aquifer is characterized by a heterogeneous spatial arrangement of porosity and hydraulic conductivity, making conceptualization difficult. The Biscayne aquifer is the primary source of drinking water for millions of people in south Florida; thus, information concerning the distribution of karst features that concentrate the groundwater flow and affect contaminant transport is critical. The principal purpose of the study was to investigate the ability of two-dimensional ground penetrating radar (GPR) to rapidly characterize porosity variability in the karst Biscayne aquifer in south Florida. An 800-m-long GPR transect of a previously investigated area at the Long Pine Key Nature Trail in Everglades National Park, collected in fast acquisition common offset mode, shows hundreds of diffraction hyperbolae. The distribution of diffraction hyperbolae was used to estimate electromagnetic (EM) wave velocity at each diffraction location and to assess both horizontal and vertical changes in velocity within the transect. A petrophysical model (complex refractive index model or CRIM) was used to estimate total bulk porosity. A set of common midpoint surveys at selected locations distributed along the common-offset transect also were collected for comparison with the common offsets and were used to constrain one-dimensional (1-D) distributions of porosity with depth. Porosity values for the saturated Miami Limestone ranged between 25% and 41% for common offset GPR surveys, and between 23% and 39% for common midpoint GPR surveys. Laboratory measurements of porosity in five whole-core samples from the saturated part of the aquifer in the study area ranged between 7.1% and 41.8%. GPR estimates of porosity were found to be valid only under saturated conditions; other limitations are related to the vertical resolution of the GPR signal and the volume of the material considered by the measurement methodology. Overall, good correspondence between GPR estimates and the direct porosity values from the whole-core samples confirms the ability of GPR common offset surveys to provide rapid characterization of porosity variability in the Biscayne aquifer.

The common offset survey method has several advantages: (1) improved time efficiency in comparison to other GPR acquisition modes such as common midpoints; and (2) enhanced lateral continuity of porosity estimates, particularly when compared to porosity measurements on 1-D samples such as rock cores. The results also support the presence of areas of low EM wave velocity or high porosity under saturated conditions, causing velocity pull-down areas and apparent sag features in the reflection record. This study shows that GPR can be a useful tool for improving understanding of the petrophysical properties of highly heterogeneous systems such as karst aquifers, and thus may assist with the development of more accurate groundwater flow models, such as those used for restoration efforts in the Everglades.

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1. Introduction

The Biscayne aquifer provides water for approximately 6 million people in Miami-Dade, Broward, and southern Palm Beach Counties (McPherson et al., 2000). Increases in the population of Florida since 1970 average between 280,000 and 320,000 persons per year; the population is projected to increase by 2.5 million during the next 25 years (Murley et al., 2006). Population growth will continue to deplete the supply of groundwater in south Florida, where the Biscayne aquifer is a sole source aquifer dependent on surficial recharge from the Everglades and the Lake Okeechobee drainage basin (Fish and Stewart, 1990). In addition, restoration

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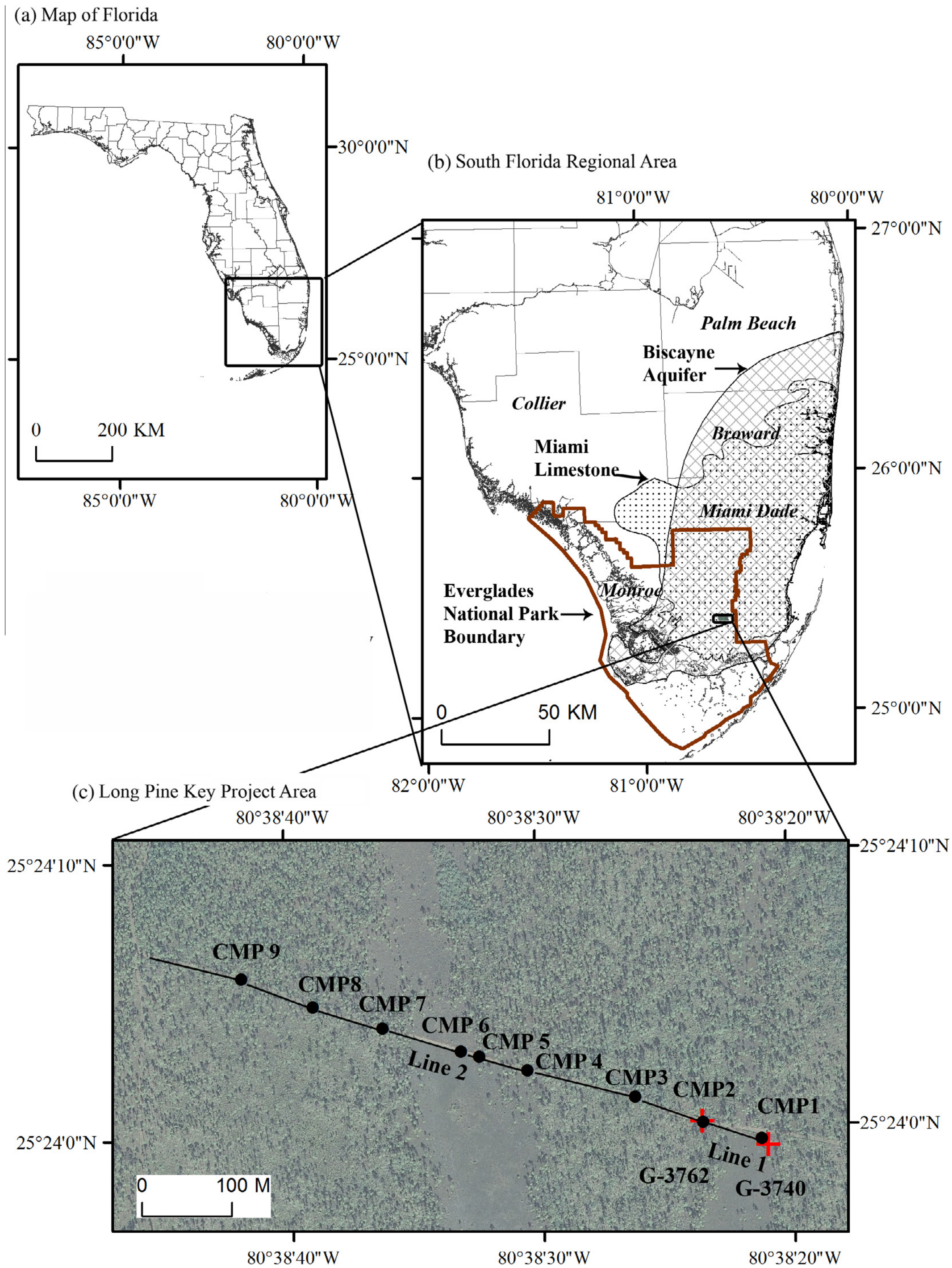

Fig. 1. (a) Map of Florida showing the regional area in relation to the state, (b) map of the south Florida regional area showing the areal extent of the Biscayne aquifer (crosshatched area and label) (U.S. Geological Survey, 2003), Miami Limestone (solid black outline and label) modified from Dicken et al. (2005) and the boundary of Everglades National Park (solid brown outline) modified from Malget (2002) in relation to the south Florida regional area, (c) aerial photograph of the Long Pine Key Nature Trail study area (http://www.labins.org) showing the location of the field site, including USGS test corehole G-3740 and test borehole G-3762 (symbolized by red crosses), Line 1 and Line 2 common offset survey transects, and common midpoints CMP1 through 9 (symbolized by black filled circles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of the Everglades may markedly affect the hydrology of this critical natural resource.

The Biscayne aquifer has a wedge-shaped volume underlying an area of approximately 7770 km^2, and reaching maximum depths of 61 m near the eastern coast of south Florida (Klein and Sherwood, 1961; Light and Dineen, 1994) (Fig. 1a and b). The Biscayne aquifer is mainly composed of two lithostratigraphic formations dominated by eogenetic karst limestone: the Miami Limestone and the Fort Thompson Formation (Perkins, 1977; Halley and Evans, 1983; Vacher and Mylroie, 2002). The Miami Limestone consists of two high-frequency cycles (HFC 5e and HFC 4) that are assigned to Marine Isotope Stage (MIS) 5e and MIS 7, respectively (Cunningham et al., 2006a,b, 2009). The base of the underlying Fort Thompson Formation is at or near the bottom of the Biscayne aquifer throughout much of its extent. In Miami-Dade County (Fig. 1b), the Fort Thompson Formation consists of multiple high-frequency cycles

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