The Relation Between Structure and Saltwater Intrusion in the Floridan Aquifer System, Northeastern Florida

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Abstract

Saltwater intrusion is a potential threat to the quality of ground water in northeastern Florida. Elevated chloride concentrations have been observed in more than 70 wells tapping the Upper Floridan and the upper zone of the Lower Floridan aquifers. In Duval and northern St. Johns County, increased chloride concentrations in water from some wells along the coast and up to 14 miles inland indicate that saline water is gradually intruding into the freshwater zones of the Floridan aquifer system. Several mechanisms may explain this intrusion of saline water and the consequent increase in concentrations of chloride in northeastern Florida. The most plausible explanation is the upward movement of saline water along joints, fractures, collapse features, faults, or other structural anomalies. Land-based seismic reflection and marine seismic reflection profiles along the St. Johns River and off the coast of northeastern Florida show the presence of widely scattered solution collapse features in the Floridan aquifer system and overlying sediments. These features can create conduits of relatively high vertical conductivity, providing a hydraulic connection between freshwater zones and deeper, more saline zones. Lower heads caused by pumping from the shallower freshwater zones of the aquifer can result in an increased potential for upward movement of saline water through nearly vertical zones of preferential permeability. Saline water then can move laterally through the porous aquifer matrix or along horizontal fractures or solution zones within the aquifer toward well fields or other areas of lower hydraulic head.

INTRODUCTION

The Floridan aquifer system is the major source of water supply in northeastern Florida (fig. 1). Ground-water withdrawals in the area increased from about 183 to 235 million gallons per day from 1965 to 1995 (Marella, 1995; 1999). Approximately 90 percent of the total withdrawal is from the Floridan aquifer system, resulting in long-term declines in the potentiometric surface of the Upper Floridan aquifer of about one-third to one-half foot per year. Associated with this decline in water levels has been an increased potential for saltwater intrusion into the freshwater zones of the aquifer. Gradual, but continual, increases in the chloride concentrations in water from the aquifer system have been observed in several inland and coastal areas (fig. 2). The potential for saltwater intrusion is expected to increase as population growth and potentiometric surface declines continue in northeastern Florida.

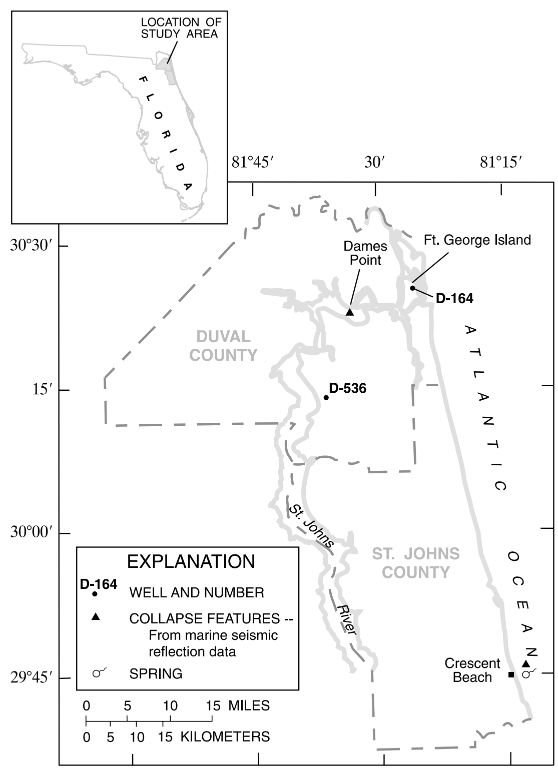

Figure 1. Location of the study area.

HYDROGEOLOGIC FRAMEWORK

Major stratigraphic and corresponding hydrogeologic units of northeastern Florida (fig. 3) include a thick sequence of marine sedimentary rocks that overlie a basement complex of metamorphic strata. The sedimentary sequences are primarily carbonates that contain interbedded evaporites in the deeper units and siliclastic material in the shallower units. Rocks of

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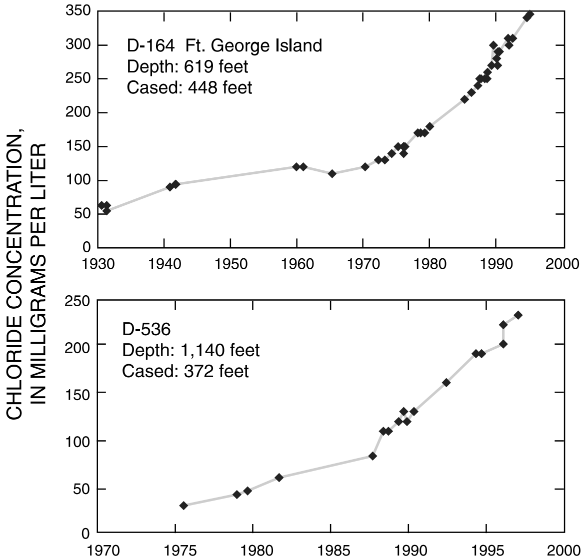

Figure 2. Chloride concentrations in water from selected wells tapping the Floridan aquifer system (locations of wells shown in figure 1).

the Cedar Keys Formation of late Paleocene age underlie all of northeastern Florida. They are overlain, in ascending order, by the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Hawthorn Group of Miocene age, and the undifferentiated deposits of late Miocene to Holocene age.

The principal water-bearing units are the surficial and Floridan aquifer systems. The two aquifer systems are separated by the intermediate confining unit, which is composed of clays, silts, and sands. The intermediate confining unit contains beds of lower permeability that confine the water in the Floridan aquifer system. The Floridan aquifer system is divided into the Upper and Lower Floridan aquifers, which are separated by a zone of lower permeability (fig. 3). The surface of the Upper Floridan is a paleokarst plain that exhibits erosional and collapse features that developed before the deposition of the overlying Hawthorn Group. Two major water-bearing zones exist within the Lower Floridan aquifer: the upper zone and the Fernandina permeable zone (fig. 3). These zones are separated by a less-permeable semiconfining unit that restricts the vertical movement of water (Brown, 1984). Water in the Fernandina permeable zone varies from fresh to highly saline in northeastern Florida.

Series	Stratigraphic unit	General lithology	Hydrogeologic unit			Hydrogeologic properties
Holocene to Upper Miocene	Undifferentiated surficial deposits	Discontinuous sand, clay, shell beds, and limestone	Surficial aquifer system			Sand, shell, limestone, and coquina deposits provide local water supplies.
Miocene	Hawthorn Group	Interbedded phosphatic sand, clay, limestone, and dolomite	Intermediate confining unit			Sand, shell, and carbonate deposits provide limited local water supplies. Low permeability clays serve as the principle confining beds for the Floridan aquifer system below.
Eocene	Ocala Limestone	Massive fossiliferous chalky to granular marine limestone	Floridan aquifer system	Upper Floridan aquifer		Principal source of ground water. High permeability overall. Water from some wells shows increasing salinity.
Eocene	Avon Park Formation	Alternating beds of massive granular and chalky limestone, and dense dolomite	Floridan aquifer system	Middle semiconfining unit		Low permeability limestone and dolomite.
Eocene	Avon Park Formation / Oldsmar Formation	Alternating beds of massive granular and chalky limestone, and dense dolomite	Floridan aquifer system	Lower Floridan aquifer	Upper zone	Principal source of ground water. Water from some wells shows increasing salinity.
Eocene	Oldsmar Formation	Alternating beds of massive granular and chalky limestone, and dense dolomite	Floridan aquifer system	Lower Floridan aquifer	Semiconfining unit	Low permeability limestone and dolomite.
Eocene	Oldsmar Formation	Alternating beds of massive granular and chalky limestone, and dense dolomite	Floridan aquifer system	Lower Floridan aquifer	Fernandina permeable zone	High permeability; salinity increases with depth.
Paleocene	Cedar Keys Formation	Uppermost appearance of evaporites; dense limestones	Sub-Floridan confining unit			Low permability; contains highly saline water.

Figure 3. General geology and hydrogeology of northeastern Florida (modified from Spechler, 1994).

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MECHANISMS OF INTRUSION

There are several possible mechanisms, some more plausible than others, that can explain the processes and pathways of saltwater movement within the Floridan aquifer system (Spechler, 1994). They are: (1) the movement of unflushed pockets of relict seawater within the aquifer system; (2) landward movement of the freshwater-saltwater interface; (3) regional upconing of saltwater below pumped wells; and (4) the upward leakage of saltwater from deeper, saline water-bearing zones of the aquifer system through semiconfining units that are thin or are breached by joints, fractures, collapse features, or other structural anomalies.

During the Pleistocene epoch, sea level stood at a much higher level than it does today and the Floridan aquifer system was invaded with seawater. Some of this water may not have been completely flushed from the aquifer. Generally, pockets of unflushed relict seawater are found in strata of relatively low permeability. Geophysical logs of many wells in Duval County, however, indicate that the more permeable zones are the source of saline water to the well, implying that unflushed relict seawater is a minor source of saline water in the study area.

Lateral encroachment of recent seawater is an unlikely explanation for the increase in chloride concentrations in the Floridan aquifer system in Duval County. If seawater were moving laterally through the Upper Floridan aquifer from outcrops in the Atlantic Ocean, the saltwater would first be detected in wells nearest the coast. However, many of the public supply and domestic wells along the coast have chloride concentrations less than 30 milligrams per liter (mg/L), whereas some wells as much as 14 miles inland of the coast have chloride concentrations exceeding 250 mg/L. In addition, data from abandoned oil wells and exploratory wells drilled off the coast indicate that the position of the freshwater-saltwater interface at the top of the Floridan aquifer is miles offshore (Johnston, 1983; Johnston and others, 1982; Wait and Leve, 1967).

Data from geophysical logging indicate that regional upconing of saline water apparently is not occurring in Duval County. If upconing were occurring, elevated chloride concentrations in water would be areally distributed under cones of depression caused by pumping. Also, the transition zone would be moving upward and chloride concentrations would be expected to increase with depth. However, fluid resistivity logs and chloride samples collected from several wells with elevated chloride concentrations indicate alternating zones of fresh and saline water, and that less-mineralized water generally underlies the shallower higher chloride zone (Phelps and Spechler, 1997).

Because of the areal and vertical variability of chloride concentrations, the most plausible mechanism for the movement of saline water into the freshwater zones of the Floridan aquifer system is the upward movement of saline water along solution-enlarged joints or fractures, and subsequently formed collapse features, combined with horizontal movement in fractures or solutionally enhanced flow zones (fig. 4). Marine seismic reflection profiles show that the Continental Shelf off the northeastern coast of Florida is underlain by solution-deformed limestone of late Cretaceous to Eocene age (Meisburger and Field, 1976; Popenoe and others, 1984; Kindinger and others, 2000). Dissolution and collapse features are widely scattered throughout the area and are expressed as: (1) sinkholes that presently breach the sea floor (Spechler and Wilson, 1997); (2) sinkholes that breached the sea floor in the past and are now filled with sand; and (3) dissolution-collapse features (fig. 5) that originated deep within the geologic section, deforming the overlying units (Popenoe and others, 1984). The deep dissolution-collapse features are believed to originate in the Upper Cretaceous and Paleocene rocks (Popenoe and others, 1984). Additional seismic- reflection investigations along the St. Johns River and in lakes in northeastern Florida by Snyder and others (1989), Spechler (1994), and Kindinger and others (2000) also revealed a number of buried collapse features (fig. 6) and other karstic features similar to those observed by Meisburger and Field (1976), and Popenoe and others (1984).

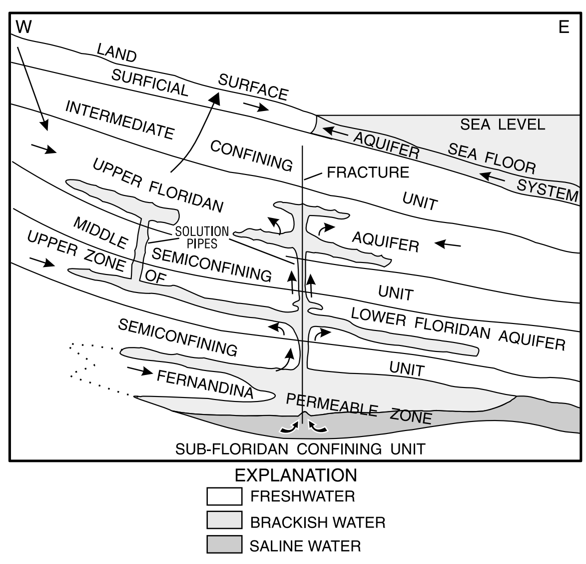

Figure 4. Simplified section of the Floridan aquifer system (modified from Spechler, 1994).

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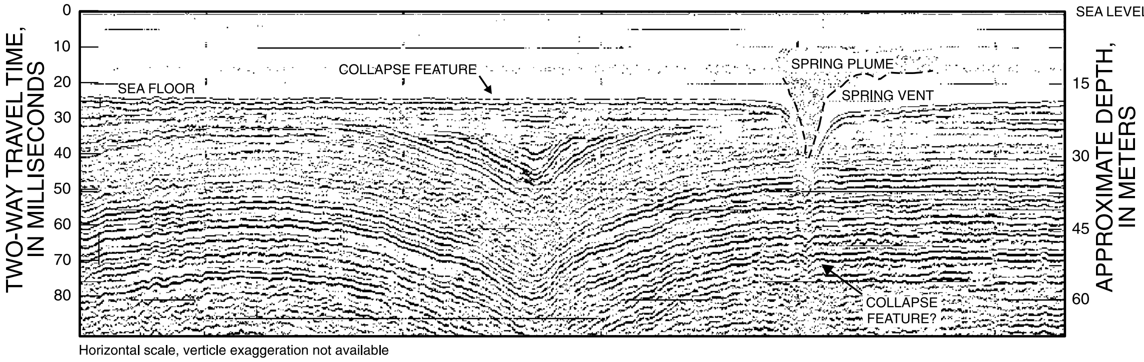

Figure 5. Seismic record showing collapse features, offshore Crescent Beach, Florida (modified from Kindinger and others, 2000).

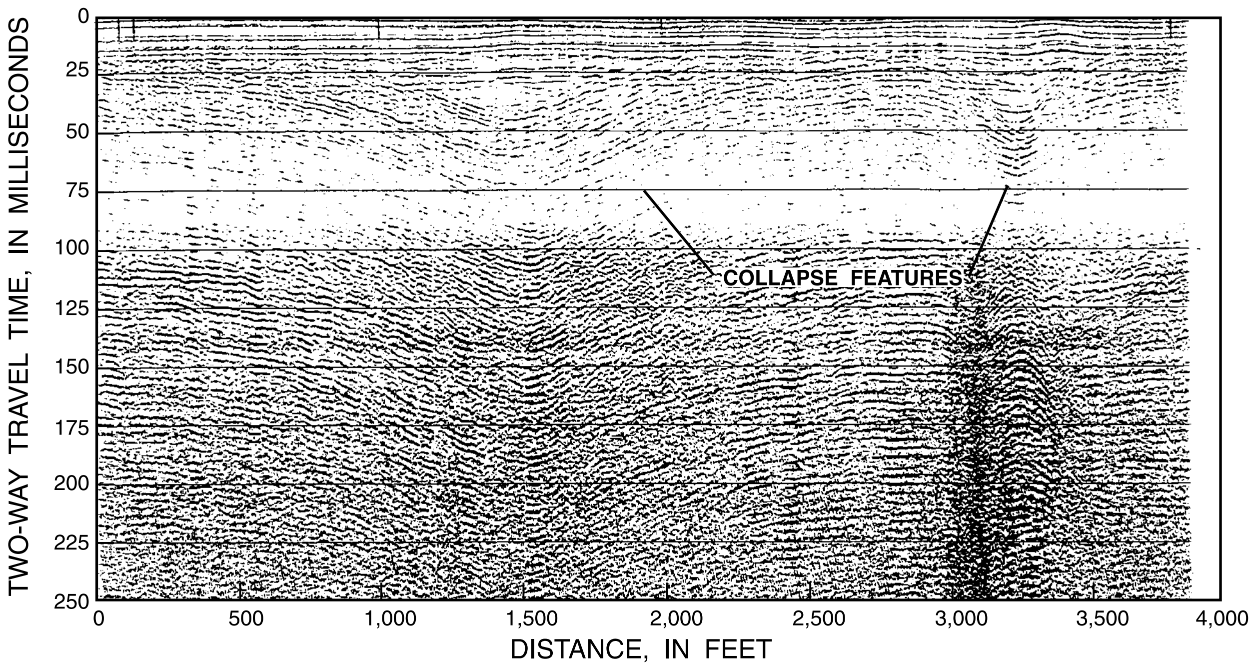

Figure 6. Seismic record showing collapse features along an approximate 4,000-foot section of the St. Johns River near Dames Point in Duval County (from Spechler, 1994).

Recent land-based seismic reflection surveys at Ft. George Island, Florida (fig. 1) show a large solution feature in the northeastern part of the island (Odum and others, 1999). Reflectors within the upper Hawthorn Group show evidence of downwarping and displacement (approximately 65 feet of vertical subsidence) as the interbedded carbonates, clay, and sand strata deform plastically downward over a deeper solution pipe. The seismic profiles show that a karst solution feature has likely breached the middle semiconfining unit within the Floridan aquifer system and possibly the semiconfining unit that separates the upper zone of the Lower Floridan aquifer from the Fernandina permeable zone. This feature may have created zones of relatively high vertical hydraulic conductivity through rocks of otherwise low vertical hydraulic conductivity, thereby providing a hydraulic connection between freshwater zones and deeper saline zones (fig. 4). Chloride concentrations in water from nearby wells (Spechler, 1994) are highest near the interpreted limits of the solution pipe (fig. 2), indicating that saline ground-water movement is controlled by these features.

CONCLUSION

The areal and vertical distribution of chloride concentrations in Duval County indicates that structural anomalies are the most likely cause for increased chloride concentrations in the Floridan aquifer system. These features can create zones of relatively high vertical hydraulic conductivity, thereby providing a hydraulic connection between freshwater zones and deeper, more saline zones. Lower heads caused by pumping from the shallower freshwater zones of the aquifer can result in an increased potential for upward movement of saline water through nearly vertical zones of preferential permeability. As saline water enters the freshwater zones, it can mix and move through the porous matrix of the aquifer or along horizontal fractures or solution zones.

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