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Prepared in Cooperation with Broward County Natural Resources Planning and Management Division

Integrating Seismic-Reflection and Sequence-Stratigraphic Methods to Characterize the Hydrogeology of the Floridan Aquifer System in Southeast Florida

Overview

The Floridan aquifer system (FAS) is receiving increased attention as a result of regulatory restrictions on water-supply withdrawals and treated wastewater management practices (fig. 1). The South Florida Water Management District's Regional Water Availability Rule[1], adopted in 2007, restricts urban withdrawals from the shallower Biscayne aquifer to pre-April 2006 levels throughout southeast Florida. Legislation adopted by the State of Florida requires elimination of ocean outfalls of treated wastewater by 2025. These restrictions have necessitated the use of the more deeply buried FAS as an alternate water resource to meet projected water-supply shortfalls, and as a repository for the disposal of wastewater via Class I deep injection wells and injection of reclaimed water. Some resource managers in Broward County have expressed concern regarding the viability of the FAS as an alternative water supply due to a lack of technical data and information regarding its long-term sustainability (Broward Water Resources Task Force, 2010).

The FAS is a regionally extensive, highly productive karst carbonate aquifer, consisting largely of limestone, dolomitic limestone, and dolomite, underlying the entire State of Florida and parts of adjacent states. The FAS lies beneath the main water supply for southeast Florida, the Biscayne aquifer, and is separated from it by a confining unit many hundreds of feet thick (fig. 1). Within the FAS, the shallowest regionally extensive aquifer is the Upper Floridan aquifer (UFA), designated throughout most of southeast Florida as an underground source of drinking water (USDW)—a hydrologic regulatory boundary defined by the U.S. Environmental Protection Agency. Beneath the UFA and separated by hundreds of feet of mostly confining, lower permeability rock is the regionally extensive Lower Floridan aquifer (LFA). Salinity generally increases with depth in the FAS. In southeast Florida, the UFA tends to be brackish, and the salinity in the LFA is generally no higher than seawater (Reese, 1994; Miller, 1990).

The water-supply potential of the FAS in southeast Florida is poorly understood. Because it is known to be extensively brackish or saline, use of the FAS for water supply requires dilution with fresher water, or desalination, for example, by

[1] *http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/ waterconservationplan.pdf.*

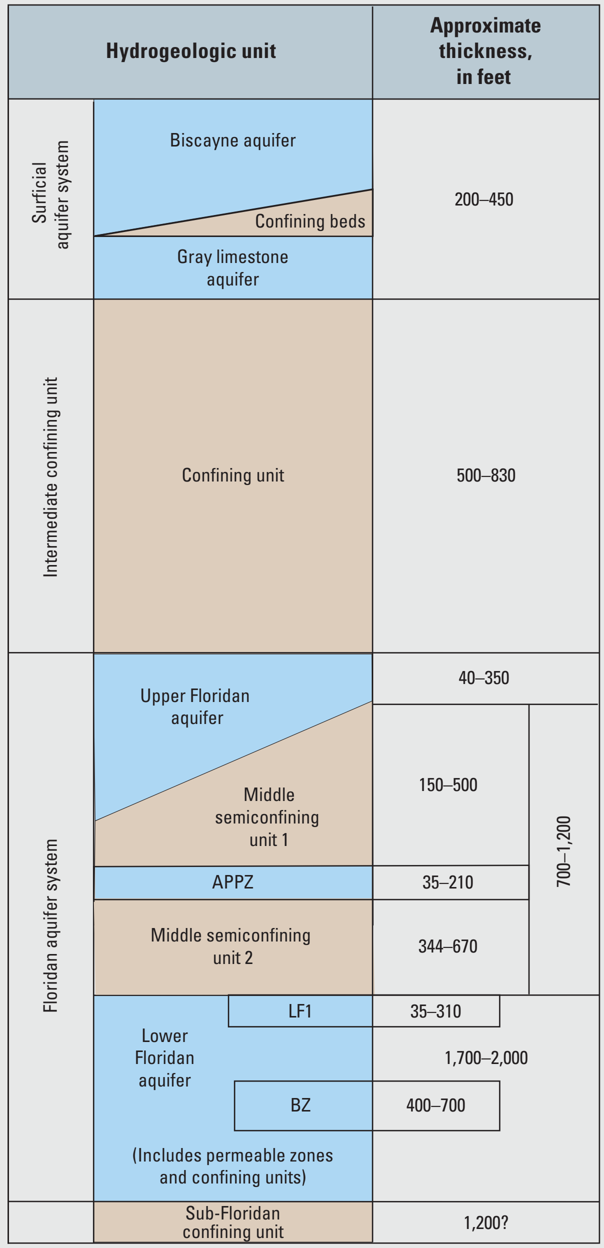


Figure 1. Generalized hydrogeologic units in southeast Florida and approximate thicknesses. Modified from Reese and Cunningham (2013).

EXPLANATION

APPZ **Avon Park permeable zone**

LF1 **Uppermost major permeable zone of the Lower Floridan aquifer**

BZ **Boulder Zone**

reverse osmosis. An alternative use of the FAS for water supply purposes is aquifer storage and recovery (ASR), in which fresh water is injected into a confined aquifer for storage and later withdrawn. Optimal application of ASR requires knowledge of the presence of extensive permeable zones and their confinement, suitable water quality, and an appropriate source-water supply. ASR has been applied in several locations in the FAS in southeast Florida, but only with limited success (Reese, 2002; Reese and Alvarez-Zarikian, 2007).

Limited information also exists regarding the potential for use of the FAS as a storage zone for injected treated wastewater. Wastewater injection may be accompanied with the risk of unpredicted transport of treated wastewater from the injection zone. This migration of buoyant wastewater has been documented at seven wastewater treatment and injection facilities in Miami-Dade and Broward Counties (Maliva and others, 2007).

Problem Statement, Approach, and Benefits

Sustainable development and management of the FAS for water supply is uncertain because of the potential risk posed by structural geologic anomalies (faults, fractures, and karst collapse structures) and knowledge gaps in the stratigraphy of the system (Cunningham and Walker, 2009; Cunningham and others, 2012; Reese and Cunningham, 2013). The integration of seismic-reflection and borehole data into an improved geologic and hydrogeologic framework will provide a better understanding of the structural and stratigraphic features that influence groundwater flow and contaminant transport. This approach offers the opportunity to (1) improve existing groundwater-flow models, (2) evaluate the risk of upward migration of saline groundwater or treated wastewater, (3) aid in water-utility site selection, and (4) provide reasonable assurance to stakeholders and regulators that projects are scientifically defensible.

Recent and Ongoing U.S. Geological Survey Studies in Southeast Florida

To meet the needs of the Broward County water managers of the FAS, the U.S. Geological Survey (USGS) and Broward County in July 2012 commenced a 3.5-year study to refine the geologic and hydrogeologic framework of the FAS in Broward County. In part, this effort is being accomplished by acquisition, processing, and interpretation of new seismic-reflection data along 60 miles of canals in Broward County (fig. 2). The new seismic-reflection data will be integrated with existing Hillsboro Canal and northeast Miami-Dade County seismic-reflection profiles (fig. 2), and data from nearby FAS wellbores. The new study by the USGS will include mapping the geologic, hydrogeologic, and seismic-reflection framework of the FAS, and identifying structural and stratigraphic characteristics that would promote or preclude the successful use of the FAS as an alternate water supply or wastewater repository. The study will provide important new information to FAS decision-making stakeholders.

Previous relevant USGS FAS studies in southeast Florida include an investigation by Reese and Cunningham (2013) in Broward County that used borehole data acquired at 33 sites, including a new test corehole alongside of the Hillsboro Canal, and seismic-reflection data acquired in the Hillsboro Canal (figs. 2 and 3), to increase the resolution of the geologic and hydrogeologic framework of the FAS. The top of the UFA was found to be not far below a sequence-stratigraphic boundary (fig. 3) identifiable in core, geophysical well logs, and seismic-reflection data. Other notable recent studies of the FAS in southeast Florida include Reese and Richardson (2008), Cunningham and Walker (2009), and Cunningham and others (2012), which have provided new information on the possible influence of geologic structures on groundwater flow in the FAS and the hydrogeologic framework of the FAS.

Integration of Seismic-Reflection Data and Sequence Stratigraphy to Characterize Hydrogeology

The integrated use of marine seismic-reflection and sequence-stratigraphic methods can be used to refine the geologic and hydrogeologic framework of the FAS in southeast Florida (Cunningham and others, 2012). Marine seismic-reflection methods involve the acquisition, processing, and interpretation of seismic-reflection data. Marine seismic-reflection data are acquired using a survey boat that tows a sound source (a percussive device) and a cable containing multiple sound receivers (fig. 4). As the survey boat moves through the water, sound waves or oscillations of pressure are induced by the sound source and transmitted at regularly timed intervals through the water column and into the subsurface rock. When the sound waves travel through the subsurface and encounter a change in rock density, part of the sound energy is reflected upward to the sound receivers and recorded at the survey boat (fig. 4). In the laboratory, the traveltime of the sound waves from the energy source to the receivers is used to assemble the sound-wave amplitudes into two-dimensional profiles (for example, fig. 3). Sonic-borehole geophysical data available for many FAS utility wells in Broward County will be used to produce synthetic-seismic data (fig. 5) that will assist in correlation of well data to seismic-reflection profiles. Correlation of seismic-reflection data with borehole hydrogeologic, geologic, and geophysical data acquired from test wells near the seismic-reflection profiles will enable mapping of hydrogeologic units and geologic features, such as sequence-stratigraphic units, folds, and faults (fig. 3).

Sequence stratigraphy is a method of geologic analysis in which sedimentary deposits are divided into three-dimensional bodies of rock (sequences) and separated by surfaces of erosion or non-deposition, called unconformities, at their tops and bases. The fundamental mappable elements of the sequences are layers of sedimentary deposits (beds and bedsets), repeating patterns of sedimentary layers (depositional cycles), and unconformities. The careful characterization and mapping of sequences

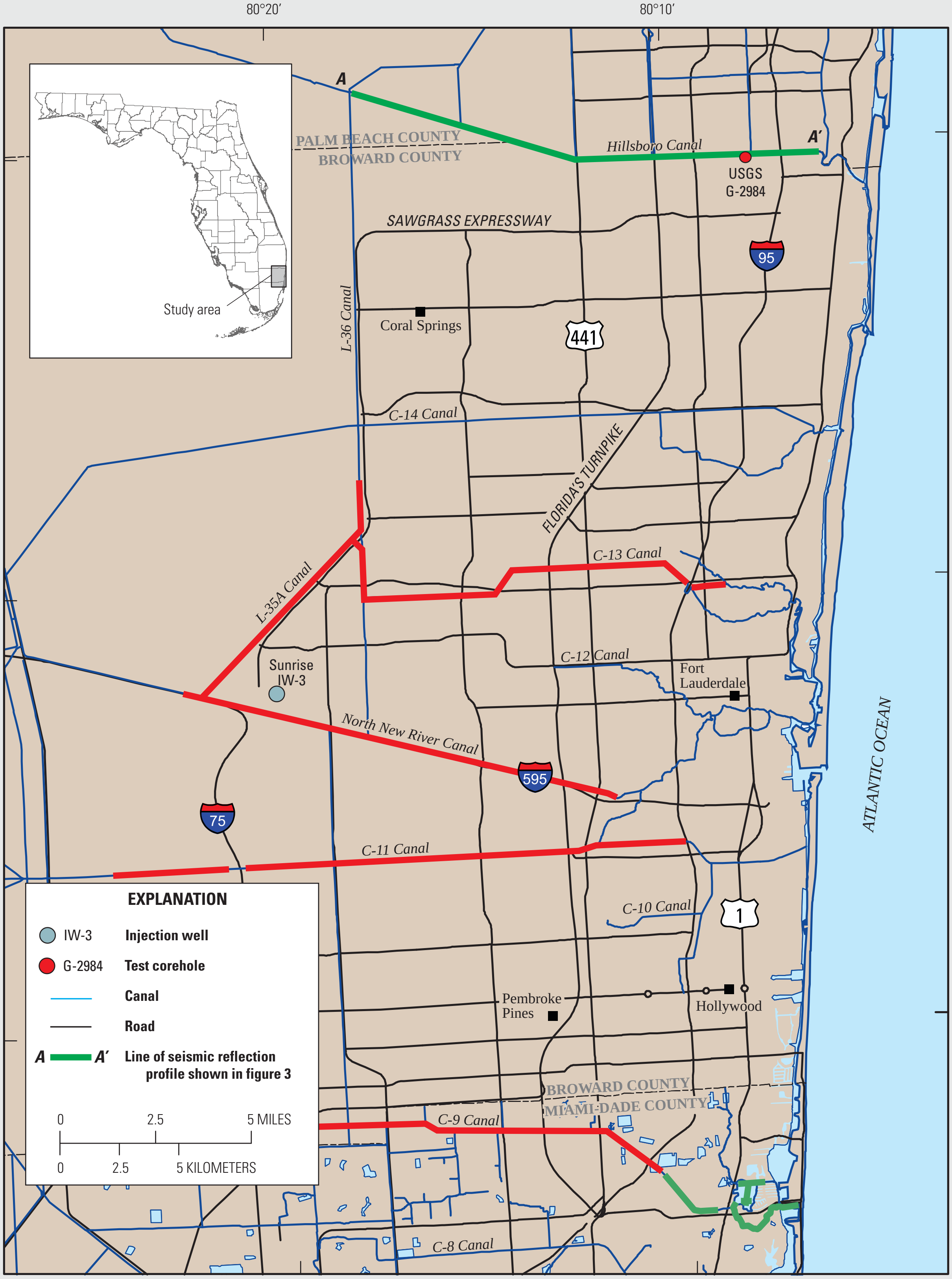
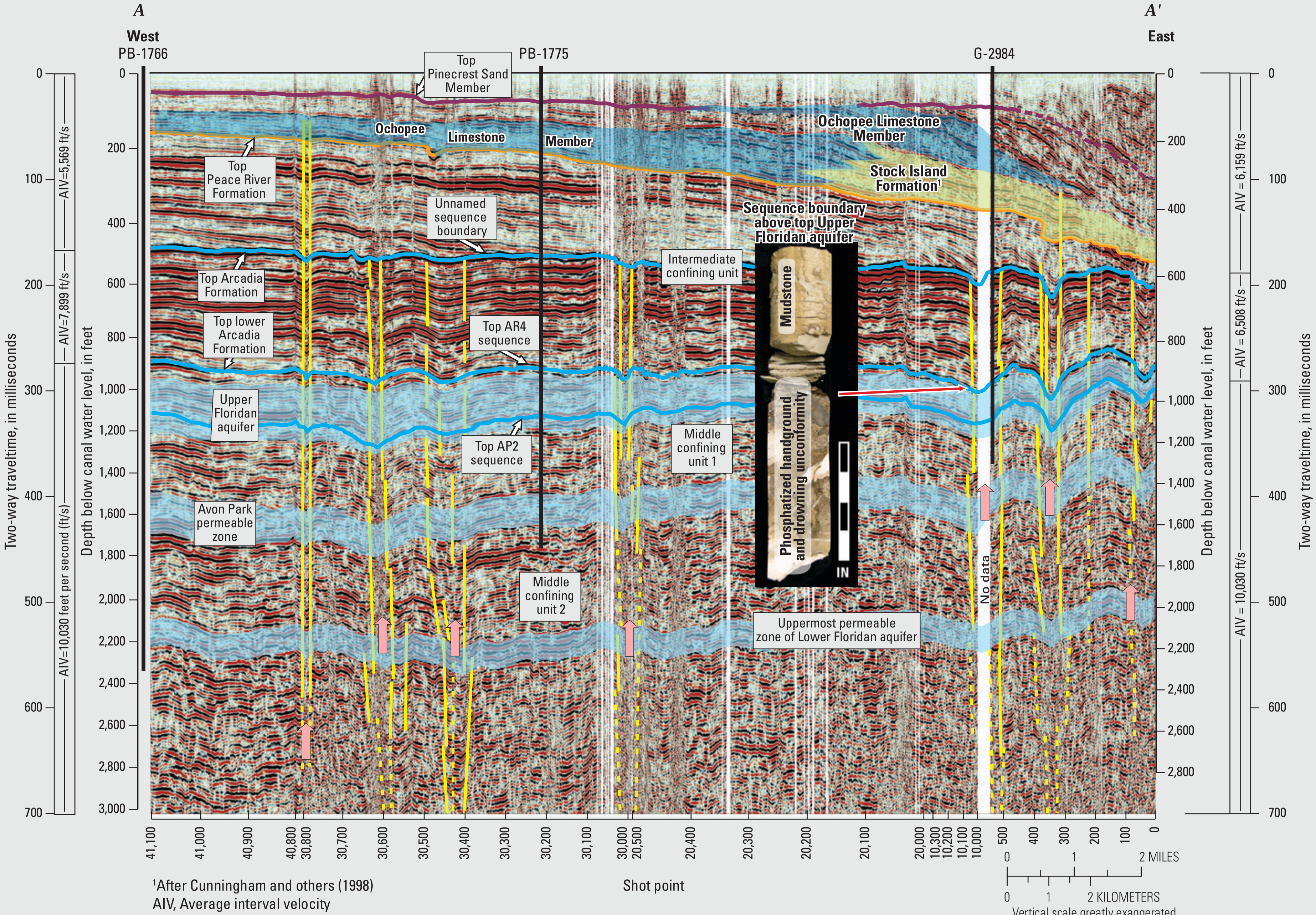


Figure 2. Marine seismic-reflection lines proposed (red lines) and recently acquired (green lines) for use in a new cooperative study between the U.S. Geological Survey and Broward County that commenced in July 2012.



[1]After Cunningham and others (1998)
AIV, Average interval velocity
AP, Avon Park
AR, Arcadia

Figure 3. Interpreted seismic-reflection profile along Hillsboro Canal in Broward County. One aquifer unit and two permeable zones of the Floridan aquifer system are shown with light blue shading. Blue and orange lateral traces indicate important seismic reflectors. Yellow vertical lines indicate faults. The seven pink arrows indicate karst collapse structures (fig. 2). The photo of the core sample shows a prominent sequence-stratigraphic boundary not far above the top of the Upper Floridan aquifer at the Hillsboro test corehole G-2984. LF1 is the uppermost major permeable zone of the Lower Floridan aquifer (fig. 1). Modified from Reese and Cunningham (2013).

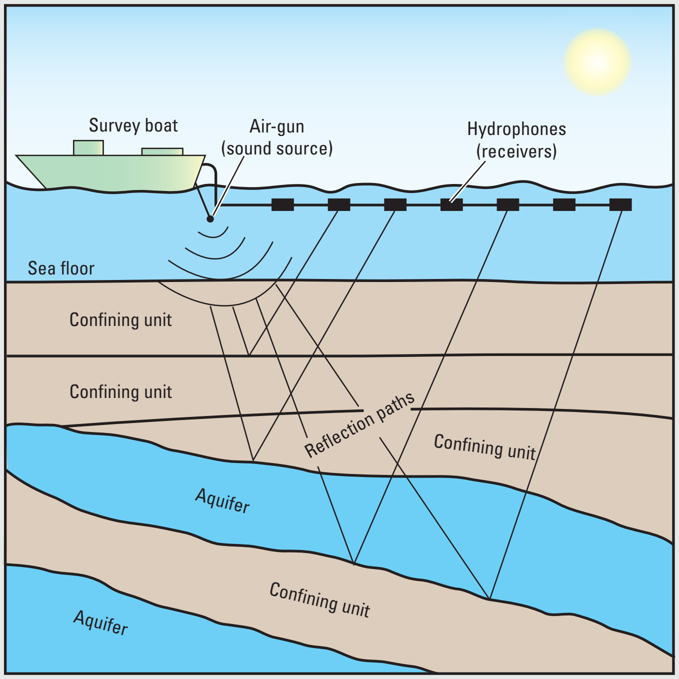


Figure 4. Conceptual diagram showing how marine seismic-reflection data are acquired.

is important in exercising this modern stratigraphic method. The geometric arrangement and physical characteristics of beds, bedsets, and depositional cycles, for example, is similar at any scale and thus they have a predictable setting in the subsurface. Mapping of the unconformities, which are usually regional in extent, provides a powerful tool for interpreting the spatial distribution of hydrogeologic parameters such as porosity and permeability within a body of rock that composes an aquifer. The unconformities that bound the surfaces of sequences commonly have a distinct signature on seismic-reflection profiles that facilitates the ability to confidently map them at the regional scale using seismic-reflection data (fig. 3). Sequence-stratigraphic methods have been used successfully to develop a high-resolution stratigraphic framework for the UFA in central Florida (Ward and others, 2003), as well as for the Biscayne aquifer in Miami-Dade County (Cunningham and others, 2006). Seismic-reflection and sequence-stratigraphic techniques that are coupled with existing borehole data offer improved resolution of subsurface geology and hydrogeology.

Structural and Stratigraphic Features of the Floridan Aquifer System Identified in Southeast Florida

Structural and stratigraphic features, such as faults and groundwater-productive depositional facies, have been identified in the FAS in southeast Florida using seismic-reflection data and sequence-stratigraphic analysis, in conjunction with geologic and hydrogeologic data from test wells. Mapping of these features would be useful in future evaluations of the FAS as an alternate water supply or as a repository for treated wastewater.

Existing seismic-reflection data acquired in 2010 on the Hillsboro Canal in Broward County (fig. 3), provided a high-quality profile of the subsurface structure in the middle to upper part of the FAS (fig. 3), as well as seismic-reflection data acquired in Biscayne Bay and Atlantic Continental Shelf east of Miami-Dade County (Cunningham and Walker, 2009; Cunningham and others, 2012). Two types of structural features have been identified in these data that disrupt the continuity of carbonate rocks of the FAS and may produce areas of high vertical permeability: (1) high-angle to vertical tectonic faults that can extend over a horizontal distance of at least 10 miles (Cunningham and others, 2012), and (2) karst collapse structures up to approximately 3 miles in diameter with associated faults that are typically near vertical (fig. 3 and 6; Cunningham and others, 2012). The single seismic-reflection profile acquired on the Hillsboro Canal indicates multiple karst-collapse structures with associated faults within the carbonate strata of the FAS (fig. 3). The faults identified in southeast Florida may promote the vertical flow of groundwater across relatively low-permeability carbonate strata that separate aquifers and high-permeability zones of the FAS.

Faults observed on seismic-reflection profiles and fractures observed in borehole data from southeast Florida, where they are associated with karst collapse structures, have the potential to form vertical fluid-migration pathways through the rocks of the FAS. Thus, they could allow for upward movement of deeply injected, buoyant wastewater or ambient, saline groundwater into brackish, shallower zones used for water supply. This type of contamination of shallower zones within the USDW could result in higher water production costs associated with additional water-treatment methods or preclude the use of the shallower zones. However, using a refined hydrogeologic framework, informed by seismic-reflection data and sequence-stratigraphic analyses, the ability to evaluate or to predict hydrogeologic characteristics within the FAS could lead to its successful use as an alternative water supply.

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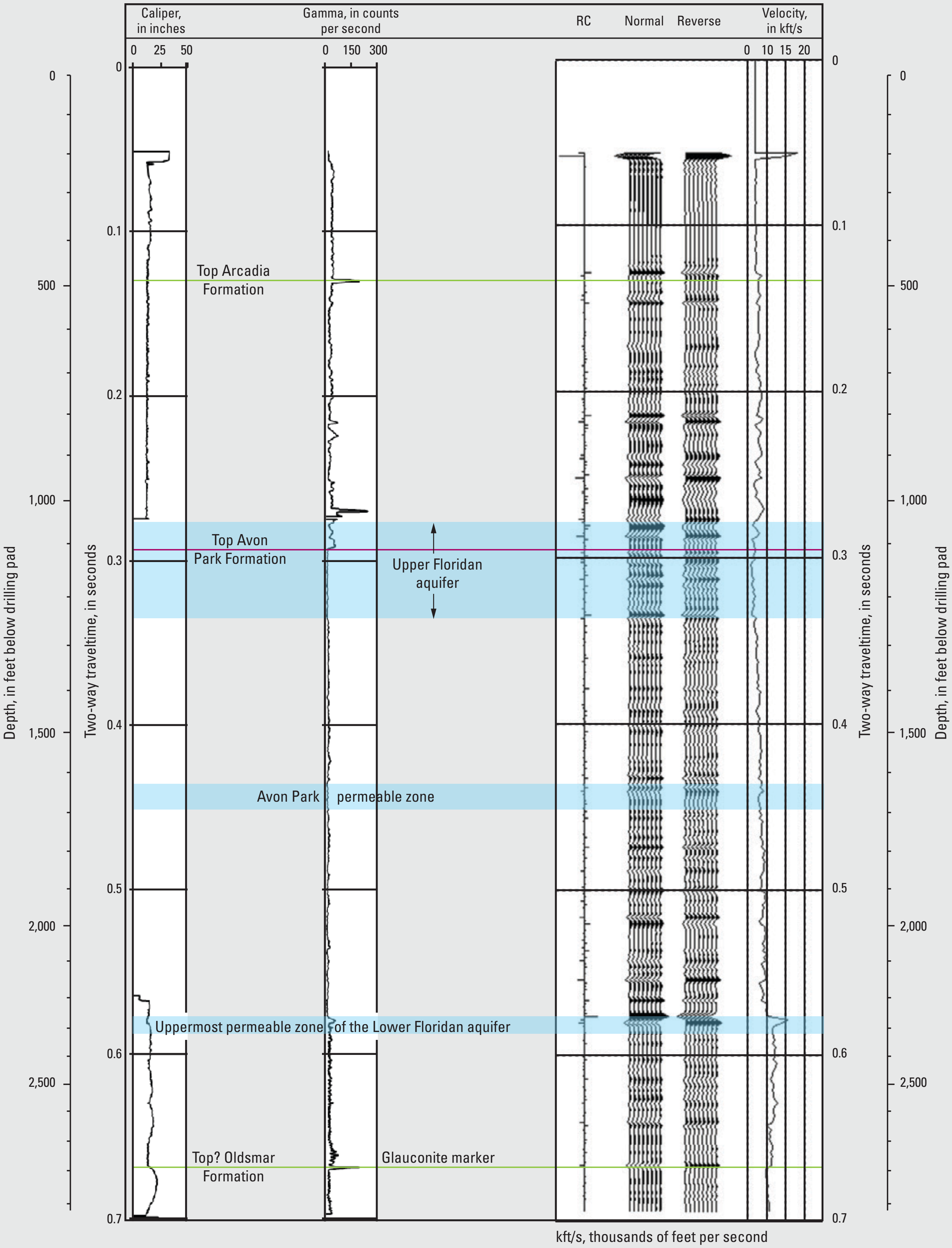

Figure 5. Borehole geophysical data acquired from the City of Sunrise Wastewater Treatment Plant IW-3 well in Broward County (fig. 2) and synthetic seismic-reflection data produced from borehole sonic geophysical data. Geophysical data shown are caliper, natural gamma ray, reflection coefficient (RC), normal polarity seismic-reflection synthetic wavelet traces, reverse polarity seismic-reflection synthetic wavelet traces, and borehole sonic-velocity log in thousands of feet per second (kft/s). Correlation of geologic and hydrogeologic units from borehole data to synthetic seismic-reflection data is shown.

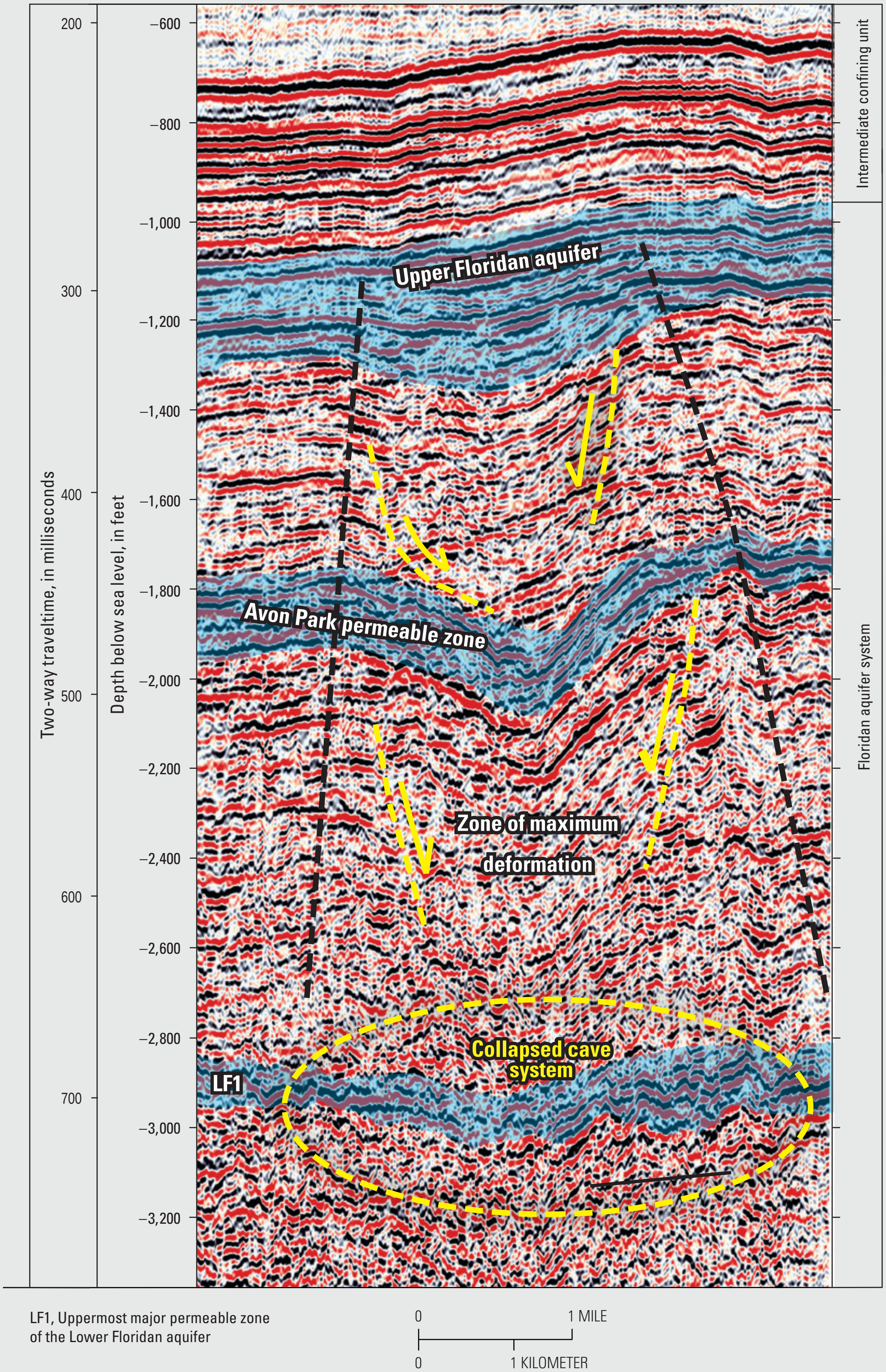

Figure 6. Interpreted seismic-reflection profile showing a large karst collapse structure in the Floridan aquifer system (FAS) located beneath Biscayne Bay in southeast Florida. This collapse structure is approximately 3 miles in width. Major possible faults (dashed yellow lines) that cross confining units have potential to provide a vertical pathway for migration of groundwater between permeable zones of the FAS. Modified from Cunningham and Walker (2009).

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