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Re-examining the Submarine Spring at Crescent Beach, Florida

Figure 1. Orange buoy marking the center of the spring discharge plume. The edge of the boil is faintly visible. Photographed by Rick Spechler, USGS.

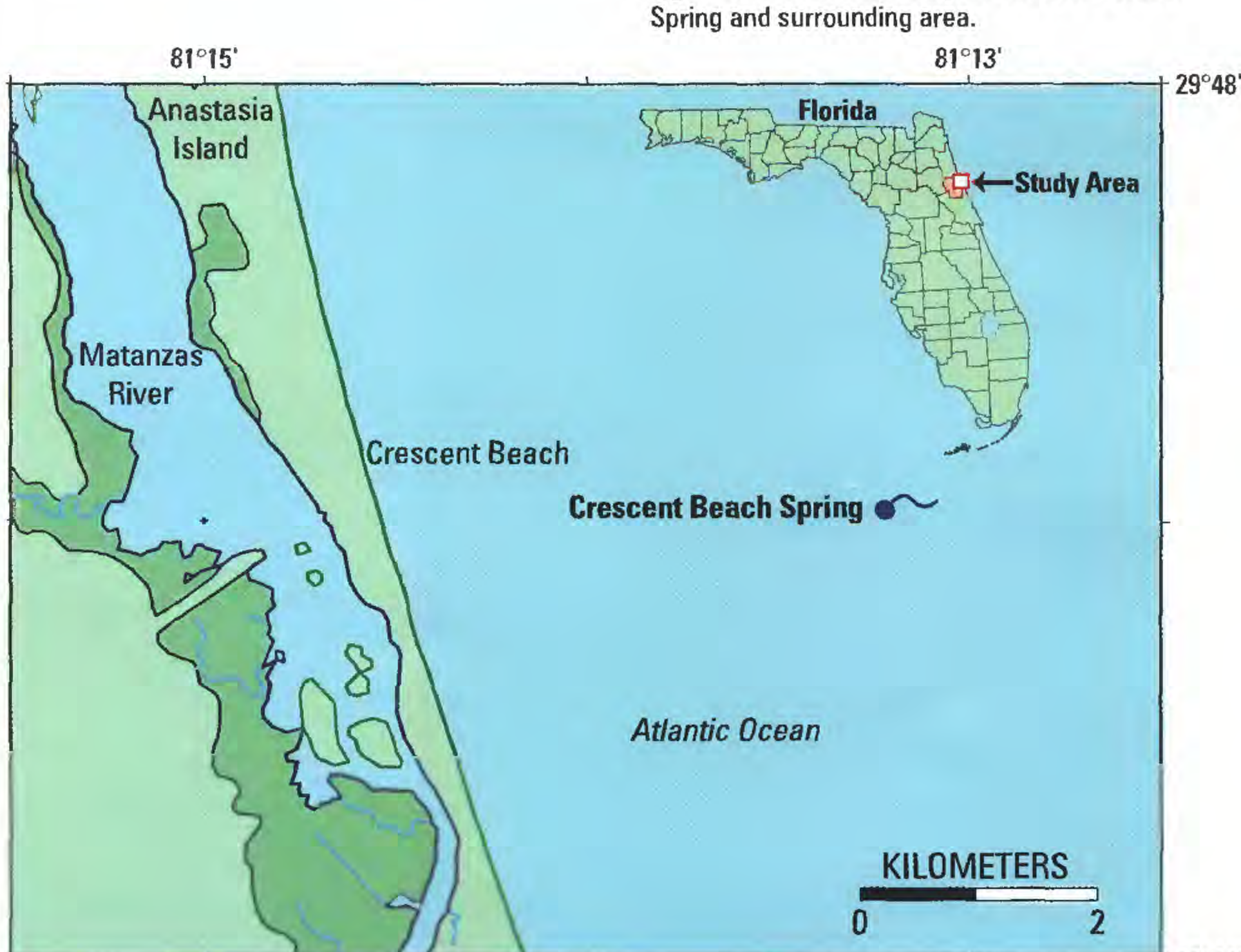
The submarine Crescent Beach Spring, off the NE coast of Florida, provides U.S. Geological Survey scientists with a unique opportunity to field-test a suite of techniques that address coastal oceanography, ground-water geochemistry, sedimentology, and geophysics. The discharge at Crescent Beach Spring is largely restricted to one well-defined vent area, and as a consequence, hydrogeologic controls between onshore recharge areas, regional hydraulic gradients, and spring discharge are more directly related than at other, more typical sites of diffuse submarine ground-water discharge.

Introduction

Submarine ground-water discharge is generally a widespread, but disperse coastal feature that occurs wherever hydrogeologic gradients enable vertical ground-water transport. Most submarine ground-water discharge occurs as diffuse seepage and identifying discharge sites or quantifying flux rates across the sediment-water interface has proven difficult. In contrast, the submarine Crescent Beach Spring, located 4 km off the northeast coast of Florida (Figs. 1 & 2), represents a rare opportunity to examine submarine ground-water discharge because the discharge is large (greatly exceeds first order spring discharge) and is confined to one prominent solution feature. At Crescent Beach Spring the Miocene confining unit as well as Plio-Pleistocene and younger overburden has been eroded away, and the principal Eocene artesian aquifer is thus in direct communication with the Atlantic Ocean. There is a long history of anecdotal and observed submarine ground-water discharge at Crescent Beach Spring, and this flow does appear to respond quite rapidly to onshore precipitation/evaporation. Our sampling efforts at this spring are focussed on examining water transport processes and water sources for the spring using geochemical tracers, geophysical surveys, and vibra coring.

There has been an active interest in Crescent Beach Spring that spans more than 100 years. The U.S. Coastal Survey produced the first detailed bathymetric chart of Crescent Beach Spring and surroundings in 1875. Pioneering efforts in defining the underlying geologic framework and hydrogeologic controls at Crescent Beach Spring were first introduced by Stringfield and Cooper (1951) and Brooks (1961). Manheim's (1967) discoveries of freshened interstitial waters as far as 120 km off the coast of Florida further suggest the occurrence of distal discharge zones that appear to be associated with Eocene outcrops, fractures or dissolution features. These early works recognized potential recharge areas for widespread coastal submarine discharge but also realized the complexity in defining flow paths in highly permeable karstic terrain. In more recent years, U.S. Geological Survey scientists have incorporated the area surrounding Crescent Beach Spring into a high-resolution seismic survey of select coastlines of Atlantic Coastal Plain states. Results from these surveys (Fig. 3) served as the impetus for renewed hydrogeochemistry research efforts at Crescent Beach Spring.

Figure 2. Site location map for Crescent Beach Spring and surrounding area.



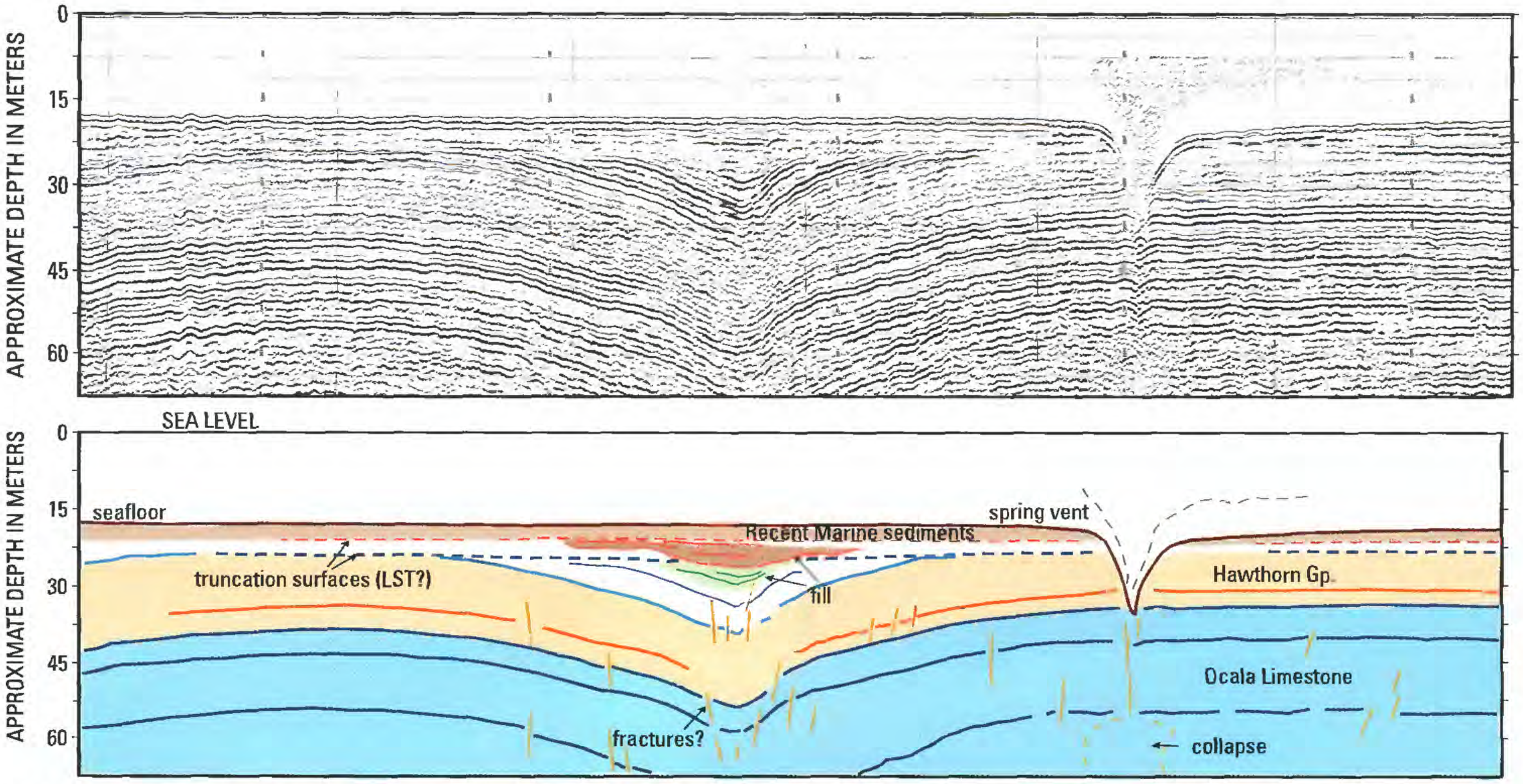


Figure 3. High-Resolution Seismic Profile (top) of Crescent Beach Spring and surrounding area. The spring discharge is visible in the seismic image. Interpretation (bottom) of seismic profile depicting the underlying geology. The Hawthorn Group was eroded (truncated) during a Pleistocene lowstand (LST) of sea level and as sea level rose during the past 25,000 years, recent marine sediments were deposited. Modified from Kindinger and others (1999).

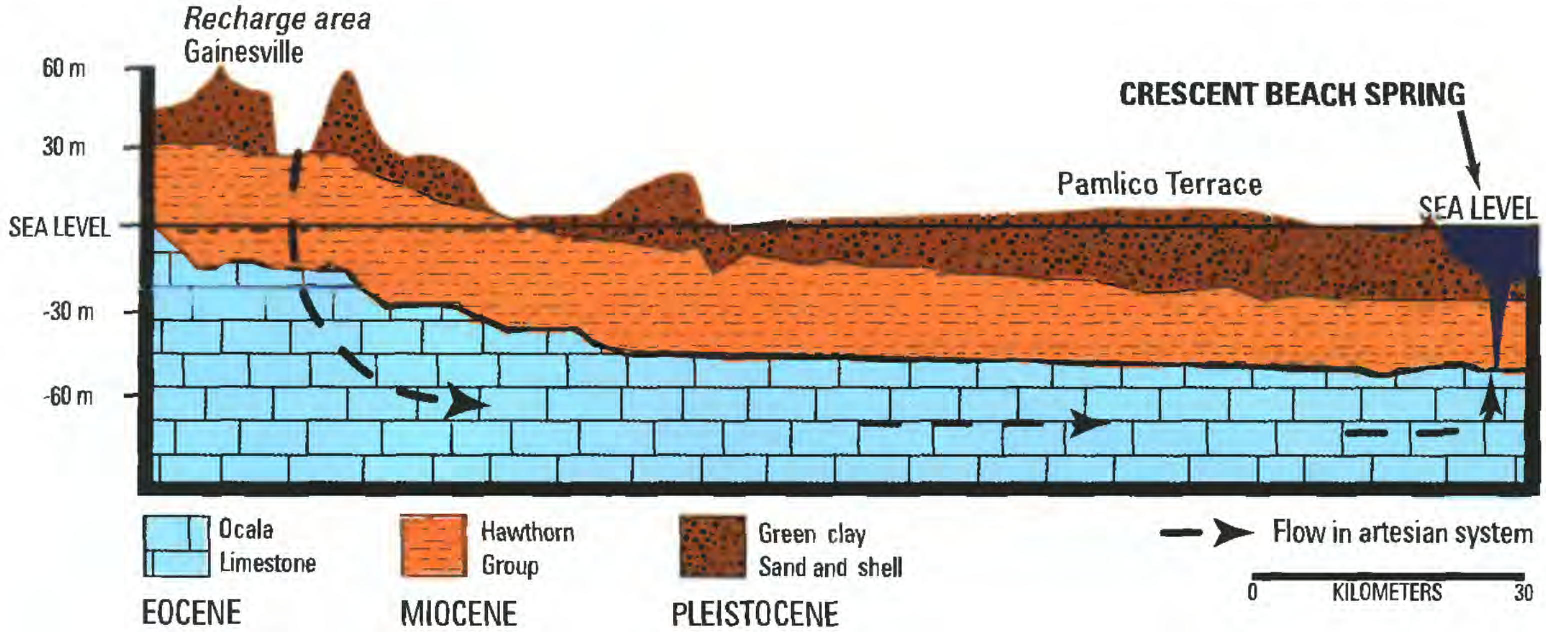
Hydrogeologic Framework

The seismic record at Crescent Beach Spring (Fig. 3) reveals a very well defined vent feature that has developed from sustained submarine discharge. The upper extent of the Crescent Beach Spring vent feature lies at a water depth of approximately 18 m, while the deepest point of the vent trough is at a depth of about 38 m. The areal extent of the bottom trough has a diameter of about 25 m, with at least one confined, steep-walled spring discharge opening. A possible source aquifer for Crescent Beach Spring is the Eocene (about 40 Ma) Ocala Limestone, and this formation is one of the most productive of the Floridan aquifer system. Surficial water is recharged into the Ocala Limestone through a complex network of lakes and sinkholes east of Gainesville, Florida (Fig. 4). The overlying clay-rich Miocene Hawthorn Group forms an effective upper confining unit for the aquifer, and consequently, numerous free-flowing springs exist in the St. John's River system and many coastal wells are artesian. The Hawthorn Group decreases in thickness along a west-to-southeast transect and is probably only about 15 m thick at Crescent Beach (Popenoe and others, 1984). At Crescent Beach Spring, the Hawthorn confining unit has been eroded away entirely, enabling the Ocala Limestone to be in direct contact with overlying seawater. The seismic record in Fig. 3 also reveals multiple large post-Miocene (?) collapse features directly adjacent to the Crescent Beach Spring vent, as indicated by the presence of a series of multiple fractures.

Water Chemistry

Inherent to any study of submarine ground-water discharge is the difficulty of isolating 'true' spring or seep water

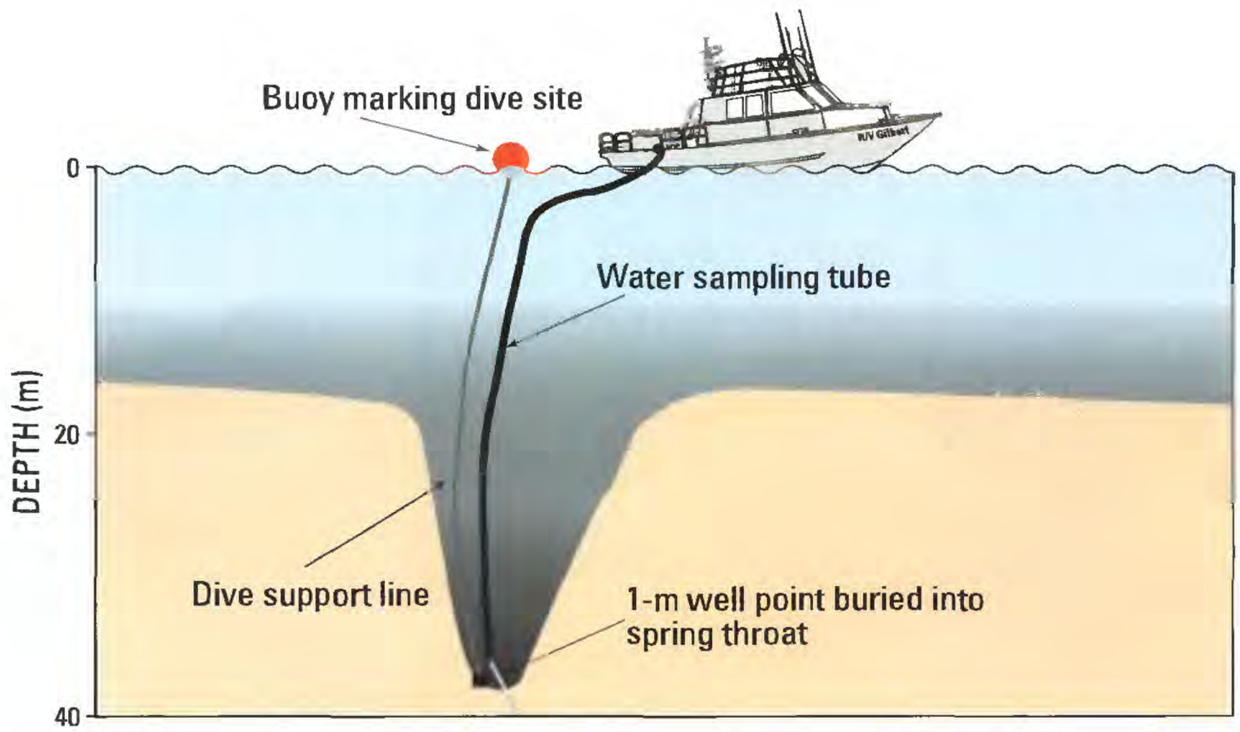
Figure 4. Idealized structural-stratigraphic cross section of continental margin at Crescent Beach, Florida. Figure modified from Brooks, 1961.



from ambient seawater. Most submarine groundwater discharge occurs as diffuse seepage, and identifying sites of submarine ground-water discharge or quantifying flux rates of this discharge across the sediment-water interface can be difficult. As a consequence, it is often easier to assess submarine ground-water discharge by synoptic mass balance calculations within a water column rather than by identifying specific discharge sites. At Crescent Beach Spring there is a well-defined plume of ground water that discharges into the Atlantic Ocean. The difficulties associated with sampling Crescent Beach Spring waters stem from the depth of the spring throat, which at 38 m is at the lower limit attainable by conventional SCUBA diving techniques, and the extreme low visibility (<0.5 m). To obtain an uncontaminated spring sample from Crescent Beach Spring, a 1-m long PVC well point was driven into the shell hash and coarse sand in the deepest opening of the spring throat. A one-piece tube was then attached to the well point and connected to a shipboard pump (Fig. 5). Salinity and temperature were continuously monitored in the spring discharge and remained constant at 6.09 (for comparison, the salinity of seawater is about 35) and 24.9°C, respectively, for the sampling duration (Fig. 6).

Water sources and transport pathways at Crescent Beach Spring are being examined by collecting water from a series of shallow onshore wells, the spring itself, and the surrounding ocean water column using a suite of chemical tracers and major ions. Well water directly adjacent to Crescent Beach Spring is geochemically very similar to the Crescent Beach Spring water and vastly different compared to surrounding seawater. In contrast, the composition of a more distal onshore well is surprisingly different from Crescent Beach Spring water. Four naturally occurring radium isotopes with half-lives that range from 3.8 days to 1,600 years were also utilized to help delineate apparent ground-water flow paths. By comparing radium activities in several onshore wells with those of Crescent Beach Spring and ambient seawater, it appears that the flow regime that delivers water to Crescent Beach Spring is narrow and highly conducive for rapid water exchange (e.g., conduit/fracture flow).

Figure 5. Sampling approach for collecting uncontaminated Crescent Beach Spring waters.



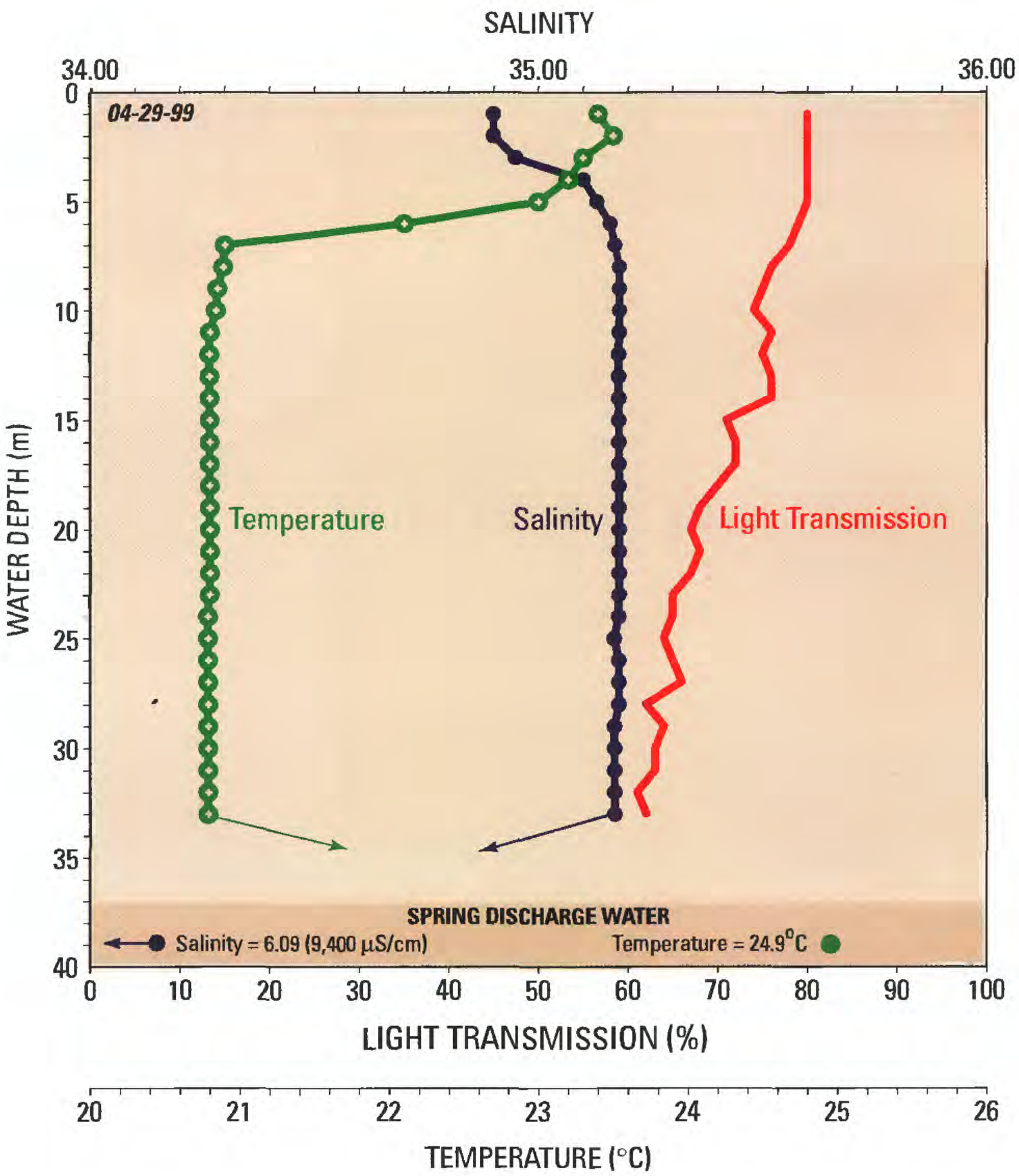
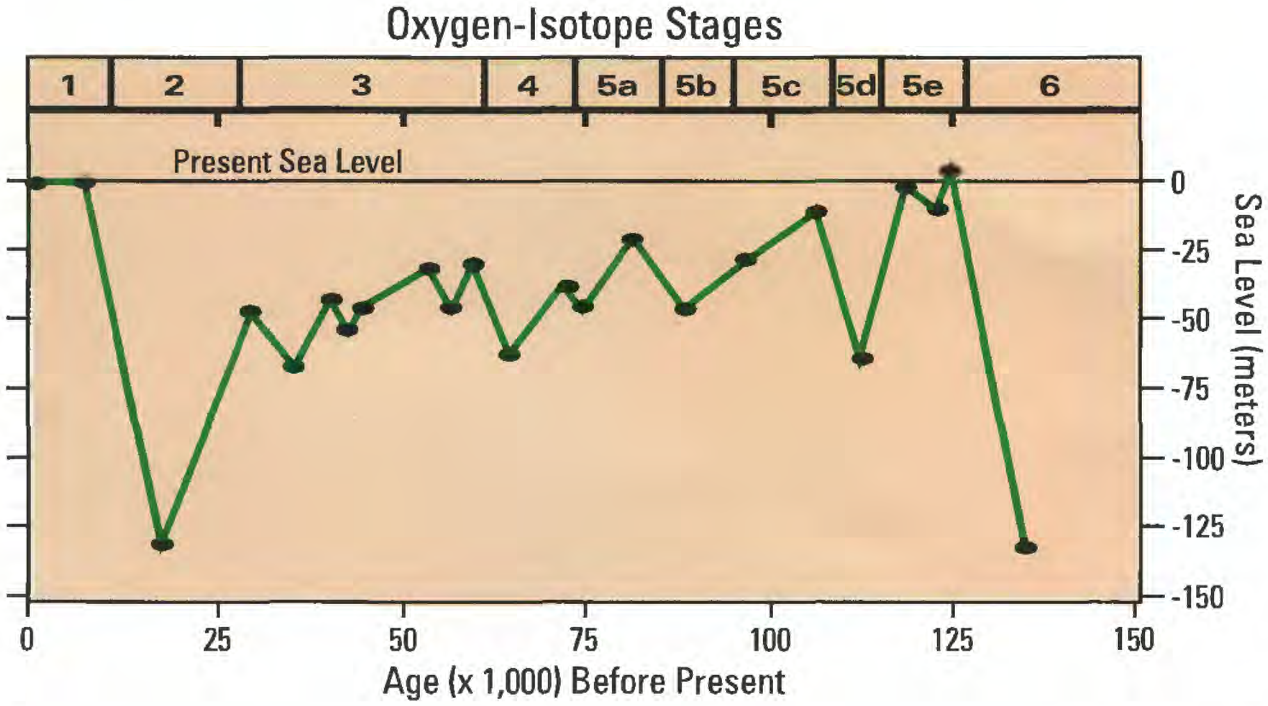


Figure 6. Profile of water salinity (conductivity), temperature, and light transmission with depth down into the opening of the vent. Note extreme differences in temperature and salinity between discharge water collected with the well point and base of profile.

Figure 7. Oxygen-isotope stages and sea-level fluctuations for the past 140,000 years based on correlation of deep-sea core data with ages of uplifted and drowned coral reefs. (Chappell and Shackleton, 1986)



Conceptual Model

To examine the geologic controls on subsurface flow anywhere in Florida, attention must be drawn to past fluctuations in sea level (Fig. 7). During the Pleistocene (about 0.1 Ma) glacial stages, the sea retreated by as much as 125 m (Chappell and Shackleton, 1986). Such large-scale changes in sea level cause drastic effects in coastal hydrologic regimes. For example, during periods of low sea-level stand, the rivers of Florida scoured deep channels across the continental shelf. If Crescent Beach Spring existed, it would have likely been a small collapse feature (?) or a terrestrial spring with an associated fluvial discharge. Seismic reflection data clearly illustrate the presence of large collapse features (post-Miocene?) and fractures adjacent to Crescent Beach Spring. One hypothesis to explain the evolution of Crescent Beach Spring is that these collapse structures created a series of multiple faults and fractures that served as efficient conduits for water transport. As sea level rose in response to Pleistocene deglaciation, the resulting change in hydraulic gradient forced an eventual breach in the confining unit where it was thinnest. It is also likely that the collapse feature may have caused localized decreases in lateral permeability, which would further enhance vertical ground-water flow. The depositional record from the last high sea-level stand has been entirely eroded by Crescent Beach Spring discharge, indicating that the vent evolved after the last sea-level rise. Once the Ocala Limestone was in direct contact with the sea, the upward flow of ground water created and then maintained the vent feature.

REFERENCES

Brooks, H.K.
1961, The Submarine Spring Off Crescent Beach, Florida. *Quart. J. Florida Acad. Sci.*, v. 24: p. 122-134.

Chappell, J. and Shackleton, N.J.
1986, Oxygen Isotopes and Sea Level. *Nature*, v. 324: p. 137-140.

Kindinger, J.L., Davis, J.B., and Flocks, J.G.
1999, Geology and Evolution of Lakes in North Central Florida. *Environmental Geology*, v. 38 (4): p. 301-323.

Manheim, F.T.
1967, Evidence for Submarine Discharge of Water on the Atlantic Continental Slope of the Southern United States, and Suggestions for Further Research. *New York Acad. Sci. Trans. Ser. 2*, v. 29: p. 839-853.

Popenoe, P., Kohout, F.A., and Manheim, F.T.
1984, Seismic-Reflection Studies of Sinkholes and Limestone Dissolution Features on the Northeastern Florida Shelf, in Proceeding of First Multidisciplinary Conference on Sinkholes; Orlando, Florida, October 15-17, 1984: p. 43-57.

Stringfield, V.T. and Cooper, J.R.
1951, Geologic and Hydrologic Features of an Artesian Submarine Spring East of Florida. *Florida Geol. Survey Rept. Invest.*, No. 7: p. 61-72.

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