INT-006

Near-Surface, Marine Seismic-Reflection Data Define Potential Hydrogeologic Confinement Bypass in the Carbonate Floridan Aquifer System, Southeastern Florida

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Summary

Approximately 210 km of near-surface, high-frequency, marine seismic-reflection data were acquired on the southeastern part of the Florida Platform between 2007 and 2011. Many high-resolution, seismic-reflection profiles, interpretable to a depth of about 730 m, were collected on the shallow-marine shelf of southeastern Florida in water as shallow as 1 m. Landward of the present-day shelf-margin slope, these data image middle Eocene to Pleistocene strata and Paleocene to Pleistocene strata on the Miami Terrace. This high-resolution data set provides an opportunity to evaluate geologic structures that cut across confining units of the Paleocene to Oligocene-age carbonate rocks that form the Floridan aquifer system.

Seismic profiles image two structural systems, tectonic faults and karst collapse structures, which breach confining beds in the Floridan aquifer system. Both structural systems may serve as pathways for vertical groundwater flow across relatively low-permeability carbonate strata that separate zones of regionally extensive high-permeability rocks in the Floridan aquifer system. The tectonic faults occur as normal and reverse faults, and collapse-related faults have normal throw. The most common fault occurrence delineated on the reflection profiles is associated with karst collapse structures.

These high-frequency seismic data are providing high quality structural analogs to unprecedented depths on the southeastern Florida Platform. The analogs can be used for assessment of confinement of other carbonate aquifers and the sealing potential of deeper carbonate rocks associated with reservoirs around the world.

Introduction

Previous investigators have found it challenging to collect good quality, high-resolution seismic data that image the subbottom of the shallow-marine shelf in southeastern Florida and Florida Keys due to an extensive hard, water-bottom interface that has been found to greatly impede penetration of an acoustic signal. Warzeski et al. (1996) attributed poor-quality, water-gun, seismic-reflection data in this area to reverberations and multiples from the shallow, lithified seafloor, which obscured all but the strongest reflections and was not used in their published subsurface interpretations. More recently, boomer-sourced acquisition methods penetrated to an approximate depth of about 30 m (Reich et al., 2008) and captured subbottom geologic features. In a study area that overlaps with the area investigated by Reich et al. (2008), Banks et al. (2007) collected CHIRP data and imaged the contact between hard bedrock of Pleistocene age and soft sediment of Holocene age. The maximum depth of this contact shown by Banks et al. (2007) is about 10 m.

Acquisition of near-surface, high-frequency, marine seismic-reflection data, reported on herein, between 2007 and 2011 on the shallow-marine shelf of southeastern Florida provides a new perspective of the subsurface to depths of about 730 m below the seafloor. Acquisition has been successful in marine water depths as shallow as 1 m. This innovative near-surface, seismic-reflection technology could serve to drive new discoveries in the subsurface Cenozoic stratigraphic section of southern Florida.

The new seismic data set is being used to evaluate structures on the profiles that could produce vertical hydraulic bypass of confinement within the Paleocene to Oligocene carbonate rocks of the Floridan aquifer system (Reese and Richardson, 2008; Cunningham and Walker, 2009). There is an immediate need for a subsurface assessment because at some wastewater treatment plants fresh wastewater injected by disposal wells into a saline lower part of the Floridan aquifer system has migrated upward into a shallow brackish-water part of the aquifer system called the USDW (Maliva et al., 2007; Walsh and Price, 2010). A USDW is an underground source of drinking water and as designated by the U.S. Environmental Protection Agency is an aquifer containing water with a total dissolved solids concentration less than 10,000 mg/L. The detection of deeply injected wastewater in the USDW in southern Florida represents a risk to public health (Maliva et al., 2007; Walsh and Price, 2010). Density-driven buoyancy provides a forcing mechanism for the upward migration of injected wastewater (Dausman et al., 2010; Walsh and Price, 2010), because in southeastern Florida the native groundwater in the Floridan aquifer system is saline to brackish and non-saline, low density fluid comprises the injected, treated wastewater. Fractured confining strata separating deep and shallower water-bearing zones may be a vertical pathway for the upward migration of injected wastewater (Maliva et al., 2007). Alternatively, poor well construction could allow vertical migration of wastewater (Walsh and Price, 2010). The purpose of this study is to examine seismic-reflection data and evaluate the evidence for geologic structures on the

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southeastern part of the Florida Platform that could act as vertical passageways for upward fresh wastewater migration

Methods

From 2007 to 2011, about 210 km of towed-streamer, high-resolution, high-frequency, marine seismic-reflection data were acquired on the southeastern part of the Florida Platform in water depths that ranged from about 1 to 390 m. The profiles were collected in and near Biscayne Bay, above the Miami Terrace, and in canals of the southeastern Florida peninsula (Figure 1) mainly using the shallow-draft

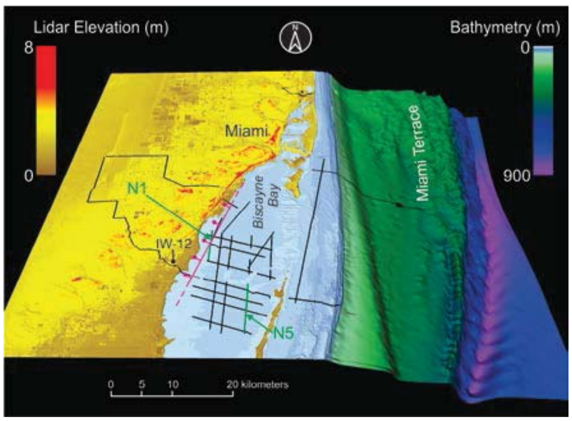

Figure 1: Map of Lidar land elevations and bathymetry showing locations of marine seismic-reflection profiles (black lines) acquired on peninsular and offshore southeastern Florida during 2007-2011. A normal fault (Figure 2) that intersects five profiles is shown as red line.

R/V T-Dragona. The seismic-reflection surveys were accomplished using a proprietary MARDAQ25™ digital-data acquisition system, an air-gun source array, and 24- or 48-channel hydrophone streamers. Typically, the speed of the R/V T-Dragona was 6 km/hour. The digital sampling rate was 4-10 kHz, shot spacing about 6-8 m, and record length was 1.0 second. Real-time navigational positions were acquired with a Trimble™ differential global positioning system (DGPS) receiver. Shot-point positions recorded offset distances from the DGPS antenna onboard the R/V T-Dragona to the streamer hydrophone groups and source array in the SEGY data headers. Post-cruise data processing was conducted by Velseis Pty. Ltd.™. Data processing included construction of a true amplitude and stack migration process. Interpretation was accomplished using Kingdom Suite SMT™ software for processed seismic profiles, and ROXAR RMS™ was used to augment and display some of the final interpretations.

A borehole sonic log from an onshore injection well (IW-12, Figure 1) was used to equate stacking velocities with semblance picks and create a set of filtered synthetic seismograms. The seismograms were correlated to lithostratigraphic and hydrostratigraphic units in the IW-12 borehole by comparing them to drill-cutting samples and a suite of borehole geophysical logs. Seismograms were then used to ground truth seismic-reflection stratigraphy.

Structural systems

Two types of structural systems identified on seismic profiles breach confinement in the Floridan aquifer system: (1) tectonic faults and (2) karst collapse systems. Though the carbonate rocks that compose the Floridan aquifer system can range in age from Paleocene to Oligocene in southeastern Florida, these types of disruption in confinement, for the most part, have only been imaged in the middle Eocene to Oligocene part of the Floridan aquifer system. Reflections representative of carbonate strata older than middle Eocene are not well imaged for almost the entire data set. These deep reflections are almost in all cases shown as chaotic reflection configurations and not interpretable. The exception is data acquired above the Miami Terrace (Figure 1), where some of the imaging extended into Paleocene strata.

(1) Tectonic faults

Two types of tectonic faults have been identified, normal and reverse. The normal faults are vertical or near vertical with offset of reflections up to about 10 milliseconds two-way travel time. One of these faults identified on five lines within Biscayne Bay, is approximately parallel to the shore, and extends through part of the data set over a distance of about 10 miles (Figures 1 and 2). This steep normal faulting probably occurred within an interval of time that includes the middle Miocene to early Pliocene Epochs. A group of reverse faults has been imaged on seismic-reflection profiles acquired above the Miami Terrace (Figure 3). Timing of the reverse fault movement is not well constrained, but probably occurred sometime during the late Eocene to early Pliocene Epochs. The movement postdates intense northward directed thrust movement in nearby Cuba during the early to middle Eocene (Pardo, 2009).

Where observed on offshore seismic-reflection profiles, both types of faults cut across the Upper Floridan aquifer (Figures 2 and 3). Though the hydraulic properties of the normal and reverse faults are not known, they have potential to act as passageways for the upward migration of buoyant wastewater injected into the lower part of the Floridan aquifer system. This migration upward could extend into permeable zones that occur within the USDW

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of the upper part of the Floridan aquifer system—Upper Floridan aquifer and Avon Park permeable zone (Figures 2 and 3, Reese, 1994; Reese and Richardson, 2008).

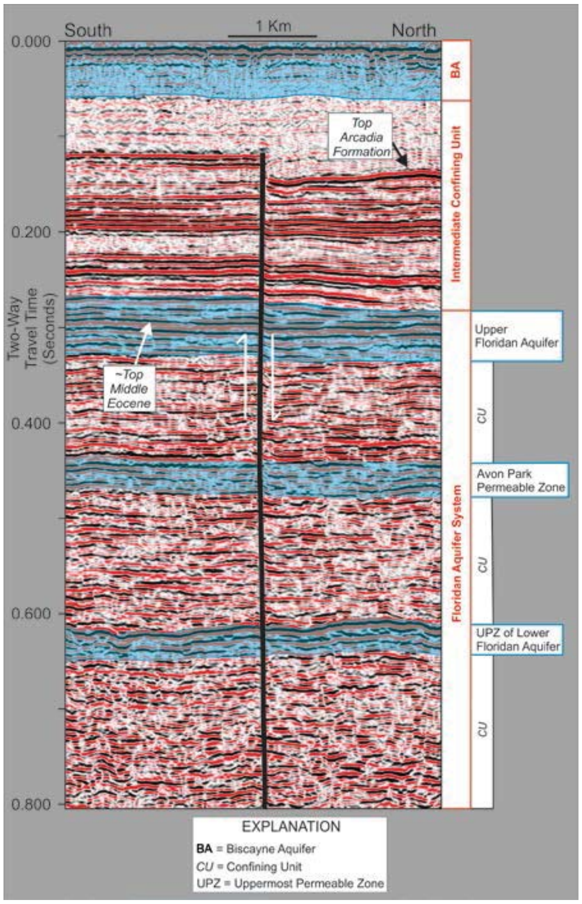

Figure 2: Seismic-reflection profile N1 from Biscayne Bay (Figure 1) shows a nearly vertical normal tectonic fault. The structure is visible on five different seismic profiles indicating length of its trace is at least 16 km. Hydrostratigraphy from onshore is projected onto profile. Onshore, the Upper Floridan aquifer and Avon Park permeable zone are protected underground sources of drinking water onshore.

(2) Karst collapse structures

Cunningham and Walker (2009) have identified numerous karst collapse structures in Biscayne Bay. Additional profile data have been acquired in canals and the southeastern Florida shallow-marine shelf since the 2009 report and substantiate that these are common structural features beneath peninsular Florida. The diameters of these structures range from about 170 m to 3.2 km (Figure 4). The karst collapse structures exhibit one or more zones of vertically-stacked, concave-upward arrangements of mainly parallel seismic-reflection patterns. These zones of seismic-reflection patterns characterize actual physical features, as indicated by accompanying onlap or prograded-fill reflection configurations, or erosional seismic-reflection terminations, or a mixture of these reflections patterns.

Documentation of similar collapse structures have been shown elsewhere, both in seismic-reflection profiles and attribute maps (Hardage et al., 1966; Loucks, 1999; Story et

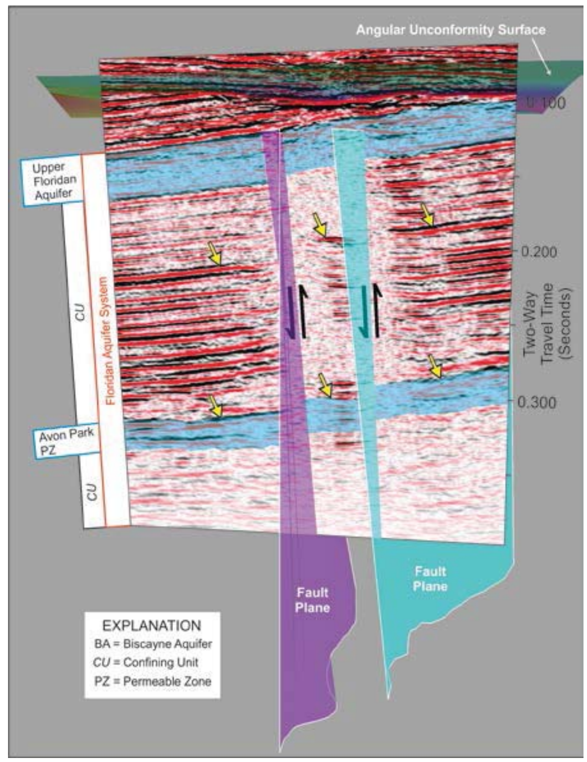

Figure 3: Geomodel based on 20 seismic-reflection profiles. Shows single seismic-reflection profile acquired from above the Miami Terrace (Figure 1), two reverse fault planes (purple and cyan colored) breaching reflections equivalent to middle Eocene carbonate strata of the Floridan aquifer system, mapped angular unconformity surface, and hydrostratigraphy from onshore projected onto profile. Three fault planes are not shown, so as to best show offset on the two principal reverse faults. Yellow arrows point to two seismic-reflections with clear structural offset between fault blocks. Reflections below the angular unconformity image carbonate strata equivalent to part of the Floridan aquifer system present onshore. Onshore, the Upper Floridan aquifer and Avon Park permeable zone are protected underground sources of drinking water.

al., 2000; Heubeck et al., 2004; Sullivan et al., 2006; Zeng et al., 2006; McDonnell et al., 2007; Hine et al., 2009; Zuo

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et al., 2009; Gou et al., 2011), observed in land-based and seafloor outcrops (Popenoe et al., 1984; Spechler and Wilson, 1997; Lucia, 1995), and in subsurface well data (Kerans, 1988; Loucks, 1999; Loucks et al., 2004) from other areas of the world. These examples serve as comparative analogs that provide clues to the origin of karst collapse structures in the southeastern part of the Florida Platform.

Conclusions

Near-surface, high-frequency, marine seismic-reflection data were acquired in the shallow-marine shelf environments and onshore canals of southeastern Florida. The quality of these seismic-reflection data is significantly better than data previously obtained from water depths as shallow as 1 m on the shallow-marine shelf of southeastern Florida. The profiles generally provide interpretable information to depths that include middle Eocene strata, and in some cases Paleocene strata. This advance in seismic-reflection technology has provided an opportunity to evaluate geologic structures that breach confining units of the karst-carbonate Floridan aquifer system within the southeastern Florida Platform. Two types of structural systems have been identified on seismic profiles that have the potential for producing a breach in confinement in the Floridan aquifer system: (1) tectonic faults and (2) karst collapse structures. The tectonic faults are of two types, normal and reverse faults. Most faults identified in the set of seismic profiles are associated with karst collapse structures. These two fault systems may serve as a pathway for vertical groundwater flow across relatively low-permeability carbonate strata that separate zones of regionally extensive high-permeability in the Floridan aquifer system.

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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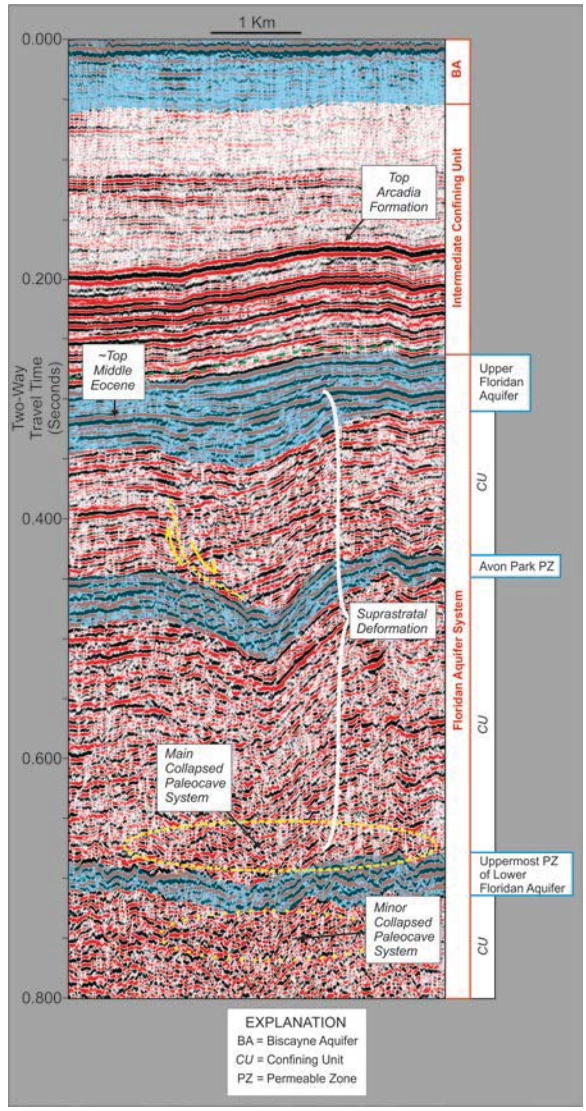

Figure 4: Seismic-reflection profile N5 from Biscayne Bay (Figure 1) shows a very broad collapse structure within the middle Eocene carbonate strata of the Floridan aquifer system. The strucutre is up to about 3.2 km wide. Hydrostratigraphy from onshore is projected onto profile. Onshore, the Upper Floridan aquifer and Avon Park permeable zone are protected underground sources of drinking water.

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