# APPENDIX 2.5AA
# POTENTIAL FOR CARBONATE DISSOLUTION AND KARST DEVELOPMENT AT THE TURKEY POINT UNITS 6 & 7 SITE

## Executive Summary

Karstification resulting from dissolution of carbonate rock can lead to the creation of subsurface voids from which sinkholes might develop when the process occurs at or near the earth's surface. However, based on investigations completed to date, including review of published reports pertaining to karst development in south Florida, geologic field reconnaissance, and a detailed subsurface geotechnical investigation, it is concluded that formation of large subsurface voids with the potential for collapse and development of sinkholes is not likely at the Turkey Point Units 6 & 7 site.

Two types of features related to dissolution of carbonate rock have been identified at the site: (1) vegetated depressions at and near the ground surface and (2) zones of secondary porosity within the underlying limestone. The vegetated depressions are thought to be the result of a subaerial, epigenic, gradual process of carbonate dissolution caused by downward seepage of slightly acidic meteoric water following fractures, joints and bedding planes in the near-surface rock. These features have formed either currently (onsite) or during the Wisconsinan glacial stage (on the floor of Biscayne Bay) when continental glaciation had lowered sea level approximately 100 meters and exposed the limestone on the floor of Biscayne Bay to subaerial weathering and dissolution. The vegetated depressions are surficial dissolution features that are not subject to collapse into an underground solution cavity.

Because seawater saturated with calcium carbonate contains far less calcium carbonate than freshwater saturated with calcium carbonate, the combined fluids become undersaturated with respect to calcium carbonate, and dissolution of carbonate rocks (limestone) occurs within the mixing zone at the freshwater/saltwater interface of the two fluids (Reference 2.5.1-945). Carbonate dissolution in paleomixing zones of freshwater and saltwater has formed a second type of feature on the site: zones of secondary porosity. These zones of secondary porosity have formed microkarst features of generally centimeter scale in limestone beneath the site and provide pathways of preferential groundwater flow. The microkarst features are thought to have formed by solution enlargement of sedimentary structures in the rock near the contact of the Miami Limestone and Key Largo Limestone and within the Fort Thompson Formation. The zones of secondary porosity were formed during the Pleistocene, when periods of continental glaciation lowered the sea level and allowed mixing of freshwater and saltwater within the stratigraphic intervals of the zones. During these periods, fresh groundwater flowed from inland areas, mixed with seawater near the shoreline, and facilitated dissolution as it flowed through the zones to the sea.

The zones of secondary porosity have developed by solution enlargement of two types of sedimentary structures— “touching-vug porosity” and “moldic porosity” (Subsection 2.5.1.2.4). Touching-vug porosity forms the upper zone of secondary porosity on the site that occurs near the contact of the Miami Limestone and the underlying Key Largo Limestone, within the approximate depth interval of 6.1 to 10.7 meters (20 to 35 feet) below the current land surface (Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353). Because the current land surface elevation at the site is approximately 0 meters (0 feet) NAVD 88, this depth interval is also the approximate elevation interval of –6.1 to –10.7 meters (–20 to –35 feet) NAVD 88. This zone will be removed completely during excavation of the nuclear island foundations.

Moldic porosity forms the lower zone of secondary porosity on the site and occurs in pockets within the approximate depth interval of –18.3 to –22.9 meters (–60 to –75 feet) NAVD 88 in the Fort Thompson Formation. While both the upper and lower zones of secondary porosity formed in paleomixing zones of fresh groundwater and seawater, groundwater in these zones now is saline (Tables 2.4.12-210 and 2.4.12-211) and not conducive to further dissolution of the limestone host rock.

Mixing zones can occur in both surface water as point source discharge and in groundwater as submarine groundwater discharge. An instance of a point source discharge in the vicinity of Turkey Point Units 6 & 7 is the outfall of a drainage canal into Biscayne Bay. Because the closest outfall is more than 1 mile from the site (Figure 2.4.1-203), dissolution of carbonate rocks at the site due to point source discharge is not likely.

Submarine groundwater discharge occurs as shoreline flow or further offshore as deep pore water upwelling. The zones of secondary porosity in limestone at the site are thought to have formed in the past by the process of shoreline flow. Evidence that this process is active or was active in the past at several other areas within the site region and why it is not likely to pose a sinkhole hazard at the site is discussed in Subsection 2.5.1.1.1.1.1.1. These areas include a submarine paleokarst sinkhole in the Key Largo National Marine Sanctuary, flank margin caves in the Bahamas, and the cenotes terrain of the Yucatan, Mexico, where shoreline flow was the formative process for karstification. Because groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), carbonate dissolution in a fresh groundwater/saltwater mixing zone by the process of shoreline flow is not likely to develop large underground voids with the potential for collapse and formation of sinkholes at the site.

Evidence for hypogene speleogenesis in or near the site region is also discussed in Subsection 2.5.1.1.1.1.1.1. Hypogene speleogenesis is generally described as dissolution-enlarged permeability (flow) structure development via ascending waters, driven by regional and/or more localized hydraulic potentials (i.e., hydrostatic pressures) or other convective circulation mechanisms. Given the vertical heterogeneity inherent in most sedimentary sequences, this upward groundwater flow implies some hydrological confinement (artesian conditions) rather than surface recharge. In southeastern Florida, confinement is largely provided by the Peace River and middle and upper (non-carbonate) Arcadia formations. Potential for ascending flow (and, by inference, hypogene speleogenesis) thus exists in the lowermost Arcadia Formation and the underlying Suwannee and Ocala limestones, and the Avon Park, Oldsmar, and upper Cedar Keys formations (i.e., the Floridan aquifer system).

At the site, the underlying Tamiami Formation and Hawthorne Group combined comprise more than approximately 152 meters (500 feet) of low-permeability rocks and sediments that overlie and confine the Floridan aquifer (Figures 2.4.12-202 and 2.4.12-204). For this reason, carbonate dissolution associated with hypogene speleogenesis is not likely to pose a threat of surface collapse or sinkhole hazard at the site.

Data from the extensive site geotechnical subsurface investigation for Turkey Point Units 6 & 7 described in References 2.5.1-708, 2.5.1-995, and 2.5.1-996, including a multi-method surface geophysical survey designed to detect subsurface cavities, offers no evidence that karstification of the area has developed cavernous limestone with the potential for collapse and formation of sinkholes (within the limits of the geophysical survey imposed by diminishing resolution with increasing depth, decreasing cavity size, and increasing offset from survey lines). Structure contour and isopach maps for the Key Largo Limestone and Fort Thompson Formation and cross-sections prepared with data from the site subsurface investigation do not suggest the existence of large underground caverns or sinkholes.

The effects of potential changes in sea level and groundwater level during the life of the Turkey Point Units 6 & 7 plant have little potential to induce formation of large underground cavities or sinkholes at the site. Because of the planned method of groundwater control during site construction, no significant change in groundwater level or associated hydrodynamic stress that might lead to formation of sinkholes is anticipated.

## 1. INTRODUCTION

This appendix summarizes information previously provided in the FSAR and in the responses to various requests for additional information by the NRC, and provides additional information pertaining to the potential for carbonate dissolution and karst development at the Turkey Point Units 6 & 7 site. This summary outlines the extent to which karst features have developed on and adjacent to the site, the processes by which they were formed, and the improbability of contemporary carbonate dissolution resulting in the formation of large subsurface voids with the potential for collapse. Based on investigations completed to date, including review of published reports pertaining to karst development in south Florida and a detailed site subsurface geotechnical investigation, two types of features related to carbonate dissolution have been identified on the site: vegetated depressions at and near the ground surface and zones of secondary porosity within the underlying limestone. The vegetated depressions have formed by a surficial dissolution mechanism, as discussed further in Section 2. The zones of secondary porosity have formed by a subsurface mechanism of solution enlargement of sedimentary structures in the carbonate rock, as discussed further in Section 3. Neither of these features is believed to pose a hazard of sinkhole development or foundation instability at the site, as detailed in the discussions in Sections 2 and 3.

Chemical disequilibrium with respect to carbonate saturation in a freshwater/saltwater mixing zone provides an important mechanism for carbonate dissolution, several examples of which are provided in Section 4 along with a discussion of the potential for formation of cavernous limestone susceptible to collapse in a mixing zone on or near the site. Section 5 provides clarification of issues related to interpretation of the data from the detailed site subsurface geotechnical investigation as it pertains to carbonate dissolution and formation of karst features on the site.

The fresh groundwater/saltwater interface within the surficial aquifer that underlies the site is located approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207). Groundwater in the aquifer is saline at the site (Tables 2.4.12-210 and 2.4.12-211), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206). Therefore, a fresh groundwater/saltwater mixing zone that would promote carbonate dissolution does not exist, and there does not appear to be a potential for development of large underground caverns with the potential for collapse at the site.

## 2. SURFICIAL DISSOLUTION FEATURES

Karstification resulting from dissolution of carbonate rock can lead to creation of sinkholes when the process occurs at or near the earth's surface. As further discussed in Subsection 2.5.1.1.1.1.1.1, the U.S. Geological Survey has identified three main types of sinkholes in Florida (Reference 2.5.1-264), and the Florida Geological Survey has classified four area types of sinkhole occurrences throughout the state (Figure 2.5.1-222). The Turkey Point Units 6 & 7 site is located within Area I where, if they occur, sinkholes are typically surface-solution sinkholes. In this type of sinkhole, limestone is exposed at the ground surface or under a thin mantle of overburden and subject to subaerial dissolution by slightly acidic surface water. Dissolution is concentrated at the surface and along fractures, joints, and other openings in the rock.

The Florida Geological Survey generally assigns a low hazard to karst features that form when limestone is exposed at the surface or beneath a thin veneer of permeable sediment, as is the case within the site area. In these cases, such solution potholes are generally expected to be shallow, broad, and to develop gradually rather than in a sudden collapse event (Subsection 2.5.3.8.2.1, Reference 2.5.3-229). Development of surface-solution features proceeds with a slow decline of the ground surface that results in the formation of a generally bowl-shaped depression commonly filled with organic-rich sediments. This process is thought to be currently active on the site and has formed the vegetated depressions that serve as sediment traps and contain an accumulation of Holocene peat deposits (Reference 2.5.1-996). The vegetated depressions are surficial solution features and are not subject to collapse into an underground solution cavity.

## 2.1 Vegetated Depressions at the Site

Numerous circular or ellipsoidal vegetated and/or water-filled depressions that are generally less than 1 foot lower than the surrounding area have been identified on the site (Subsection 2.5.3.8.2.1). Based on published literature (Reference 2.5.1-264), for Turkey Point Units 3 and 4 (Reference 2.5.1-712), geologic field reconnaissance and data from a detailed site subsurface investigation that included a multi-method surface geophysical survey (References 2.5.1-708, 2.5.1-988, and 2.5.1-995), these features on the site and nearby on the floor of Biscayne Bay are thought to be the result of a subaerial, epigenic, gradual, top-down process of carbonate dissolution caused by downward seepage of slightly acidic meteoric water following fractures, joints, and bedding planes. This process of carbonate dissolution is currently active on the site and was active beneath Biscayne Bay during the Wisconsinan glacial stage when continental glaciation had lowered sea level approximately 100 meters and exposed the limestone on the floor of Biscayne Bay to subaerial weathering and dissolution. Formation of the vegetated patterns beneath the bay is discussed further in Section 2.2.

Subsection 2.5.4.4.5 discusses a multi-method surface geophysical survey designed to detect possible dissolution features beneath the footprint of the nuclear islands at the site. The locations of the vegetated depressions correlate well with data from the geophysical surveys (Figures 2.5.4-223 and 2.5.4-228).

The sampling indicates that the features are characterized by up to 3.4 meters (11 feet) of peat accumulated over soft zones of the Miami Limestone. Outside of the vegetated depressions, a surficial layer of muck generally 0.6 to 1.8 meters (2 to 6 feet) thick is present throughout the site. The areas of thicker muck likely represent zones of increased dissolution with possible small voids, dissolution-enlarged fractures, and softer rock. Soft zones within the Miami Limestone indicated by relatively low standard penetration test “N” values recorded in logs of soil borings drilled on the geophysical survey lines correlate well with low-gravity anomalies, suggesting that the gravity anomalies identify areas of soft rock rather than large subsurface voids. As discussed in Subsection 2.5.4.4.5.4, the original microgravity was remodeled for the profile lines that intersect vegetated depressions (Reference 2.5.4-320). The remodeling of the microgravity data was performed considering the newly described material densities, which correlates the presence of only lower density peat inside the vegetated depressions with low-gravity anomalies (Reference 2.5.1-996). Within the limits of the geophysical survey imposed by diminishing resolution with depth, measured variations in shear and compressional seismic wave velocities integrated with microgravity data (Figures 2.5.4-226 and 2.5.4-227) indicate the vegetated depressions appear to be underlain by relatively un-karstified, undeformed rock of the Miami Limestone rather than rock that has been undermined to the extent that it may be subject to collapse.

## 2.2 Vegetated Patterns on the Floor of Biscayne Bay

The seafloor of Biscayne Bay east of the Turkey Point Units 6 & 7 site includes many dark, vegetated patches that appear to be similar to the dark, vegetated patches mapped subaerially at the site (Figure 2.5.3-202 and Figure 2.5AA-203), as discussed in Section 2.1. The subaerial vegetated patches at the site are generally wet or water-filled depressions that are generally less than 1 foot lower than the surrounding area (Subsection 2.5.3.8.2.1).

The locations of the vegetated depressions on site correlate well with results of the geophysical surveys conducted to identify possible subsurface cavities as part of the site subsurface investigation (Figures 2.5.4-223 and 2.5.4-228) as described in Section 2.1 of this Appendix.

Analysis of the submarine vegetated patches included visual examination of imagery (References 202, 203, 204, and 205) to identify features within a distance of 3 kilometers (1.9 miles) east of the site in Biscayne Bay (Figure 2.5.3-202 and Figure 2.5AA-203). Four circular areas with radii of 0.48 kilometer (0.3 mile) were evaluated for density of surficial depressions or vegetated patches. Two onshore circles were drawn, one just west of the site (circle 1) and one centered on the site (circle 2). Similarly, two offshore circles were drawn (circles 3 and 4), both east of the site (Figure 2.5AA-203). Subaerial depressions were interpreted from 1940 aerial photography (1:40,000 scale) with results described in Subsection 2.5.1.2.3, and submarine vegetated patches were interpreted from 1986 aerial photography (1:40,000 scale). Detailed mapping was performed to a scale of approximately 1:2000 to define the location and extent of patches within and immediately surrounding each circular area. Density data for the patches from the two subaerial circular areas (circles 1 and 2 in Figure 2.5AA-203) and the two submarine circular areas (circles 3 and 4 in Figure 2.5AA-203) is shown in Table 2.5AA-201.

The average areas of the individual vegetated patches in the subaerial circles 1 and 2 are 780 and 540 square meters (8396 and 5812 square feet), respectively, and the average areas for the submarine patches in circles 3 and 4 are 180 and 320 square meters (1938 and 3444 square feet), respectively (Table 2.5AA-201). While the submarine patches have lower average areas, the average values for both locations (subaerial and submarine) are of the same order of magnitude. The size distribution of the patches in both the subaerial and submarine environments is variable, with high standard deviations for the patch areas, and a size range that varies from 20 square meters (215 square feet) to greater than 7900 square meters (85,000 square feet). Very similar vegetated patch densities are calculated for subaerial and submarine areas (Table 2.5AA-201). The statistics for the subaerial circles are somewhat skewed by the presence of a few very large patches (especially in circle 1), reflected by the fact that the standard deviations of the patch areas in these circles are actually larger than the mean. These outliers may in fact consist of several smaller patches, which have been obscured by vegetation. Otherwise, the patches in all four circles display similar characteristics with similar minimum patch sizes and population densities.

The larger average subaerial patch size relative to the average submarine patch size is consistent with their inferred origin (Subsection 2.5.3.2). The patches on the floor of Biscayne Bay likely formed during the Wisconsinan glacial advance, when sea level was approximately 100 meters (328 feet) lower than the modern ocean. At that time, the floor of the bay and the area of the Turkey Point Units 6 & 7 site both were subject to subaerial weathering and surficial dissolution. At the beginning of the Holocene, sea level rose, flooded the area that is now Biscayne Bay, and prevented further subaerial weathering and surficial dissolution in the bay. However, because it is at a higher elevation, the area of the site has remained subaerial since the Wisconsinan and has been subject to subaerial weathering and surficial dissolution for several thousand years longer than the floor of the bay. Some of the vegetated patches on the floor of Biscayne Bay have been identified as the locations of historic and current submarine springs within the Biscayne aquifer (Reference 2.5.1-1000). While most springs have been documented about 20 kilometers or more north of the site, one has been documented just off shore of the site (Figures 2.5.1-390 and 2.5.1-391).

Occasional areas of linear patterns or alignment of the vegetated patches were identified by analysis of aerial photographs of the site area This linear pattern is commonly noted throughout southern Florida, in particular the Everglades, and corresponds with tidal and/or surface water flow directions (Reference 2.5.3-236) as discussed in Subsections 2.4.1.2 and 2.5.3.2 and shown in Figure 2.4.1-206.

The available imagery was reviewed specifically to look for possible semicircular alignments in the surficial depressions or vegetated patches located in Biscayne Bay. Two possible semicircular arrangements of vegetated patches are observed just east of the site in imagery from March 2011 (Figures 2.5AA-202 and 2.5AA-204). These arcs of vegetation have radii of roughly 480 meters (1575 feet) and 368 meters (1207.5 feet), respectively (Figure 2.5AA-202). Hence, if these features were each a complete circle rather than a half-circle or arc, they would be similar in diameter to the Key Largo submarine paleosinkhole of Shinn et al. (Figure 2.5AA-205) (Reference 2.5.3-228) discussed in Subsection 4.1.2.1 and Section 2.3.

Shinn et al. postulate that the Key Largo sinkhole is a cenote that formed during the Pleistocene and filled with marine sediment during the Holocene when the rising sea level inundated the cenote. The 54.6 meters (179 feet) of sediments cored in the Key Largo submarine paleokarst sinkhole investigated by Shinn et al. consist mostly of gray aragonite mud visually lacking sedimentary laminations and fossils except for a cap of carbonate sands (Reference 2.5.3-228). This sequence of sediments has not been observed in the geotechnical borings drilled at the Turkey Point Units 6 & 7 site (References 2.5.1-708, 2.5.1-995, and 2.5.1-996). This finding suggests that there are no sinks beneath the site similar to the one investigated by Shinn et al., and because the vegetated depressions on the site and the vegetated patches in nearby Biscayne Bay are believed to be of the same origin, the finding also suggests that the features on the floor of Biscayne Bay near the site do not indicate the presence of submarine paleokarst sinkholes such as the one investigated by Shinn et al.

The visual analysis of the semicircular arrangement of vegetated patches in Figure 2.5AA-204 found little to no similarities with the Key Largo submarine paleosinkhole in Figure 2.5AA-205. It is concluded that the two features are not of the same origin. The different morphology (a circle versus a semicircle) and differing vegetation patterns of the two features are apparent in Figures 2.5AA-204 and 2.5AA-205. In addition, an earlier air photo from 1994 (Figure 2.5AA-206) of the possible semicircular feature shows a less well-defined arc of vegetation. The Key Largo submarine paleosinkhole and other submarine sinkholes reported on the Miami and Pourtales terraces are typically associated with a bathymetric relief on the order of 5 to 200 meters (16 to 656 feet) (References 2.5.3-228 and 2.5.1-951). A 1-foot contour interval map of bathymetry data for Biscayne Bay adjacent to Turkey Point Units 6 & 7 (Reference 202) was evaluated to identify any potential depressions associated with the semicircular vegetation patterns. Depressions associated with the semicircular vegetated patches discussed in this supplemental response are not discernible at this resolution.

As discussed in Subsection 4.1.2.2, studies were conducted in Biscayne Bay west of the Miami Terrace (References 2.5.1-958 and 2.5.1-989) and onshore in the Broward and Miami-Dade counties (References 2.5.1-999, 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015) (Figures 2.5.1-390 and 2.5.1-391) using high-resolution, multichannel seismic-reflection data (Figure 2.5.1-356). The data exhibits disturbances primarily in parallel seismic reflections that correspond to the carbonate rocks of the Floridan aquifer system and the lower part of the overlying intermediate confining unit (Figure 2.5.1-357), however, some are observed to affect layers of the lower Tamiami Formation which overlies the Floridan aquifer (Figure 2.5.1-392). The disturbances in the seismic reflections are indicative of deformation in carbonate rocks of Eocene to Pliocene age. This deformation is interpreted to be related to collapsed paleocaves or collapsed paleocave systems (References 2.5.1-958 and 2.5.1-989). The formation of these features are presumably related to the processes of hypogenic speleogenesis involving formation of karstic conduits via dissolution by upward flow of confined groundwater through a cave-forming zone (Reference 2.5.1-1005).

Regardless of the mechanism of formation, the geophysical data indicates the absence of deformation in rocks younger than Pliocene (Figures 2.5.1-357, 2.5.1-358, and 2.5.1-359). This finding suggests that if the same mechanism had been active at the Turkey Point Units 6 & 7 site during the Eocene, none of the strata younger than Pliocene would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, and upper Tamiami Formation.

Formation of the cenotes on the Yucatan Peninsula is directly related to the position of the fresh groundwater/saltwater mixing zone relative to the location of cave development, as discussed in Subsection 4.1.2.1. The greater topographic relief of the cenotes terrain of the Yucatan Peninsula provides a stark contrast with the flat topography at the Turkey Point Units 6 & 7 site and in the available bathymetric data for the near-site area of Biscayne Bay.

The apparent origin of the greater topographic relief and a much more developed karst regime within the cenotes terrain in the Yucatan Peninsula relative to the Turkey Point Units 6 & 7 site and its vicinity is the relatively high rate of fresh groundwater discharge from a large inland watershed in the Yucatan that produces a more robust mixing zone and more carbonate dissolution (Reference 2.5.1-965). The fresh groundwater/saltwater interface at the site is located approximately 6 miles inland (Figure 2.4.12-207) and groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211). Therefore, a fresh groundwater/saltwater mixing zone that would promote dissolution of the limestone underlying the vegetated features on the floor of Biscayne Bay does not now exist at the site. The absence of a more developed karst topography or an active mixing zone near the site suggests that the process of carbonate dissolution that is instrumental in forming the cenotes of the Yucatan is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site or beneath the vegetated patches on the floor of nearby Biscayne Bay.

Biscayne Bay has been modified and dredged and has an average water depth that ranges from 1.8 to 4 meters (6 to 13 feet) (Reference 2.5.1-991). Assuming the water level in the bay is at 0 feet NAVD 88, the floor of Biscayne Bay ranges in elevation from approximately –6 to –13 feet NAVD 88. According to Rich et al. (Reference 2.5.1-992), sediments overlying bedrock in the bay range in thickness from less than 6 inches to 30 feet. Using this information and the elevations of the bottom of the bay, it is concluded that the surface elevation of the bedrock over which the vegetated patches occur on the floor of the bay ranges from approximately –6.5 to –43 feet NAVD 88. As discussed in Subsection 2.5.1.2.4, an upper zone of secondary porosity within the Biscayne aquifer is located near the contact of the Miami Limestone and Key Largo Limestone at an approximate elevation of –28 feet NAVD 88. A lower zone of secondary porosity is located within the Fort Thompson Formation at an approximate elevation of –65 feet NAVD 88. Based on site stratigraphic data collected during the subsurface investigation (References 2.5.1-708 and 2.5.1-995), the units are relatively flat and, therefore, it appears that the upper zone of secondary porosity at the site occurs within the stratigraphic interval of the limestone surface over which the vegetated patches occur on the floor of Biscayne Bay. The results of the site subsurface investigation described in Subsection 2.5.1.2 and 2.5.4.1.2.1 as well as the results of a multi-method surface geophysical survey designed to detect subsurface cavities (within the limitations of the geophysical survey imposed by diminishing resolution with increasing depth, decreasing cavity size, and increasing offset from survey lines), demonstrate the absence of large solution features at this stratigraphic interval.

Although the upper zone of secondary porosity and the vegetated patches on the floor of Biscayne Bay may be in the same stratigraphic interval, the formation of these dissolution features is somewhat different. Dissolution features such as the vugs in the upper zone of secondary porosity are typically post-depositional and occur in a subsurface freshwater/saltwater mixing zone or in a freshwater phreatic system in which groundwater has filled open spaces and causes dissolution. The vegetated patches on the floor of the bay appear to be surficial paleo-dissolution features that formed during the Wisconsinan glacial stage of the Pleistocene when sea level was approximately 100 meters (328 feet) lower than the modern ocean (Reference 2.5.1-262) and at an elevation favorable for surficial dissolution by rainwater of subaerial limestone in what is now the bay. However, some of the vegetated patches on the floor of Biscayne Bay have been identified as the locations of historic and current submarine springs within the Biscayne aquifer (Reference 2.5.1-1000). While the majority of springs have been documented about 20 kilometers or more north of the site, one has been documented just off shore of the site (Figure 2.5.1-391).

## 2.3 Comparison of Vegetated Depressions in the Site Vicinity to Other Paleokarst Features

The available imagery was reviewed specifically to look for possible semicircular alignments in the onsite surficial depressions and vegetated patches in Biscayne Bay. Two possible semicircular arrangements of vegetated patches are observed just east of the site in images obtained on March 26, 2011 (Figures 2.5AA-202 and 2.5AA-204). These arcs of vegetation seem to have radii of roughly 480 meters (1575 feet) and 368 meters (1208 feet). If these features were each a complete circle rather than a semicircle or arc, they would be similar in diameter to the approximately 600-meter (1968-foot)-diameter submarine paleokarst sinkhole investigated by Shinn et al. in the Key Largo National Marine Sanctuary (Reference 2.5.3-228). This submarine paleokarst sinkhole is discussed in Subsection 4.1.2.1 and Subsection 2.5.1.1.1.1.1.1.

However, visual analysis found little to no similarities between the submarine paleokarst sinkhole investigated by Shinn et al. (Reference 2.5.3-228) and the semicircular arrangement of vegetated patches east of the site. The different morphology (a circle versus a semicircle) and differing vegetation patterns of the two features are apparent in comparing Figures 2.5AA-204 and 2.5AA-205. Further, earlier imagery from 1994 (Figure 2.5AA-206) of the semicircular feature shows a less distinct arc of vegetation.

The Key Largo submarine paleokarst sinkhole and other submarine sinkholes reported on the Miami and Pourtales terraces are typically associated with bathymetric relief on the order of 5 to 200 meters (16 to 656 feet) (References 2.5.3-228 and 2.5.1-951). A 0.3-meter (1-foot) contour interval map of bathymetry data for Biscayne Bay adjacent to the Turkey Point Units 6 & 7 site (Reference 201) was evaluated to identify any potential depressions associated with the semicircular vegetation patterns. No depressions associated with the identified semicircular vegetated patches are discernible at this resolution.

The 54.6 meters (179 feet) of sediments cored in the Key Largo submarine paleokarst sinkhole investigated by Shinn et al. (Reference 2.5.3-228) consist mostly of gray aragonite mud visually lacking sedimentary laminations and fossils except for a cap of carbonate sands (Reference 2.5.3-228). This sequence of sediments has not been observed in the geotechnical borings drilled at the Turkey Point Units 6 & 7 site (References 2.5.1-708 and 2.5.1-995). This finding suggests that there are no sinks beneath the site similar to the one investigated by Shinn et al., and because the vegetated depressions on the site and the vegetated patches in nearby Biscayne Bay are believed to be of the same origin, the finding also suggests that the features on the floor of Biscayne Bay near the site do not indicate the presence of submarine paleokarst sinkholes such as the one investigated by Shinn et al.

The Jewfish Creek paleosinkholes are subsurface features known from multiple independent sets of microgravity, seismic reflection, borehole, photo analysis and historical data that indicate anomalous subsurface conditions located between Lake Surprise and Jewfish Creek on Key Largo (Figure 2.5.1-390) (Reference 2.5.1-1016). Because seismic reflection surveys and borehole data indicate that dipping reflectors do not reach the surface of the overlying shallow rock and that it is not overdeepened, it is concluded the gravity anomaly is not related to shallow geologic conditions but something deep-seated (Reference 2.5.1-1016). Due to the fact that these features are rooted at great depth (213 meters [700 feet]) and the lack of surface expression, the Jewfish Creek paleosinkholes probably have no similarlity in origin to the semicircular vegetated patches on the seafloor of Biscayne Bay. The Jewfish Creek karst features are more likely similar in origin to the seismic-sag structures described by Cunningham and Walker (Reference 2.5.1-958) below Biscayne Bay, as well as those onshore in Broward and Miami-Dade counties (References 2.5.1-999, 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015).

Formation of the cenotes on the Yucatan Peninsula that is discussed in Subsection 4.1.2.1 and Subsection 2.5.1.1.1.1.1.1 occurred during multiple phases directly related to the changing position of the fresh groundwater/saltwater mixing zone as it varied during glacio-eustatic changes in sea level. The greater topographic relief of the cenotes terrain of the Yucatan Peninsula provides a stark contrast with the flat topography at the Turkey Point Units 6 & 7 site and in the available bathymetric data for the near-site area of Biscayne Bay. The apparent origin of the greater topographic relief and a much more developed karst regime within the cenotes terrain in the Yucatan Peninsula relative to the Turkey Point Units 6 & 7 site and its vicinity is the relatively high rate of fresh groundwater discharge from a large inland watershed in the Yucatan that produces a more robust mixing zone and more carbonate dissolution (Reference 2.5.1-965). The absence of a more developed karst topography or an active mixing zone near the site (because of the location of the fresh groundwater/saltwater interface and the saline groundwater at the site) suggests that the process of shoreline flow that was instrumental in forming the cenotes of the Yucatan is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site or beneath the vegetated patches on the floor of nearby Biscayne Bay.

## 3. SUBSURFACE DISSOLUTION FEATURES AT THE TURKEY POINT UNITS 6 & 7 SITE

The second type of feature related to carbonate dissolution identified on the site is secondary porosity. Zones of secondary porosity have formed in limestone beneath the site where microkarst features have developed (Subsections 2.4.12.3.1 and 2.5.1.2.4). These zones of secondary porosity provide pathways of preferential groundwater flow. The microkarst features formed when fresh groundwater formerly flowed from inland areas, mixed with seawater, and facilitated dissolution of sedimentary structures in the rock as it flowed through the zone of secondary porosity to the sea. However, the data from extensive site investigation for Turkey Point Units 6 & 7 (References 2.5.1-708 and 2.5.1-995) offers no evidence that karstification of the area has developed cavernous limestone with the potential for collapse. The zones of secondary porosity can be subdivided into two categories— touching-vug porosity and moldic porosity.

### 3.1 Touching-Vug Porosity

Touching-vug porosity occurs on the site within the approximate depth interval of 6.1 to 10.7 meters (20 to 35 feet) below the current land surface (-6.1 to -10.7 meters or –20 to –35 feet NAVD88) (Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353) near the contact of the Key Largo Limestone and the Miami Limestone and forms the "upper zone" of secondary porosity. The origin of this porosity is solution enlargement of burrows, inter-burrow vugs, moldic fossils, root molds, and vugs between root casts (Reference 2.5.1-405). These structures are sufficiently numerous and closely spaced so as to form a laterally continuous zone of interconnected voids. Data from drilling and coring within the zone of touching-vug porosity during the site subsurface investigation has shown the zone to be laterally persistent, with voids generally of centimeter scale, and very few indications of larger voids. A description of rod drops and their significance is further discussed in Section 5.2.

Dissolution of the limestone in this zone of secondary porosity likely occurred during the Wisconsinan glacial stage of the Pleistocene when sea level was lower than during the preceding interglacial stages when the Miami Limestone and Key Largo Limestone were formed (Reference 2.5.1-928) and fresh groundwater from the Everglades mixed with seawater and discharged through the zone toward the sea. The coralline vugs within the Key Largo Limestone typically exhibit evidence of precipitation of secondary minerals (i.e., calcite) (Subsection 2.5.1.2.2). This finding suggests that the environment within the upper zone of secondary porosity is currently one dominated by calcite recrystallization rather than solution. The position of the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), groundwater within the zone of touching-vug porosity is saline (Tables 2.4.12-210 and 2.4.12-211), and there is no freshwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote further dissolution of the limestone within the zone of touching-vug porosity does not now exist, and development of large underground caverns with the potential for collapse is not likely within this upper zone of secondary porosity. Further, this zone will be completely removed during excavation of the nuclear island foundations (Subsection 2.5.4.5.1).

### 3.2 Moldic Porosity

Moldic porosity occurs in pockets within the approximate depth interval of 18.3 to 22.9 meters (60 to 75 feet) below current land surface (–18.3 to –22.9 meters [–60 to –75 feet] NAVD 88) (Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353) in the Fort Thompson Formation and forms the lower zone of secondary porosity at the site. The origin of this zone is preferential dissolution of fossil shells and other organic structures rather than the matrix rock within which they are contained, resulting in void spaces within molds of the structures. Data from drilling and coring within the zone of moldic porosity during the site subsurface investigation has shown the zone to be persistent, with very few indications of voids larger than the molds of the bivalve shells.

Dissolution of the limestone in this zone of secondary porosity likely occurred during the mid-Pleistocene Epoch when sea level fluctuated to a level lower than when the Fort Thompson Limestone was formed and fresh groundwater from inland areas discharged through the formation toward the sea. As noted previously, the position of the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), groundwater within the zone of moldic porosity is saline (Tables 2.4.12-210 and 2.4.12-211), the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), and there is no freshwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote further dissolution of the limestone within the zone of moldic porosity does not now exist and development of large underground caverns with the potential for collapse is not likely within this lower zone of secondary porosity.

## 4. POTENTIAL FOR FORMATION OF OTHER TYPES OF CARBONATE DISSOLUTION FEATURES AT THE TURKEY POINT UNITS 6 & 7 SITE

### 4.1 Carbonate Dissolution Mechanisms

As noted previously, in addition to surficial dissolution, subsurface dissolution in a freshwater/saltwater mixing zone is an important mechanism for karst formation. This section provides examples of mixing zones that are currently active or have been active in the past in different environments within the site region, and discusses whether or not the active process in each example is likely to pose a hazard of carbonate dissolution and karst development at the site. Mixing zones can occur in both surface water as point source discharge and in groundwater as submarine groundwater discharge.

#### 4.1.1 Point Source Discharge

Point source discharge is a concentrated flow of spatially constricted fresh surface water into a saltwater body, and can affect the local water chemistry equilibrium with the potential to alter the rate of dissolution or deposition of carbonates within the mixing zone in the vicinity of the discharge. An example of a point source discharge is the outfall of a drainage canal into Biscayne Bay.

Outfalls closest to the site are the Model Land Canal (C107) outfall near the southeast corner of the Turkey Point cooling fresh canals, approximately 8 kilometers (5 miles) south of the site, and the Florida City Canal outfall, approximately 1.9 kilometers (1.2 miles) north of the site (Figure 2.4.1-203). Because of their distance from the site and the effects of variable discharge from the outfalls related to operation of their control structures, variable rainfall, tidal fluctuations, and hurricanes, neither outfall is likely to induce formation of cavernous limestone with the potential for collapse at the site.

#### 4.1.2 Submarine Groundwater Discharge

Submarine groundwater discharge is fresh groundwater flow from beneath the seafloor into the overlying ocean. This process can be subdivided into two types— shoreline flow and deep pore water upwelling.

##### 4.1.2.1 Shoreline Flow

Shoreline flow is the movement of groundwater into the nearshore ocean driven by an inland hydraulic head through an aquifer to the nearshore mixing zone at the interface of the freshwater lens near the top of the aquifer and the saltwater wedge near the bottom of the aquifer. The resulting chemical disequilibrium with respect to calcium carbonate saturation (Reference 2.5.1-945) promotes dissolution of carbonate rock. The nearshore groundwater flow domain has been referred to as a subterranean estuary because of its similarity to the dynamic nature of a surface estuary with respect to tidal influence and mixing of waters with differing chemistry (Reference 2.5.1-946). As further discussed in the following subsections, several features identified within the site region provide evidence of current or former shoreline flow.

### Freshwater Springs Near the Shore of Biscayne Bay

As further discussed in Subsection 2.5.1.1.1.1.1.1, fresh groundwater had formerly discharged along the shoreline east of the Atlantic Coastal Ridge and offshore as submarine freshwater springs in Biscayne Bay before lowering of surface water and groundwater levels in southeast Florida related to construction of drainage canals and withdrawals of groundwater to support urban development. Saline to brackish shoreline springs still exist in the bay (Reference 2.5.1-1000). Their flow paths were likely formed originally by freshwater dissolution (Figure 2.5.1-391) (Reference 2.5.1-1000).

Aerial imagery for the shoreline near Turkey Point Units 6 & 7 from 1938 clearly captures an offshore spring and groundwater seepage only 1500 meters (4921 feet) from the approximate site center-point (Figure 2.5.1-391). Gonzalez (Reference 2.5.1-1000) relocated the seepage/discharge point in 2004, but did not observe flow. Generally though, the approximately relocated spring site was characterized by sediment-filled, seagrass-covered karst holes.

At least 21 additional offshore springs (identified by green circles on Figure 2.5.1-391) were located in 2006 by Gonzalez (Reference 2.5.1-1000) in an area approximately mid-way between the aforementioned Mowry and Coral Gables canals. Generally, Gonzalez (Reference 2.5.1-1000) classified these seepage points as small, ephemeral openings in soft sediment, typically less than 15 centimeters (6 inches) across, or as more persistent, large diameter (1 to 4 meters [3 to 13 feet]) features. Discharge from the larger diameter features was described as strong with resulting exposure of the limestone surface and associated karst conduits, although dry season flow was apparently discernible only during low tide. Flow in the smaller, ephemeral springs was visible only in the wet season, or following precipitation events. Flow in all springs was diminished when nearby canal flood gates were opened.

These low discharge rates are most likely due to blockage by sand and rising sea level. Rising sea level, interception of shallow groundwater flow by the drainage canals throughout much of southeast Florida, and redistribution of the discharge to point locations have also caused the fresh groundwater/saltwater interface to move further inland, resulting in increased salinity of the discharge from the springs. Gonzalez (Reference 2.5.1-1000) reported that the spring waters were slightly acidic, and ranged in salinity from approximately 8 to 31 grams per liter (g/L) (equivalent to 8 parts per thousand [ppt] to 31 ppt). The diminished discharge and water quality in the shoreline springs suggests that the propensity for further development of dissolution features by shoreline flow in nearshore areas of southeast Florida, including the Turkey Point Units 6 & 7 site, is diminished compared to the prevailing conditions before redistribution of the groundwater flow.

### Cave Development Along the Atlantic Coastal Ridge

There are no freshwater springs discharging into Biscayne Bay, primarily due to interception of groundwater flow by the drainage canals in southeast Florida and the general trend of rising sea level (Reference 2.4.5-206). However, what remains are the currently dry channels of past groundwater flow that were formed by dissolution in the shoreline mixing zone. As further discussed in Subsection 2.5.1.1.1.1.1.1, these are the caves of Miami-Dade County (Reference 2.5.1-955 and Figure 2.5.1-354).

Most caves of southeastern Florida occur on or along the eastern flanks of the Atlantic Coastal Ridge or along the edges of transverse glades that cut through the Atlantic Coastal Ridge, where 27 caves have been identified (References 2.5.1-955 and 2.5.1-1004) (Figure 2.5.1-391). This landform ranges in elevation from approximately 3 to 15 meters (10 to 50 feet) above sea level and averages approximately 8 kilometers (5 miles) wide. Entrances to the caves are either along the glade wall or occur as pits subjacent to the glade wall (Reference 2.5.1-1004). The Atlantic Coastal Ridge is composed of the Miami Limestone (Figures 2.5.1-201 and 2.5.1-217), which was formed during the two most recent high sea level stands of the Pleistocene interglacial stages (References 2.5.1-405 and 2.5.1-928). As sea level decreased during the Wisconsinan glacial stage that followed the last interglacial stage, meteoric water infiltrated the emergent portion of the Miami Limestone and formed a freshwater aquifer. The hydraulic head within the aquifer drove groundwater to flow toward the sea.

The Atlantic Coastal Ridge caves formed by solution enlargement of sedimentary structures in the Miami Limestone as groundwater entered the freshwater/saltwater mixing zone and discharged as shoreline flow on the margin of the coastal ridge. The freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the coast (Figure 2.4.12-207), groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), resulting in shoreline flow at the Turkey Point Units 6 & 7 site that is brackish to saline. Additionally, the strata within the Atlantic Coastal Ridge, where the cave formation has taken place, are at a higher elevation than the layers of Miami Limestone that underlie the site. Therefore, the mixing zone process that formed the caves along the flanks of the Atlantic Coastal Ridge is not likely to be currently active in formation of cavernous limestone with the potential for collapse in the area of the site.

### Karst Development on Emergent Carbonate Islands in the Bahamas

As further discussed in Subsection 2.5.1.1.1.1.1.1, flank margin caves form on emergent carbonate islands in the Bahamas as large globular mixing chambers at the freshwater/saltwater interface near the shoreline. Banana holes are another karst feature in the Bahamas. These features form inland from the flank margin caves and near the top of the fresh groundwater lens where the vadose and phreatic freshwaters mix. Both flank margin caves and banana holes are found in the Bahamas at elevations of 1 to 6 meters (3.3 to 20 feet) above the current sea level. The caves likely formed during the Sangamon interglacial stage (Reference 2.5.1-263), when sea level was higher than it is now. The process of shoreline flow that formed the flank margin caves may be active in the Bahamas today, but at an elevation closer to modern sea level. However, similar processes are not likely to be active at the Turkey Point Units 6 & 7 site because of the absence of fresh groundwater shoreline flow near the site. The position of the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206). Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist.

### Submarine Paleokarst Sinkhole in the Key Largo National Marine Sanctuary

As further discussed in Subsection 2.5.1.1.1.1.1.1, a large sediment-filled submarine paleokarst sinkhole with a diameter of approximately 600 meters (1968 feet) and a depth likely to exceed 100 meters (328 feet) has been investigated by Shinn et al. in the Key Largo National Marine Sanctuary off Key Largo, Florida (Reference 2.5.3-228). Shinn et al. postulate that the Key Largo submarine paleokarst sinkhole is a cenote that developed during the Pleistocene. As sea level rose during recession of the last (Wisconsinan) glacial stage, a freshwater lake in the bottom of the sinkhole would have deepened as the groundwater level adjusted to the rising sea level. Infilling of the sinkhole most likely began with precipitated freshwater calcite muds (i.e., marl). The area of the sinkhole eventually became engulfed by the sea, marine sedimentation ensued and the area evolved to the current marine environment, at which point conditions conducive for continued limestone dissolution and sinkhole formation no longer existed.

As noted previously, because the position of the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), there is no fresh groundwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist, and the process of shoreline flow that formed the Key Largo submarine paleokarst sinkhole is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site.

### Blue Holes in Eastern South Andros Island, Bahamas

As further discussed in Subsection 2.5.1.1.1.1.1.1, the blue holes beneath South Andros Island, Bahamas, are surface openings leading to an extensive system of submarine caves developed along nearshore fracture systems. Formation of the blue holes, which reach depths exceeding 100 meters, began during a previous eustatic sea level low stand associated with advance of continental glaciation during the Pleistocene. Circulation of fresh groundwater to the blue holes is facilitated by the fracture permeability that exists within the fracture systems in the carbonate rock. Mixing of fresh groundwater and seawater in the fracture systems has facilitated dissolution of the rock and vertical development of the blue holes as sea level rose during one or more interglacial stage(s) of the Pleistocene.

A similar nearshore fracture system has not been identified in the limestones within the area of the Turkey Point Units 6 & 7 site. As noted previously, the position of the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), and there is no fresh groundwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist. For these reasons, conditions favorable for formation of dissolution features similar to the blue holes of the Bahamas do not appear to exist in the site area.

### Karst Development on the Yucatan Peninsula, Quintana Roo, Mexico

The Yucatan Peninsula is outside of the 200-mile radius “site region,” but karst development there provides evidence of former shoreline flow and, therefore, is discussed here. As further discussed in Subsection 2.5.1.1.1.1.1.1, caves have formed in the Yucatan Peninsula along the margin of the discharging fresh groundwater lens as a result of freshwater/saltwater mixing near the coast.

Cave sediment fill, speleothem, and ceiling-level data indicate multiple phases of cave development. These multiple phases are associated with glacio-eustatic changes in sea level. Because of the continued accretion of carbonate rocks along the coast during the Pleistocene, caves that are now located in the interior of the Yucatan Peninsula were near the coast during past sea level high stands and have gone through multiple phases of development that alternate between active phreatic enlargement and vadose incision and sedimentation. Collapse of the cave roofs on the Yucatan Peninsula is extensive and ubiquitous, which results in development of crown-collapse surface cenotes. Collapse is a result of the large roof spans caused by lateral expansion of passages at the level of the mixing zone, the low strength of the poorly cemented Pleistocene limestones, and the withdrawal of buoyant support during sea level low stands.

The greater topographic relief of the cenotes terrain of the Yucatan Peninsula provides a stark contrast with the flat topography seen at the Turkey Point Units 6 & 7 site and in the available bathymetric data for the near-site area of Biscayne Bay. The apparent origin of the greater topographic relief and a much more developed karst regime in the cenotes terrain of the Yucatan Peninsula relative to the Turkey Point Units 6 & 7 site and its vicinity is the relatively high rate of fresh groundwater discharge from a large inland watershed in the Yucatan that produces a more robust mixing zone and more carbonate dissolution (Reference 2.5.1-965). The absence of a more developed karst topography and an active mixing zone near the site (because of the location of the freshwater/saltwater interface as shown in Figure 2.4.12-207 and the presence of saline groundwater at the site as demonstrated by Tables 2.4.12-210 and 2.4.12-211) suggests that the process of shoreline flow that is instrumental in forming the caves on the Yucatan Peninsula is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site.

#### 4.1.2.2 Hypogene Dissolution

Klimchouk (References 2.5.1-1005 and 2.5.1-1006) has generally described hypogene speleogenesis as dissolution-enlarged permeability (flow) structure development via ascending waters, driven by regional and/or more localized hydraulic potentials (i.e., hydrostatic pressures) or other convective circulation mechanisms. Given the vertical heterogeneity inherent in most sedimentary sequences, this upward groundwater flow implies some hydrological confinement (artesian conditions) rather than surface recharge. In southeastern Florida, confinement is largely provided by the Peace River and middle and upper (non-carbonate) Arcadia formations. Potential for ascending flow (and, by inference, hypogene speleogenesis) thus exists in the lowermost Arcadia Formation and the underlying Suwannee and Ocala limestones, and the Avon Park, Oldsmar, and upper Cedar Keys formations (i.e., the Floridan aquifer system).

Kohout (References 2.5.1-1007 and 2.5.1-1008) posited that thermally-induced convective circulation was occurring in the Floridan aquifer system within southern Florida. Specifically, Kohout (References 2.5.1-1007 and 2.5.1-1008) suggested upward flow from the lower Floridan aquifer through a middle, semi-confining unit in the aquifer (namely, the Avon Park Formation) and subsequent seaward flow within the upper Floridan aquifer. In the Turkey Point Units 6 & 7 vicinity, the aforementioned upper Floridan aquifer includes the lower Arcadia, Suwanee, and uppermost Avon Park formations. Aquifer units ascribed to the Ocala limestones are missing in the site vicinity.

Specifically, the Kohout circulation mechanism assumes that horizontal and vertical temperature distributions in the Florida Straits (and Gulf of Mexico) allow cold, dense saline water to flow into the Florida Platform at depth. At depth, this water is warmed by geothermal flow. A corresponding reduction in density produces an upward convective circulation which brings saline water (seawater) into contact with fresh waters recharged via downward flow in central Florida karst regions. Mixing with fresh water results in further density reductions, and allows the diluted seawater (saltwater) to migrate (flow) seaward and discharge (by upward leakage through confining beds) into the shallow coastal zone or deeper submarine springs on the continental shelf and/or slope.

Meyer (Reference 2.5.1-1009) noted that groundwater ages and radiocarbon and uranium isotope concentration data within the Floridan aquifer substantiate Kohout convection, and suggested that inland flows associated with the circulation pattern were as high as 52 meters (172 feet) per year in the early Holocene, at least in the so-named boulder zone in the Oldsmar Formation. Meyer (Reference 2.5.1-1009) estimated modern Kohout circulation inland flows to be only about 1.5 meters (5 feet) per year. It is thus assumed that Kohout circulation (and, by inference, hypogene dissolution) has slowed over the Holocene, as sea levels stabilized. Morrissey et al. (Reference 2.5.1-1010) argued that this decreased inland flow was associated with increased coastal groundwater levels (i.e., hydraulic head) from long-term Holocene sea level rise, and subsequent reduced hydraulic gradients (and thereby flow velocities) across the Florida platform.

Very few studies from southeastern Florida explicitly address (or invoke) hypogene dissolution processes as a cave or cavity/void forming mechanism. Most notably, Cunningham and Walker (Reference 2.5.1-958) proposed two hypogene mechanisms to possibly explain structural sags in

Biscayne Bay and the Atlantic Ocean: (1) upward groundwater flow via Kohout convection and subsequent carbonate dissolution by mixed fresh and saline waters, and (2) dissolution associated with upward ascending hydrogen-sulfide-rich groundwater, sourced from calcium sulfates in deeper Eocene (or Paleocene) age rocks.

Generally, the aforementioned sag structures in Biscayne Bay and the Atlantic Ocean are multi-storied (vertically stacked) features that vary in total width from about 200 meters (655 feet) to well-over 1 kilometer (0.6 miles). Cunningham and Walker (Reference 2.5.1-958) interpreted the larger (i.e., kilometer-scale [mile-scale]) stacked sag structures as evidence for coalesced, collapsed, multi-story maze paleocave systems and associated deformation (fractures, faults, sagging, etc.). Narrower stacked sag structures were interpreted as evidence for more isolated (i.e., individual) subsurface void collapses. Generally, the hypogene dissolution process (speleogenesis) is associated with such multi-story maze caves and isolated subsurface cavities/voids.

Cunningham and Walker (Reference 2.5.1-958) also suggested that submarine sinkholes located along the Pourtalès and Miami terraces as identified by Land et al. (Reference 2.5.1-1018) and Land and Paull (Reference 2.5.1-951) were potential evidence for freshwater/saltwater mixing and subsequent dissolution resulting from upward flow during Kohout circulation. It is important to note that Land et al. (Reference 2.5.1-1018) and Land and Paull (Reference 2.5.1-951) only intimated that upward convective (Kohout) circulation could be responsible for the sinkholes, but did not completely discount epigenetic formation processes.

Additional data related to the aforementioned sag and sinkhole features is provided below. In summary, though, it should be noted that Cunningham and Walker (Reference 2.5.1-958) present no real (i.e., tangible) evidence to support a hypogene origin for these features, either via Kohout circulation and freshwater/saltwater mixing or dissolution by hydrogen-sulfide-rich waters.

### Submarine Paleokarst Sag Structures Beneath Biscayne Bay

As indicated above, Cunningham and Walker (References 2.5.1-958 and 2.5.1-989) collected high-resolution, multichannel seismic-reflection data in Biscayne Bay and identified disturbances in parallel seismic reflections that correspond to the carbonate rocks of the Floridan aquifer system and the lower part of the overlying intermediate confining unit. The disturbances in the seismic reflections are indicative of structural deformation in carbonate rocks of Eocene to middle Miocene age. As discussed further in Subsection 2.5.1.1.1.1.1.1, the deformation is interpreted by Cunningham and Walker to be related to collapsed paleocaves and includes fractures, faults, and seismic-sag structural systems. The study suggests alternative mechanisms that might have led to formation of the caves, including hypogene speleogenesis.

Regardless of the formative process, the geophysical data indicates the absence of deformation in rocks younger than Pliocene (Figures 2.5.1-357, 2.5.1-358, and 2.5.1-359). This finding suggests that, if the same mechanism had been active at the Turkey Point Units 6 & 7 site during the Eocene, none of the strata younger than Pliocene would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, and upper Tamiami Formation.

### Onshore Sag Structures in Broward and Miami-Dade Counties

Cunningham and Walker (Reference 2.5.1-958) and others (References 2.5.1-1013, 2.5.1-1014, 2.5.1-1015 and 2.5.1-999) also identified 24 onshore sag structures in northeastern Miami-Dade and eastern Broward counties (Figure 2.5.1-391). These features are also interpreted as paleokarst sinkholes or faults and fractures and have the same formation history as the broad and narrow seismic sag structural systems in Biscayne Bay (Reference 2.5.1-1013).

Although Cunningham and Walker (Reference 2.5.1-958) did not explicitly attribute the aforementioned sags to hypogene dissolution processes, the vertical stacking is consistent with collapse in a multi-story hypogene cave system, as described by Klimchouk (Reference 2.5.1-1005). Nevertheless, Cunningham (Reference 2.5.1-999) cites evidence (unspecified) for hypogenic karst collapse in just one southeast Florida location, a borehole (well) in the Miami-Dade Water and Sewer Department (MDWASD) northern wastewater injection field, at depths attributed to the much deeper and older Avon Park and Oldsmar formations. Moreover, Cunningham (Reference 2.5.1-999) has suggested that a different sag feature within the MDWASD's southern wastewater injection field could reflect subaerial exposure and sinkhole development (i.e., epigenetic dissolution) along a major sedimentation and subsidence stratigraphic/sequence boundary.

Cunningham and Walker (Reference 2.5.1-958) suggested that Kohout circulation (and hypogene speleogenesis) in southern Florida were likely initiated in the Eocene. At least one structure was interpreted by Cunningham and Walker (Reference 2.5.1-958) as indicating four cave formation and collapse cycles in middle Eocene to middle Miocene rocks.

Importantly, in the Turkey Point Units 6 & 7 site vicinity, deformation associated with the aforementioned structural sags does not seem to extend beyond (above) the Oligocene to Miocene age Arcadia Formation. Nevertheless, sag features with deformation extending upward into the Peace River and Tamiami formations have been imaged below the North New River and Hillsboro canals, located approximately 77 kilometers and 101 kilometers (48 miles and 63 miles) from the site, in Broward and Palm Beach counties (References 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015). It is possible then that cave formation and/or collapse occurred as late as the Pliocene.

As already noted, Meyer (Reference 2.5.1-1009) and Morrissey et al. (Reference 2.5.1-1010) have suggested that Kohout circulation remains active in southeastern Florida. Carbonate dissolution via hypogene mechanisms (mixing-induced dissolution or dissolution by ascending sulfide-rich waters) is thus possible in the lower and middle (semi-confining) Floridan aquifer units (i.e., in areas wherein groundwater flow is predominantly upward). Existing cross-formational permeability structures (faults, fractures, cavities, etc.) could also drive upward flow (and corresponding hypogene speleogenesis) in localized areas. Consequently, various tectonic faults, folds, and fractures and the faults and fractures associated with the sag structures identified by Cunningham and Walker (Reference 2.5.1-958) and others (References 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015) could thus serve as vertical groundwater flow paths (Reference 2.5.1-958) and loci for active hypogene speleogenesis in southeastern Florida.

### Jewfish Creek Paleokarst Feature

In addition to the sag structures in Biscayne Bay and Miami-Dade and Broward counties, a relatively large karst collapse feature was also identified during design work for a new bridge across Jewfish Creek and adjacent Lake Surprise on northern Key Largo (Figure 2.5.1-390) (Reference 2.5.1-1016).

Specifically, data from 34 geotechnical borings located on Jewfish Creek and within Lake Surprise provided evidence for localized loose sand layers that were interpreted as possible evidence for sediment transport (i.e., piping) into dissolution cavities (References 2.5.1-1016). At some locations, drilling water (circulation) losses were also observed, suggesting voids and/or highly permeable subsurface layers. For the most part, these water losses were concentrated at depths between 6 meters and 30 meters (20 feet and 100 feet).

Subsequent microgravity surveys over the same area provided evidence for a 100 microgal (μGal) anomaly centered between Jewfish Creek and Lake Surprise (References 2.5.1-1016). Generally, this gravity anomaly coincided with the aforementioned borehole locations showing evidence for cavities. Supplemental shallow and deep seismic reflection surveys in Lake Surprise also provided evidence for downward dipping reflectors located near the aforementioned gravity anomaly center and edges, and identified seven collapse (subsidence) structures filled with sediments derived from overlying materials. Generally, these collapse structures ranged in width from 30 to 60 meters (100 to 200 feet) and were distributed over a 580 meters (1900 feet) distance.

Technos (Reference 2.5.1-1016) interpreted the largest subsidence structure at Jewfish Creek/Lake Surprise as a cavity collapse in a soluble limestone layer, the Arcadia Formation, at depths below approximately 213 meters (700 feet). Corresponding subsidence in overlying Arcadia Formation layers, and in younger unconsolidated sands and capping limestone, inferred to be the Peace River, Tamiami, Caloosahatchee or possibly Fort Thompson, and Key Largo formations, was also interpreted from the seismic reflection data at depths between approximately 21 meters and 213 meters (70 feet and 700 feet). Density logs from geotechnical borings located adjacent to the collapse structure indicated voids and porous zones in the shallower formations, primarily between 6.1 meters and 21.3 meters (20 feet and 70 feet). Technos (Reference 2.5.1-1016) interpreted the seven structures as localized collapses, or collapse features associated with closely spaced and enlarged dissolution joints.

Given its great depth and lack of surface expression, the Jewfish Creek feature likely is not similar in origin to the semicircular vegetated patches on the seafloor of Biscayne Bay. The Jewfish Creek karst feature is more likely similar in origin to the seismic-sag structures described by Cunningham and Walker (Reference 2.5.1-958) below Biscayne Bay, as well as those onshore in Broward and Miami-Dade counties (References 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015). Alternatively, void formation may be linked to eogenetic (or syngenetic) dissolution processes, namely submarine groundwater discharge during sea level highstands and consequent enhanced carbonate dissolution at a former freshwater/saltwater interface.

### Crescent Beach Spring and Red Snapper Sink

Crescent Beach is located on a barrier island near St. Augustine, in northeast Florida. They are outside of the 200-mile radius “site region,” but the spring and sink are evidence of deep pore water upwelling and warrant discussion here. As further discussed in Subsection 2.5.1.1.1.1.1.1, Crescent Beach Spring is a freshwater submarine spring located approximately 4 kilometers (2.5 miles) east of Crescent Beach and is considered a first-order spring with a flow rate of greater than 40 cubic meters per second (634,000 gallons per minute) (Reference 2.5.1-946). The spring is located at a depth of 18 meters (59 feet) in the Atlantic Ocean, and erosion of confining strata to a depth of 38 meters (125 feet) at the mouth of the vent has enabled direct hydrologic communication of confined groundwater in the Floridan aquifer with coastal bottom waters.

The Red Snapper Sink is located approximately 42 kilometers (26 miles) off of Crescent Beach and is incised approximately 127 meters (417 feet) into the continental shelf at a water depth of 28 meters (99 feet). Divers investigating the sink observed that seawater was flowing into small caves at its base, indicating possible recharge to the Floridan aquifer, and that the water in the bottom of the sink was similar in salinity and sulfate content to ambient seawater. According to Moore (Reference 2.5.1-946), Red Snapper Sink was similar to Crescent Beach Spring before the piezometric head was lowered along the coast due to human activities and rising sea level.

The existence of Crescent Beach Spring and, by inference, Red Snapper Sink, indicates the presence of abundant fresh groundwater within confined aquifers on the continental shelf. Breaching of the confining layer overlying such aquifers by erosional or tectonic mechanisms has the potential to create similar submarine springs on the shelf off southern Florida. No capable faults that could induce a breach of the confining layer have been identified in the site vicinity (Subsection 2.5.3.6). Groundwater in the Biscayne aquifer (the surficial aquifer) is saline (Tables 2.4.12-210 and 2.4.12-211). Therefore, dissolution of carbonate rocks in the vicinity of deep pore water upwelling from this aquifer into the overlying ocean is not probable. At the site, the underlying Tamiami Formation and Hawthorne Group combined comprise more than approximately 152 meters (500 feet) of low-permeability rocks and sediments that overlie and confine the Floridan aquifer (Figures 2.4.12-202 and 2.4.12-204). Deep pore water upwelling generally occurs well offshore, where the slope of the shelf is steeper and erosion of this thickness of confining sediments is more likely. For this reason, carbonate dissolution associated with deep pore water upwelling from the Floridan aquifer is not likely to pose a threat of surface collapse or sinkhole hazard at the site.

### 4.2 Effect of Sea Level Fluctuation on Migration of the Freshwater/Saltwater Interface

Groundwater within the Biscayne aquifer is saline in the area of the site (Tables 2.4.12-210 and 2.4.12-211). Dissolution of limestone generally occurs where fresh, weakly acidic groundwater circulates through soluble carbonate rock or within zones of mixing fresh and seawater (References 2.5.1-263 and 2.5.1-965). The freshwater/saltwater interface within the Biscayne aquifer is located approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206). Therefore, the site is not a location of fresh groundwater discharge or mixing of fresh and saltwater, and the mechanism necessary to form large solution cavities does not appear to be active on or near the site.

A rise in sea level will increase the ocean hydrostatic head and tend to force intrusion of the freshwater/saltwater interface further inland and away from the site. Therefore, the mixing zone mechanism necessary to increase the potential for carbonate dissolution and formation of large solution cavities on or near the site will not exist. Collapse of solution cavities is generally associated with lowering of groundwater levels and withdrawal of buoyant support. A rising sea level will counter this effect.

Conversely, any potential lowering of sea level would tend to move the freshwater/saltwater interface seaward and toward the site. However, the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Reference 2.4.5-206), and sea level has been rising throughout the current interglacial stage of the Holocene. A significant lowering of sea level is not likely to occur until a future advance of continental glaciation, which is not likely to occur within the operating lifetime of the Turkey Point Units 6 & 7 plant. The magnitude of sea level lowering and the corresponding time necessary to move the interface to a location within the area of the site is not likely to occur within the lifetime of the Turkey Point Units 6 & 7 plant (Reference 2.4.5-206). Therefore, increased carbonate dissolution or formation of large solution cavities on or near the site due to a lowering of sea level is not likely to occur during construction or operation of the plant.

### 4.3 Potential for Sinkhole Development During Site Construction

The deepest excavations during plant construction will be approximately 10.7 meters (35 feet) below the current grade level (Subsections 2.5.4.5.4 and 2.5.4.6.2). This depth is also approximately 10.7 meters (35 feet) below the water table (Appendix 2AA). The current plan to provide temporary ground support and control groundwater during site construction is discussed in Section 5.1 and in Subsection 2.5.4.6.2.

Construction of the proposed reinforced concrete diaphragm walls and grout plug is expected to provide a low-permeability barrier to groundwater flow that will minimize seepage into the foundation excavations and lowering of the hydrostatic head within the Biscayne aquifer surrounding the excavations. Dewatering requirements during construction are expected to be greatly reduced by use of these construction techniques. Change in hydrostatic stress or reduction of buoyant support of the limestone due to lowering of groundwater levels within the Biscayne aquifer related to construction dewatering is expected to be negligible and not to induce carbonate dissolution, cavity formation, or sinkhole collapse.

## 5. CLARIFICATION OF ISSUES RELATED TO INTERPRETATION OF DATA FROM THE SUBSURFACE INVESTIGATION AT THE TURKEY POINT UNITS 6 & 7 SITE

### 5.1 Assumptions in the Interpretation of the Microgravity Survey Data

As further discussed in Subsection 2.5.4.4.5, a microgravity geophysical survey was conducted within the footprint of the nuclear islands at the Turkey Point Units 6 & 7 site. The objective of the geophysical surveys was to identify subsurface voids that may pose a risk of collapse. Density is the property measured by a microgravity survey. Gravity anomalies occur where there is sufficient contrast in density of materials. The magnitude and, therefore, the detectability of a microgravity anomaly depends on the density contrast between the target feature and its surrounding rock and the size, depth and location of the target with respect to the survey line. The density values used to interpret and model the subsurface density distribution at the site were determined by laboratory testing of soil and rock samples from the site, published literature, and experience conducting similar geophysical surveys in southern Florida.

Repeated measurements at 22 percent (135) of the microgravity stations at the site produced an average deviation of approximately 3 microgals (µGals) (Subsection 2.5.4.4.5.1). Therefore, anomalies equal to or greater than 10 µGals should be routinely detectable above the noise related to instrumentation and measurement variability. In general, subsurface structures approximated as spherical in shape can be detected at a depth to their center of approximately two times their effective diameter at the 10 µGal detection threshold. A spherical cavity provides the most conservative analysis because it contains the most compact form of “missing mass” and, therefore, produces the smallest gravity anomaly for a given cavity diameter.

Under more geologically plausible conditions, cavities formed by karst dissolution would require at least one entrance and one exit conduit and would approximate a more detectable horizontal cylindrical shape. A water-filled horizontal conduit 3 meters (10 feet) in diameter theoretically would be near the conservatively chosen detection threshold of 10 µGal if centered within the Key Largo Limestone at a depth of 12.2 meters (40 feet). In contrast, a water-filled spherical cavity at the same depth would have to be 7.6 meters (25 feet) or more in diameter to be detected (Subsection 2.5.4.4.5.1). On this basis, it is reasonable to assume that, if a roughly horizontal and cylindrical underground cavity sufficiently large to pose a risk of surface collapse (on the order of 3 meters [10 feet] in diameter) were present beneath one of the microgravity survey lines at the depth of the bottom of the nuclear island foundations (approximately 10.7 meters [35 feet], Subsections 2.5.4.5.4 and 2.5.4.6.2), it would be detectable in the microgravity data.

Lateral resolution of microgravity survey data is limited by the spacing between measurements and the geometry of the subsurface target. Because a gravimeter measures the vertical component of the earth's gravitational field, as the lateral offset between a buried target and the survey line increases, the vertical component of the gravitational acceleration due to the target is reduced and a smaller anomaly will be measured. Very shallow targets produce short wavelength (narrow) anomalies, whereas deeper targets produce longer wavelength (wide) anomalies. As spacing between two targets becomes smaller, the ability to resolve the two diminishes because their anomalies merge into one.

The evaluated data within the vegetated surface depressions includes: the existing boring data (References 2.5.1-708 and 2.5.1-995); the surficial deposit sampling (Reference 2.5.1-996); and the updated microgravity models and recontouring of MASW results (Reference 2.5.4-320). All of these data indicate that low density measurements are associated with the presence of peat in vegetated depressions and density variations within more weathered Miami Limestone (Reference 2.5.4-320), rather than with large deep cavities. Significantly lower density of the peat deposits (Reference 2.5.1-996) explains the anomalies encountered during the original microgravity survey (References 2.5.4-286 and 2.5.4-320).

Based on review of the complete geophysical data set, there is no evidence for the presence of large paleokarst sinkholes or large open voids within the survey area. However, resolution of the geophysical data diminishes with increasing depth, decreasing cavity size, and increasing offset from survey lines, introducing an element of uncertainty regarding the interpretation of this data at and below the approximate depth of the nuclear island foundations.

To reduce uncertainties in the resolution and interpretation of microgravity data with depth and offset from geophysical survey lines and boreholes, a second microgravity survey at the base of the excavations for the nuclear island foundations is proposed. As further discussed in Subsections 2.5.4.5.4 and 2.5.4.6.2, the current plan to provide temporary ground support and control groundwater while excavating is to install (before excavation) reinforced concrete diaphragm walls from the ground surface to approximately elevation –18.3 meters (–60 feet) NAVD 88 on all four sides of the excavation and an approximately 7.6– meter (25-foot) thick grout plug throughout the entire area within the diaphragm walls in the elevation interval from approximately –10.7 to –18.3 meters (–35 to –60 feet) NAVD 88 (immediately below the bottom of the foundations). The objective of the grout plug is to fill voids that may exist beneath the nuclear island excavations to reduce vertical groundwater seepage into the excavations.

It is anticipated that the density of the grout plug will be similar to that of the rock on which the nuclear islands will be founded (Key Largo Limestone). Therefore, the grout plug effectively will be transparent to the proposed microgravity survey and the survey should be capable of detecting an anomaly produced by a water-filled cavity that is 3 meters (10 feet) in diameter if it is roughly the shape of a horizontal cylinder, or 7.6 meters (25 feet) in diameter if it is roughly spherical, centered approximately 12.2 meters (40 feet) below the base of the excavation (and 4.6 meters [15 feet] below the bottom of the grout plug). Preliminary estimates indicate that a hypothetical solution cavity with an approximate diameter of 9.1 meters (30 feet) at a depth immediately below elevation –18.3 meters (–60 feet) NAVD 88 would have a negligible effect on the stability of the nuclear island foundation.

## 5.2 Significance of Rod Drops as Indicators of Possible Subsurface Cavities

A “rod drop” occurs when, while drilling, the bit encounters a relatively soft zone or void and the drill head and rod string suddenly advances at a rate much faster than the rate when drilling the overlying more competent material. A rod drop can also occur during standard penetration testing when the weight of the string of drill rods is sufficient to advance the standard penetration testing sampler at the bottom of the borehole without additional blows of the sampling hammer. The occurrence of a rod drop indicates the presence of very soft or very loose material, which can be interpreted as void or cavity infill or as interbedded materials with substantially different hardness or compactness. Alternatively, a rod drop could indicate that the drill or sampler might have penetrated a cavity that is only partially filled with soft or loose material.

The evaluation of all data (References 2.5.1-708 and 2.5.1-995) indicates that outside the vegetated depressions and drainages (in vertical borings), a total of 20.1 feet of interpreted tool drops (due to voids and/or voids filled with soft sediments) are observed, in a total of 7919 feet cored, for a 0.3 percent of the total cored in 93 borings. Individual drops in the vertical borings range from 0.4 feet to 4 feet (1.5 feet max within the Unit 6 & 7 building footprints). Results from the site investigations (References 2.5.1-708 and 2.5.1-995) show that interpreted tool drops are found more often under the vegetated depressions and drainages. In the three inclined borings, a total of 15.2 feet of tool drops are observed, in a total of 356.4 feet cored, for a 4.3 percent of the total cored length. Individual drops in the inclined borings range from 0.3 to 2.5 feet. Boring locations with interpreted tool drops, among all sampling locations, are shown in Figure 2.5.1-378. The maximum length of interpreted tool drop (due to voids and/or voids filled with soft sediments) is limited to 1.5 feet within the Unit 6 & 7 building footprints, and the frequency of encountering an interpreted tool drop is less than 0.5 percent site-wide. These statistics are based on the drilling conducted during both, the initial and supplemental site investigations (References 2.5.1-708 and 2.5.1-995).

Groundwater levels monitored in onsite observation wells indicate a consistent site-wide upward vertical flow potential within the Biscayne aquifer (Table 2.4.12-204). In this situation, the upward hydrostatic head within the aquifer may have caused an upward blowout of the sand into the borehole when the confining layer above the sand was breached. The rod drops may have occurred not because the drill or sampler encountered very soft or very loose material indicative of void infill, but because liquefaction of the sand in the blowout zone reduced its bearing capacity to less than the down-pressure on the drill or the weight of the rod string.

### 5.3 Significance of Closed Contours on the Key Largo Isopach Map

Isopach and structure contour maps for the Key Largo Limestone and Fort Thompson Formation illustrate the thickness and surface topography of these units, which may show evidence for subsurface voids in either unit. These maps are included here as Figures 2.5AA-207, 2.5AA-208, 2.5AA-209, and 2.5AA-210. Geologic cross-sections A-A', B-B', C-C' and D-D' have also been revised. The locations of their surface traces are shown on Figures 2.5AA-207, 2.5AA-208, 2.5AA-209, and 2.5AA-210. Two versions of each of the four cross-sections are provided. Cross-sections in the first set (Figures 2.5AA-211, 2.5AA-212, 2.5AA-213, and 2.5AA-214) are truncated at the elevation of –61 meters (–200 feet) NAVD 88 and depict the subsurface stratigraphy with a vertical exaggeration of 12 to 1. Figures 2.5AA-215, 2.5AA-216, 2.5AA-217 and 2.5AA-201 depict a thicker section of the subsurface stratigraphy on the same cross-sections with a vertical exaggeration of only 4 to 1.

Comparison of Figure 2.5AA-207 (Isopach Map of the Key Largo Limestone) and Figure 2.5AA-208 (Structure Contour Map of the Top of the Fort Thompson Formation) suggests that there is no strong correlation between the thickness of the Key Largo Limestone and the topography at the top of the Fort Thompson Formation. There are no colocated and similarly oriented closed-contour depressions on the two maps. This observation suggests the absence of a large collapse feature within the Fort Thompson Formation that extends upward into the Key Largo Limestone. The broad depressions with 0.6 to 0.9 meter (2 to 3 feet) of relief shown on the top of the Fort Thompson Formation in the vicinity of borings B-634 and B-729 (Figure 2.5AA-208) may be an expression of paleodrainage. That paleodrainage may be reflected in the broad, relatively thin zones in the same areas of the Key Largo Limestone shown on Figure 2.5AA-207. This relationship may be a reflection of the underlying topography on which the Key Largo Limestone was deposited.

Similarly, there does not appear to be a strong correlation between Figure 2.5AA-208 and Figure 2.5AA-209 (Structure Contour Map of the Top of the Key Largo Limestone). Although both maps show a depression in the area of soil boring B-727, the topographic relief within the depression on the surface of the Fort Thompson Formation in this area is approximately 0.8 meter (2.5 feet), whereas the topographic relief in the depression on the surface of the overlying Key Largo Limestone in the same area is approximately 3 meters (10 feet). It seems unlikely that subsidence of approximately 0.8 meter (2.5 feet) in the Fort Thompson Formation due to collapse of a hypothetical solution cavity would induce corresponding subsidence of approximately 3 meters (10 feet) in the Key Largo Limestone.

It can be noted that, with one exception, in the few instances where closed-contour depressions have been mapped on the structure contour and isopach maps, the topographic relief within the depressions is no more than 0.3 to 0.6 meter (1 or 2 feet). This observation suggests that the topography of the top surface of both the Key Largo Limestone and Fort Thompson Formation is relatively flat. The one exception is on the top of the Key Largo Limestone (Figure 2.5AA-209) in the vicinity of boring B-706, where the topographic relief is approximately 1.8 meters (6 feet). Comparison with the isopach map of the Key Largo Limestone (Figure 2.5AA-207) reveals that boring B-706 is within a broad area of thinning of the unit that may be an expression of paleodrainage.

The structure contour map of the top of the Key Largo Limestone (Figure 2.5AA-209) does not correlate strongly with the locations of the vegetated depressions onsite (“mangroves” in Figure 2.5.4-223). This finding suggests that the dissolution that has occurred within and beneath these vegetated depressions has not greatly affected the top of the Key Largo Limestone.

Similarly, the structure contour map of the top of the Key Largo Limestone (Figure 2.5AA-209) does not correlate strongly with data from the microgravity geophysical survey (Figure 2.5.4-228), which provides an interpretation of the depth to which dissolution has produced softer rock with possible small voids within the Miami Limestone and Key Largo Limestone (Figure 2.5.4-226 and 2.5.4-227). This finding suggests that the depressions on Figure 2.5AA-209 do not indicate areas of dissolution that fully penetrate the overlying Miami Limestone and extend down into the Key Largo Limestone. However, it should be noted that the elevations of the bottom of the depressions on Figure 2.5AA-209 (–9.8 to –10.7 meters [–32 to –35 feet] NAVD 88) appear to be near the limit at which the microgravity survey can resolve structures of interest (Figure 2.5.4-227).

The probable origin of the depressions on the top of the Key Largo Limestone (Figure 2.5AA-209) is deposition that was influenced by paleodrainage features in the underlying Fort Thompson Formation. The depressions may also reflect restricted areas where syndepositional erosion or relatively little deposition occurred within a shallow patch reef environment.

A second possible mechanism for their formation is that the depressions in the top of the Key Largo Limestone formed by subaerial surficial dissolution during a low sea level stand of the late Pleistocene. It is widely believed (References 2.5.1-405 and 2.5.1-928) that deposition of the Key Largo Limestone and the overlying Miami Limestone occurred during the two most recent sea level high stands associated with Pleistocene interglacial stages (the Sangamonian and the preceding Yarmouthian), when sea level was near or several meters higher than the modern ocean. The Sangamonian and Yarmouthian interglacial stages correspond to the Q5 and Q4 time-stratigraphic sequences defined by Perkins (Reference 2.5.1-990) and adopted by other investigators. Subaerial dissolution of the Key Largo Limestone would have to have occurred during the downward fluctuation in sea level that followed the Q4 period. Deposition of the overlying Miami Limestone would have to have occurred during the subsequent Q5 period when sea level again rose.

## 6. CONCLUSIONS

Two types of features related to carbonate dissolution have been identified by the geotechnical subsurface investigation at the site. These features are vegetated depressions and zones of secondary porosity. Neither of these features is believed to pose a hazard of sinkhole development or foundation instability at the site. The vegetated depressions are surficial solution features formed by a subaerial, epigenic process of dissolution caused by downward seepage of slightly acidic meteoric groundwater in the near-surface carbonate rock. The zones of secondary porosity are microkarst features formed in the subsurface by solution enlargement of touching-vug and moldic porosity within former mixing zones at the interface of fresh groundwater and saltwater. The zones of secondary porosity provide pathways of preferential groundwater flow.

An upper zone of secondary porosity has formed in a zone of touching-vug porosity near the contact of the Miami Limestone and the Key Largo Limestone. A lower zone of secondary porosity has formed in a zone of moldic porosity in the underlying Fort Thompson Formation. The mixing zone in which the upper zone of secondary porosity formed was active at the site during the Wisconsinan advance of continental glaciation when the eustatic sea level was approximately 100 meters lower than the modern ocean. The lower zone of secondary porosity formed in a mixing zone during an earlier sea level low-stand of the Pleistocene that followed a sea level high-stand during which the Fort Thompson Formation was deposited.

The process that formed the vegetated depressions at the site and its vicinity is ongoing. However, the depressions appear to be no more than approximately 3.4 meters (11 feet) deep and are not subject to collapse into an underground cavity. The stratigraphic interval in which they occur will be removed completely during excavation of the nuclear islands. Because groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), the freshwater/saltwater interface is approximately 6 miles inland from the site (Figure 2.4.12-207), and mean sea level rise trend near the site is rising approximately 0.78 foot in 100 years, carbonate dissolution in a fresh groundwater/saltwater mixing zone by the process of shoreline flow is not likely to develop large underground voids with the potential for collapse and formation of sinkholes at the site.

Structure contour and isopach maps for the Key Largo Limestone and Fort Thompson Formation and cross-sections prepared with data from the site geotechnical subsurface investigation do not suggest the existence of large underground caverns or sinkholes. This conclusion is supported by the results of the evaluation and modeling of the microgravity models and recontouring of MASW results (Reference 2.5.4-320). All of these data indicate that low density measurements are associated with the presence of peat in vegetated depressions and density variations within more weathered Miami Limestone (Reference 2.5.4-320) rather than with large deep cavities.

Because of the planned method of groundwater control during site construction, no significant change in groundwater level or associated hydrodynamic stress that might lead to formation of sinkholes is anticipated. Similarly, changes in sea level and associated groundwater level that might occur during the operational life of the plant are not likely to increase the potential for formation of large underground cavities or foundation instability at the site.

## 7. REFERENCES


201. NOAA, Biscayne Bay, FL (S200) Bathymetric Digital Elevation Model (30 meter resolution) Derived from Source Hydrographic Survey Soundings Collected by NOAA, 1998. Available at www.estuarinebathymetry.noaa.gov, accessed November 7, 2011.

202. Google Earth[TM1] 25°25' 40.45"N and 80°19'17.56"W. Europa Technologies, Imagery date: March 26, 2011, accessed November 8, 2011.

203. Google Earth, 25°25'17.07"N and 80° 18'51.66"W. Europa Technologies, Imagery date: March 26, 2011, accessed November 8, 2011.

204. Google Earth, 25°08'37.11"N and 80°17'49.54"W. Imagery date: December 23, 2010, accessed November 7, 2011.

205. Google Earth, 25°25'40.45"N and 80°19'17.58"W. Europa Technologies, U.S. Geological Survey, Imagery date: January 14, 1994, accessed November 7, 2011.


[1] Google Earth is a trademark of Google Inc.

## Table 2.5AA-201
## Tabulated Data on Area and Distribution of Vegetated Patches

| Circle Area | Surface Type | No. of patches | Density of patches (per $mi^2$) | Mean patch area ($m^2$) | St. dev. of patch area ($m^2$) | Min area ($m^2$) | Max area ($m^2$) |
|---|---|---|---|---|---|---|---|
| 1 | Subaerial | 67 | 237 | 780 | 1420 | 20 | 7910 |
| 2 | Subaerial | 55 | 195 | 540 | 640 | 40 | 2440 |
| 3 | Primarily submarine | 67 | 237 | 180 | 150 | 20 | 700 |
| 4[(a)] | Submarine | 51[(a)] | 180 | 320 | 290 | 30 | 1420 |

(a) Mapping does not cover the entire area of the circle because the area of the circle extends beyond the area of aerial photo coverage; therefore, count is absolute minimum.

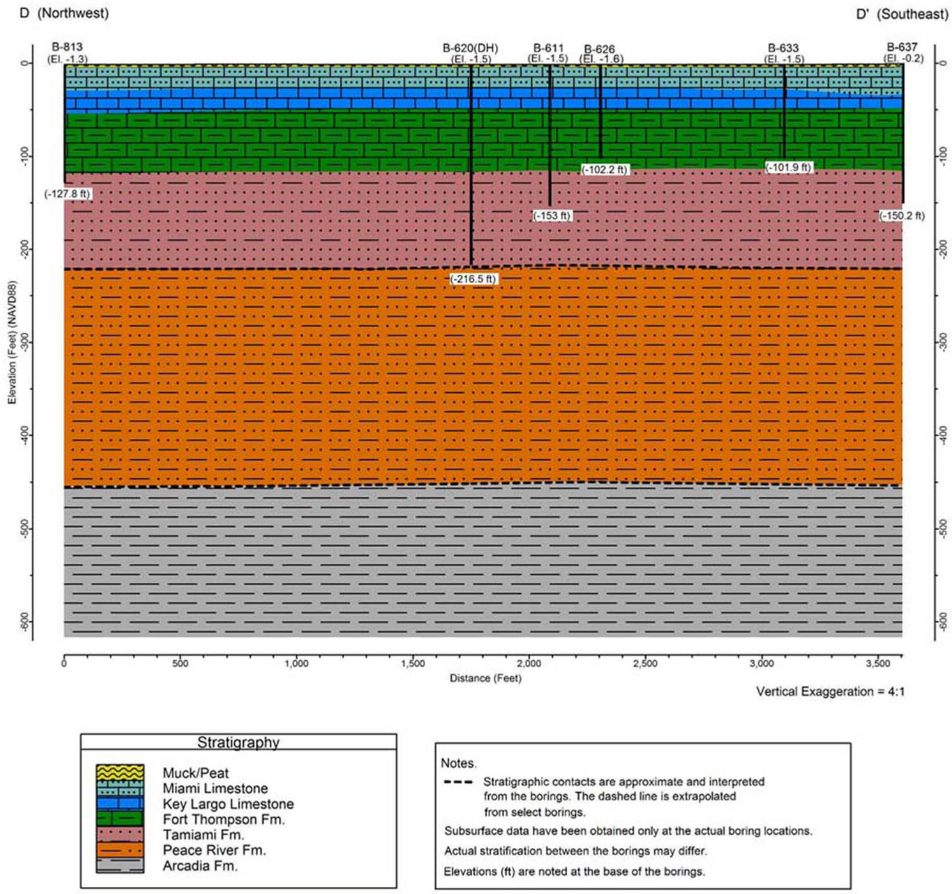
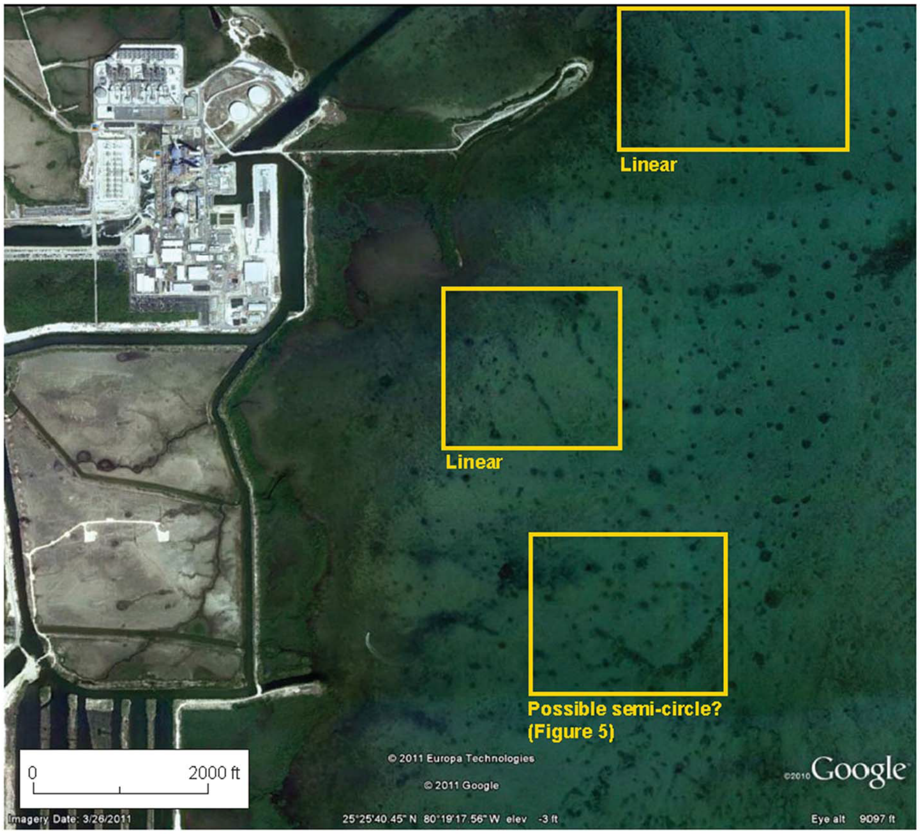


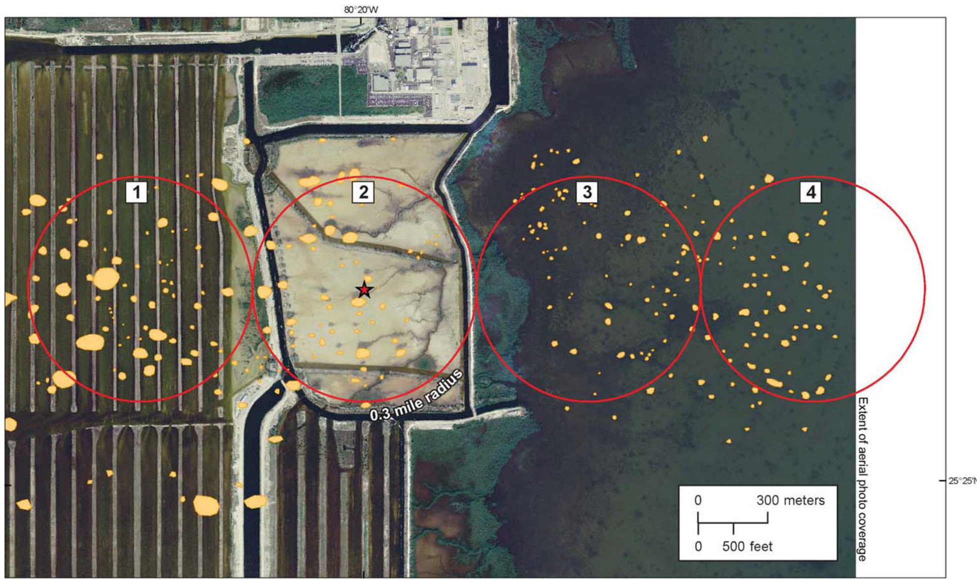

**Figure 2.5AA-201 Cross-Section D-D' (Vertical Exaggeration = 4:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-389**



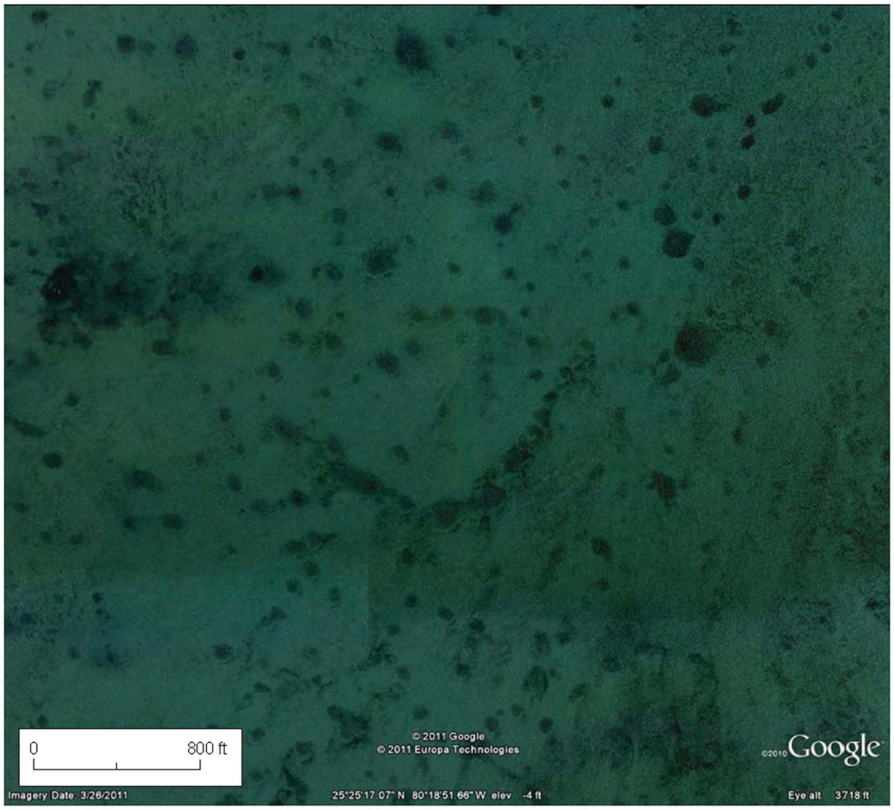

Source: Reference 202

**Figure 2.5AA-202 Google Earth Image of Biscayne Bay Adjacent to the Turkey Point Units 6 & 7 Site Showing Possible Alignments of Vegetated Patches**



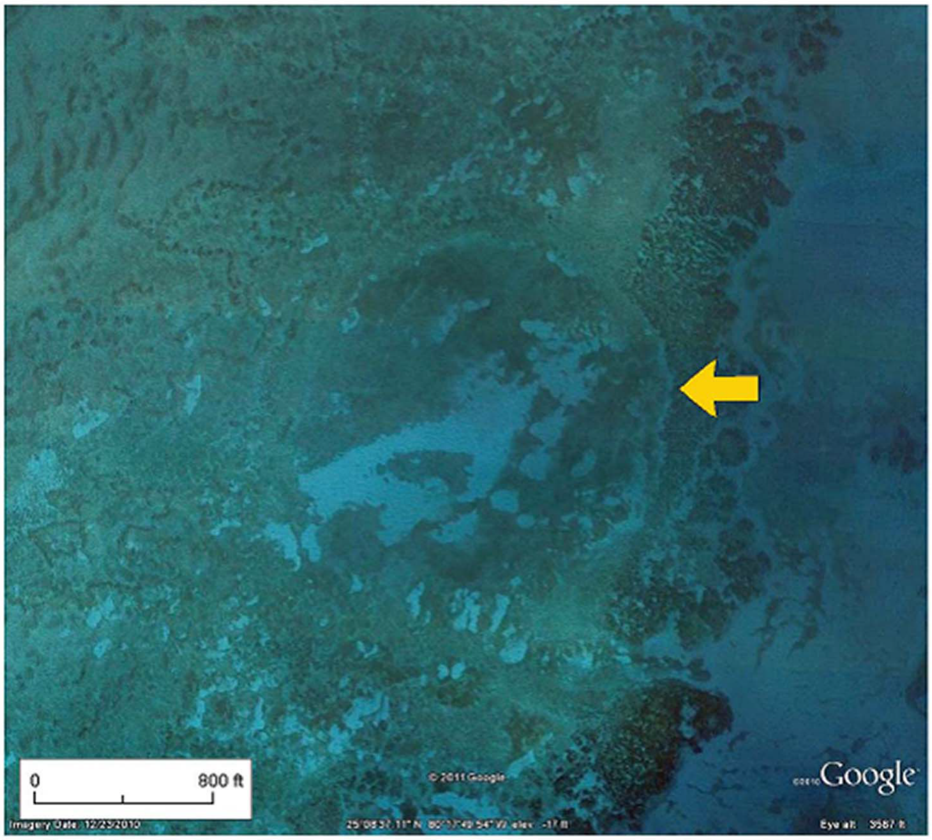

Source: See References 2.5.3-207 and 2.5.3-233

**Figure 2.5AA-203 Areas Evaluated for Size and Density of Vegetated Patches**




Source: Reference 203

**Figure 2.5AA-204 Close-Up View of Potential Semicircular Arrangement of Vegetated Patches**




Source: Reference 204

**Figure 2.5AA-205 Image of the Sinkhole Reported by Shinn et al.**


Source: Reference 205

**Figure 2.5AA-206 Aerial Photo (1994) of Biscayne Bay Adjacent to the Turkey Point Units 6 & 7 Site**

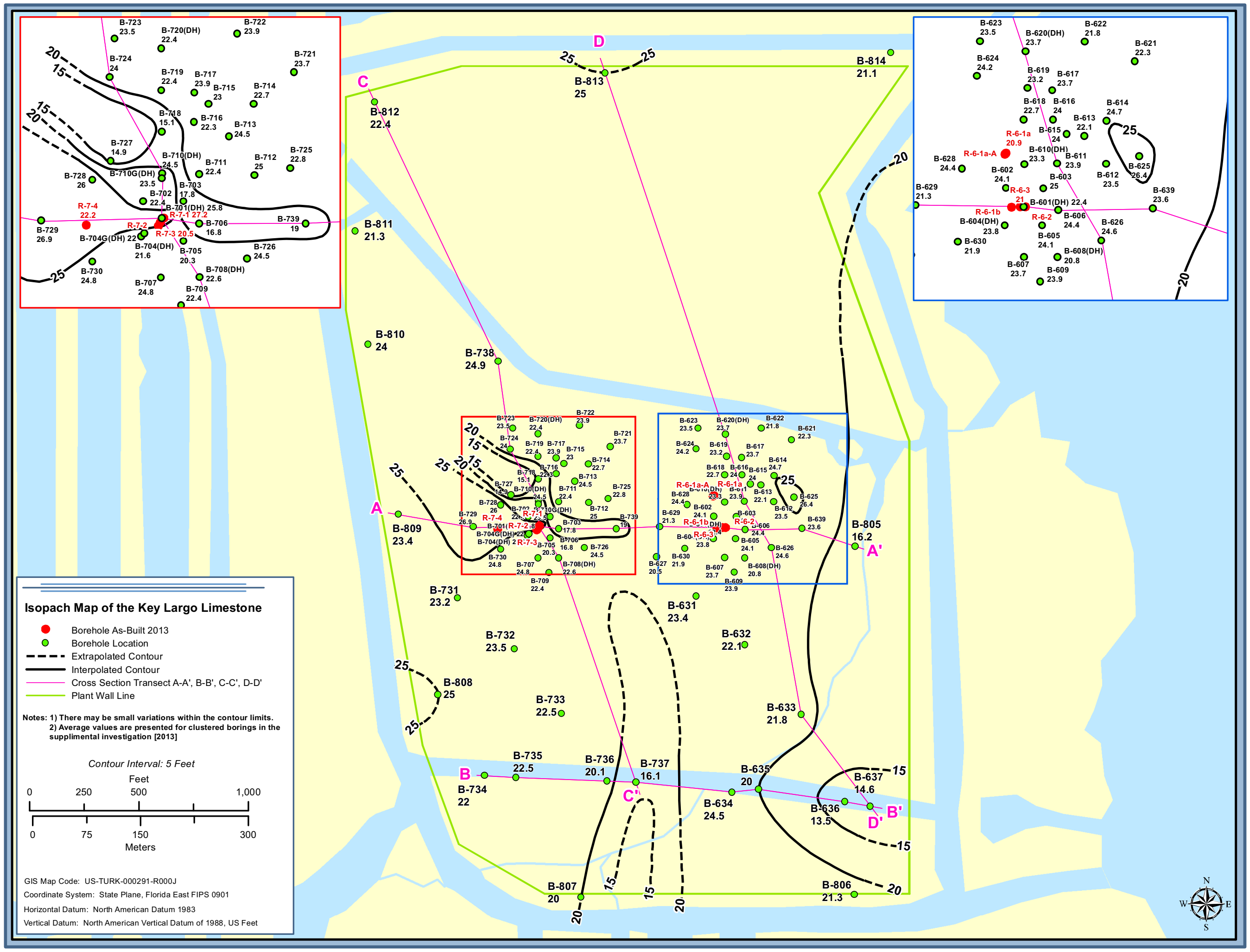



**Figure 2.5AA-207 Isopach Map of the Key Largo Limestone**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-342**

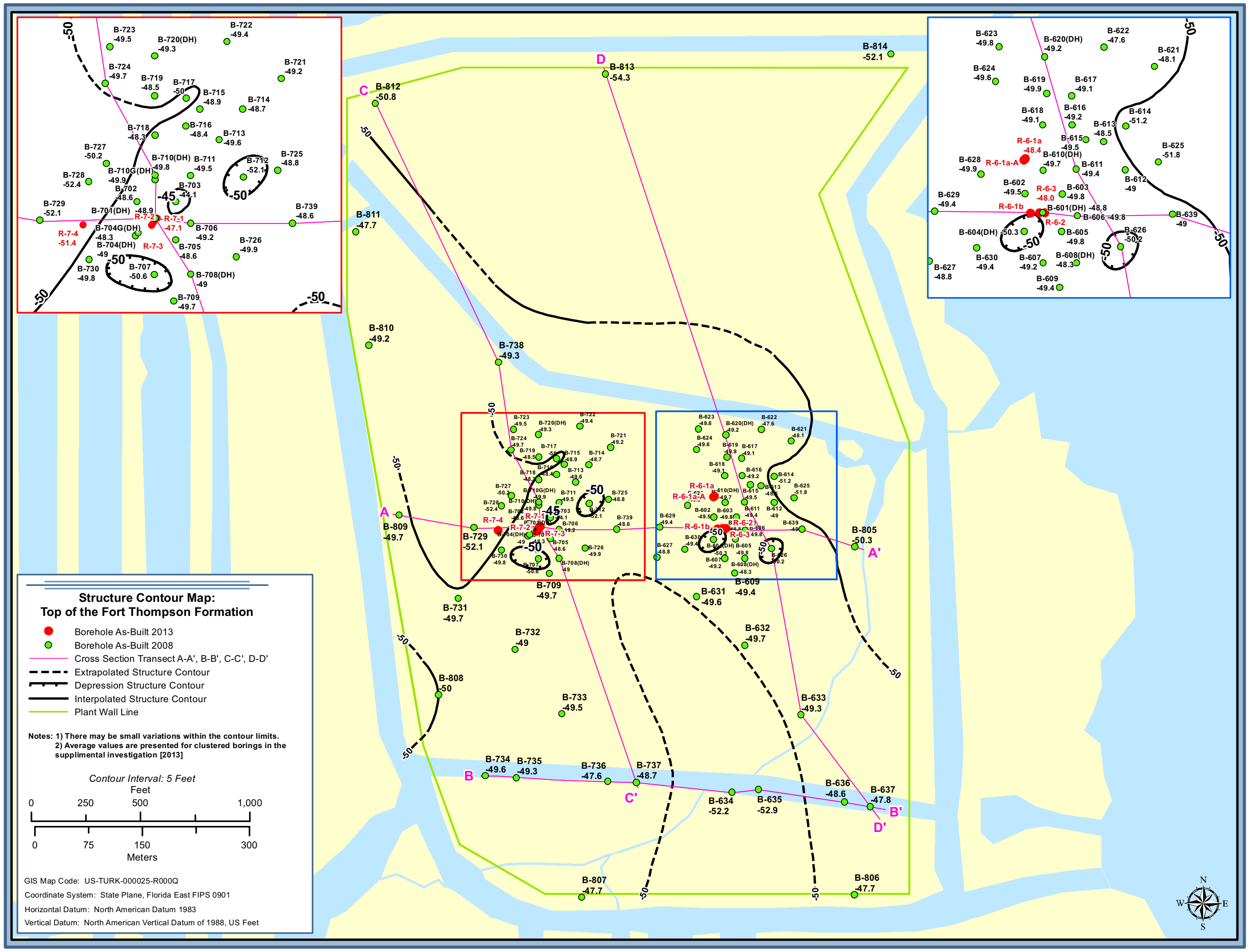



**Figure 2.5AA-208 Structure Contour Map of the Top of the Fort Thompson Formation**
**This figure appears in Subsection 2.5.1 as Figure 2.5.1-343**

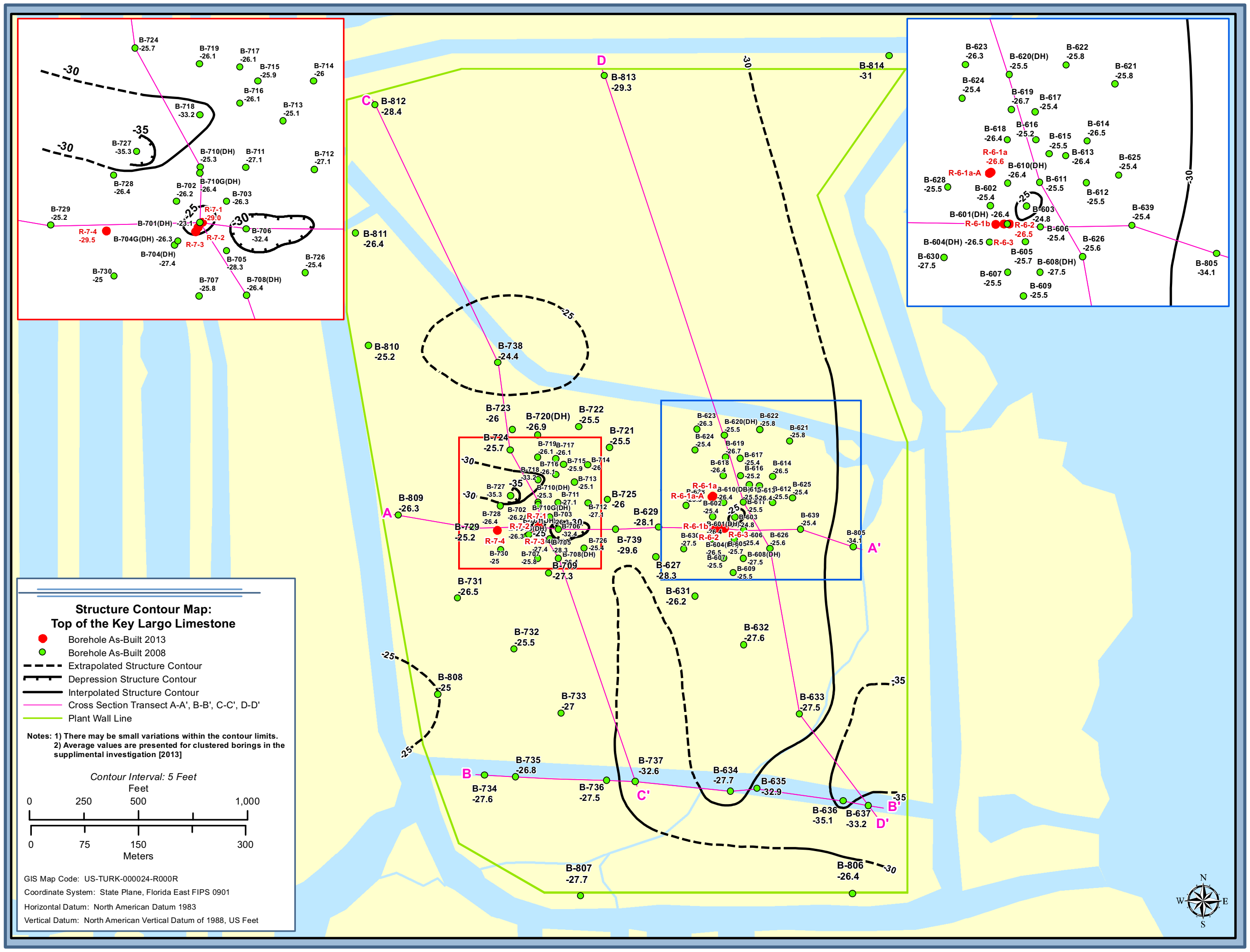



**Figure 2.5AA-209 Structure Contour Map of the Top of the Key Largo Limestone**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-349**

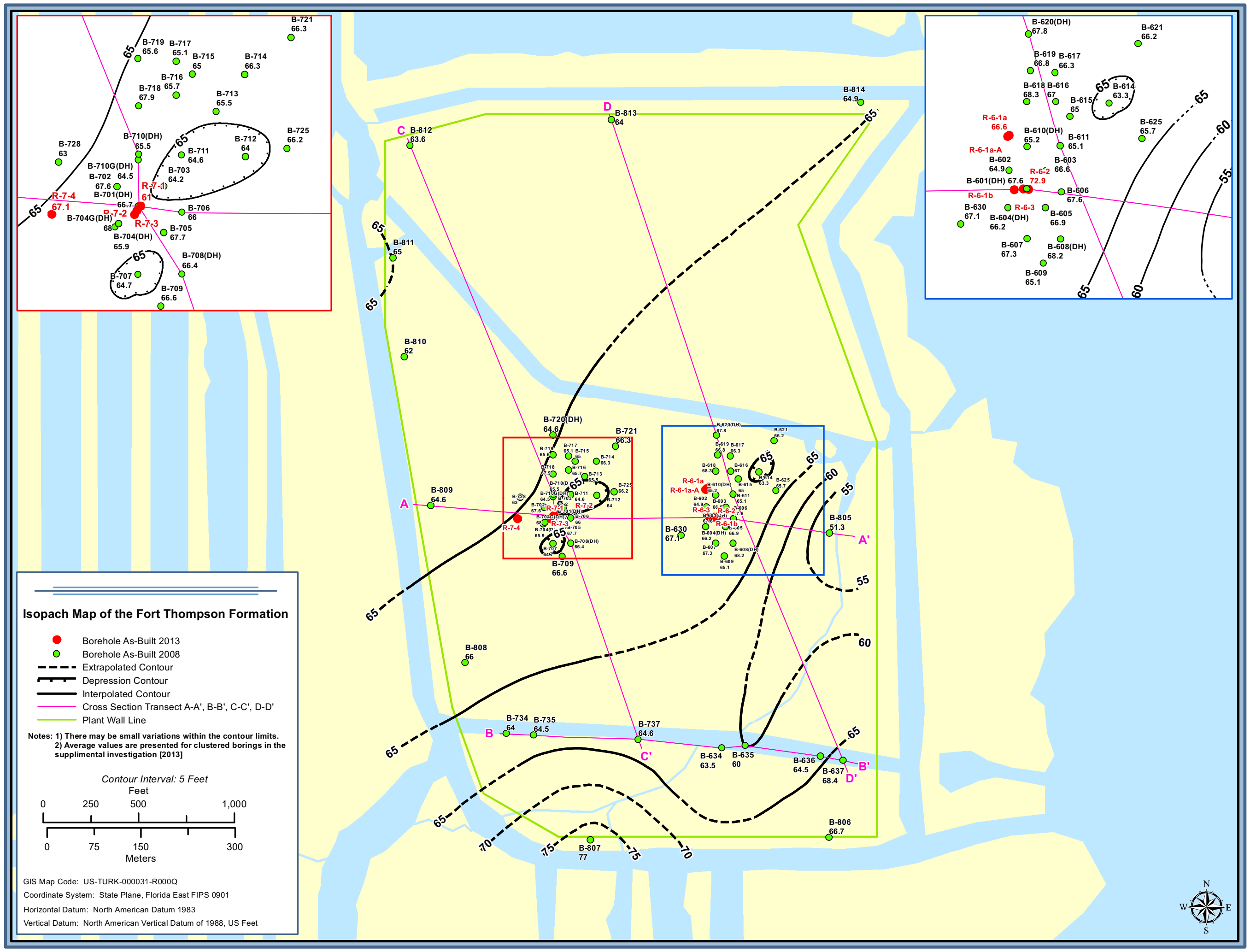



**Figure 2.5AA-210 Isopach Map of the Fort Thompson Formation**
**This figure appears in Subsection 2.5.1 as Figure 2.5.1-344**

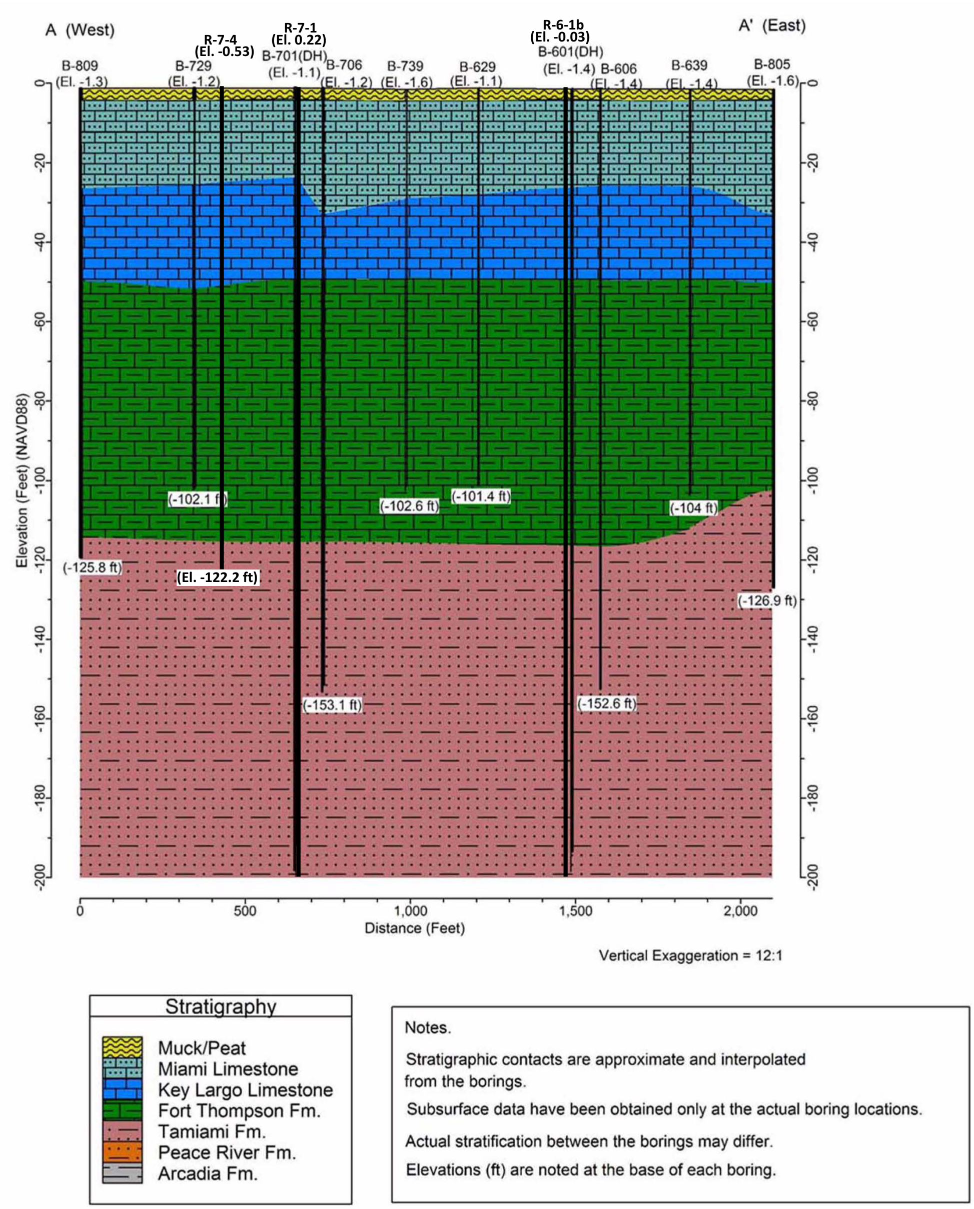



**Figure 2.5AA-211 Cross-Section A-A' Truncated (Vertical Exaggeration = 12:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-338**

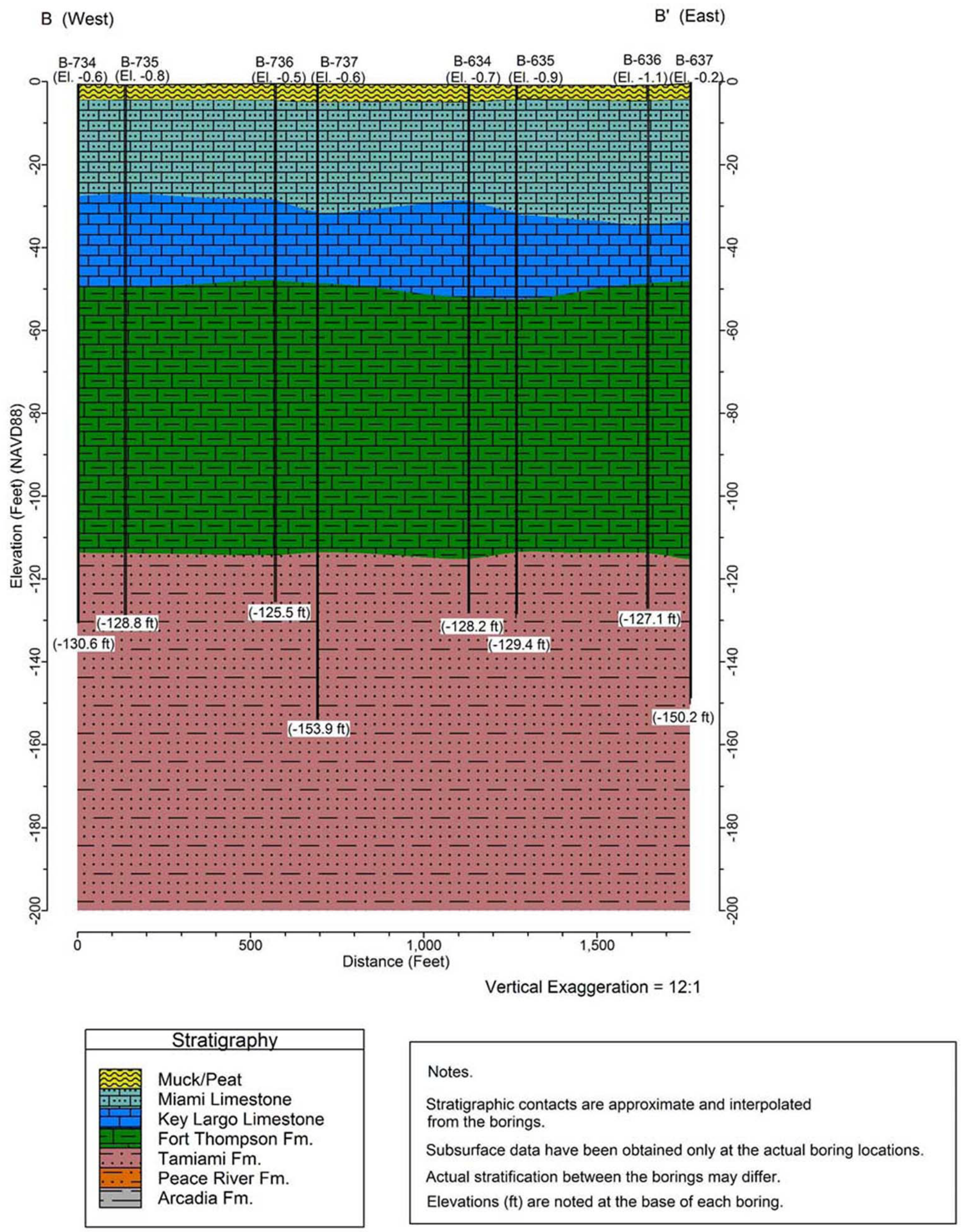



**Figure 2.5AA-212 Cross-Section B-B' Truncated (Vertical Exaggeration = 12:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-339**

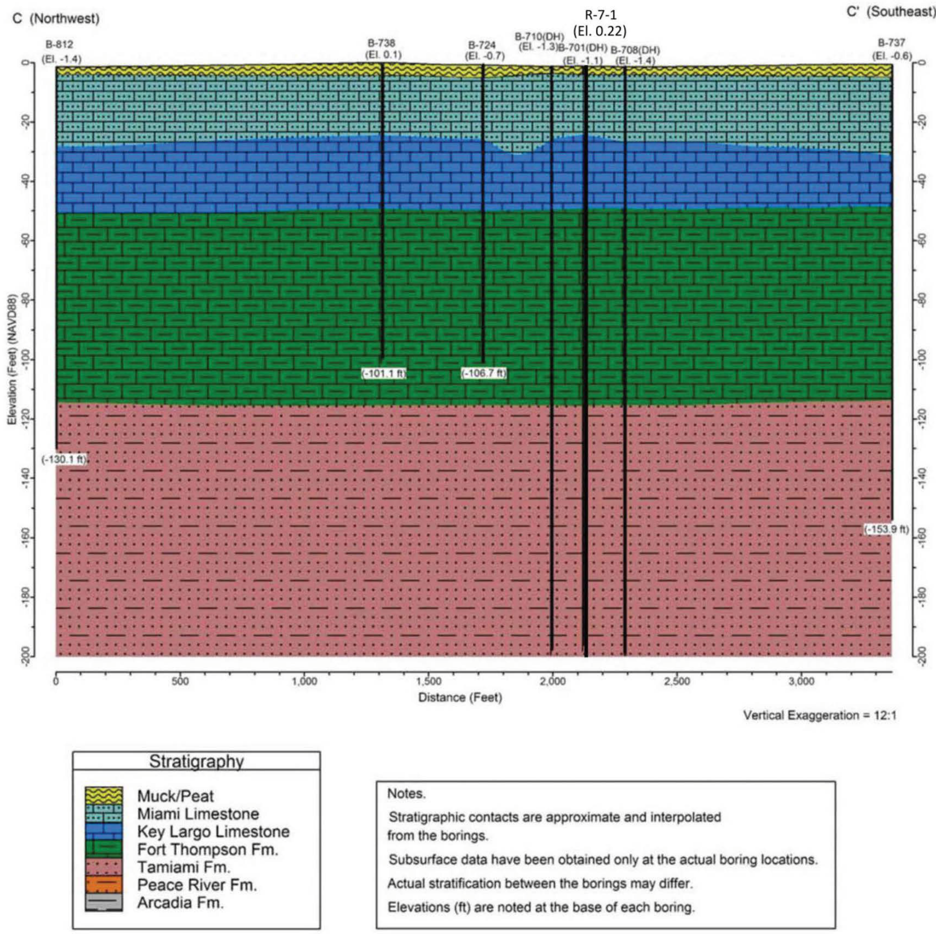



**Figure 2.5AA-213 Cross-Section C-C' Truncated (Vertical Exaggeration = 12:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-340**

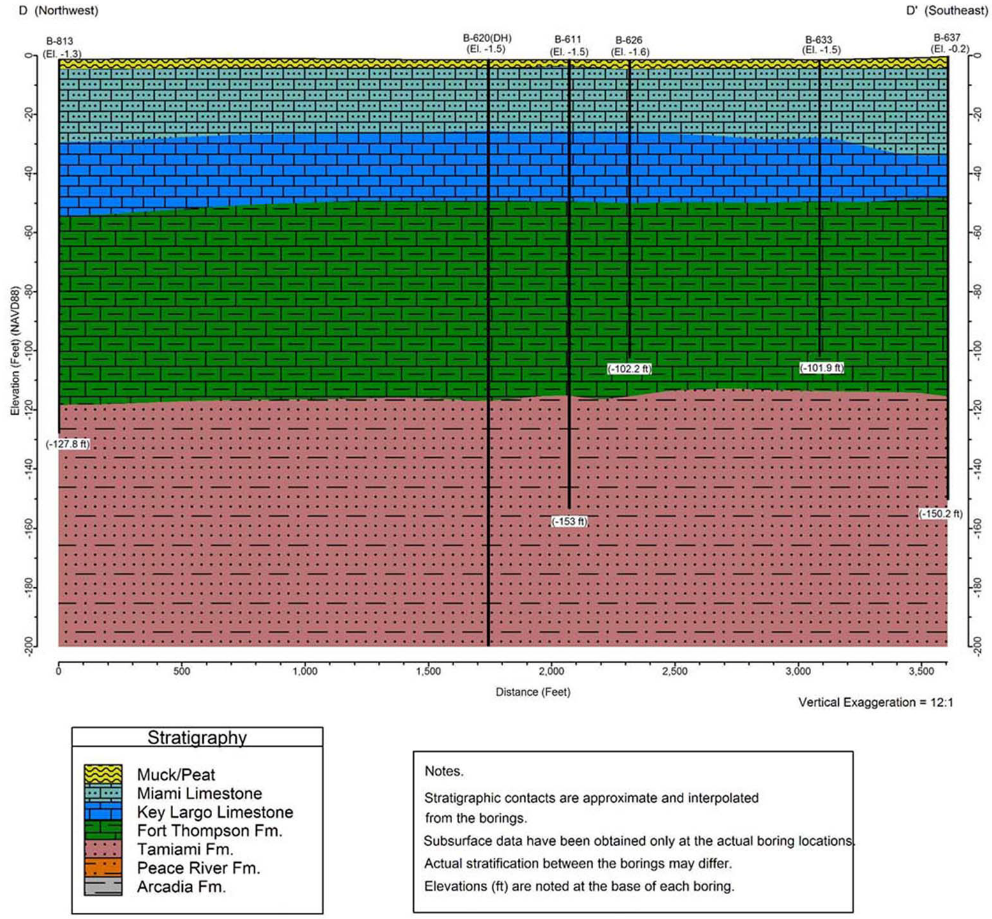



**Figure 2.5AA-214 Cross-Section D-D' Truncated (Vertical Exaggeration = 12:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-341**

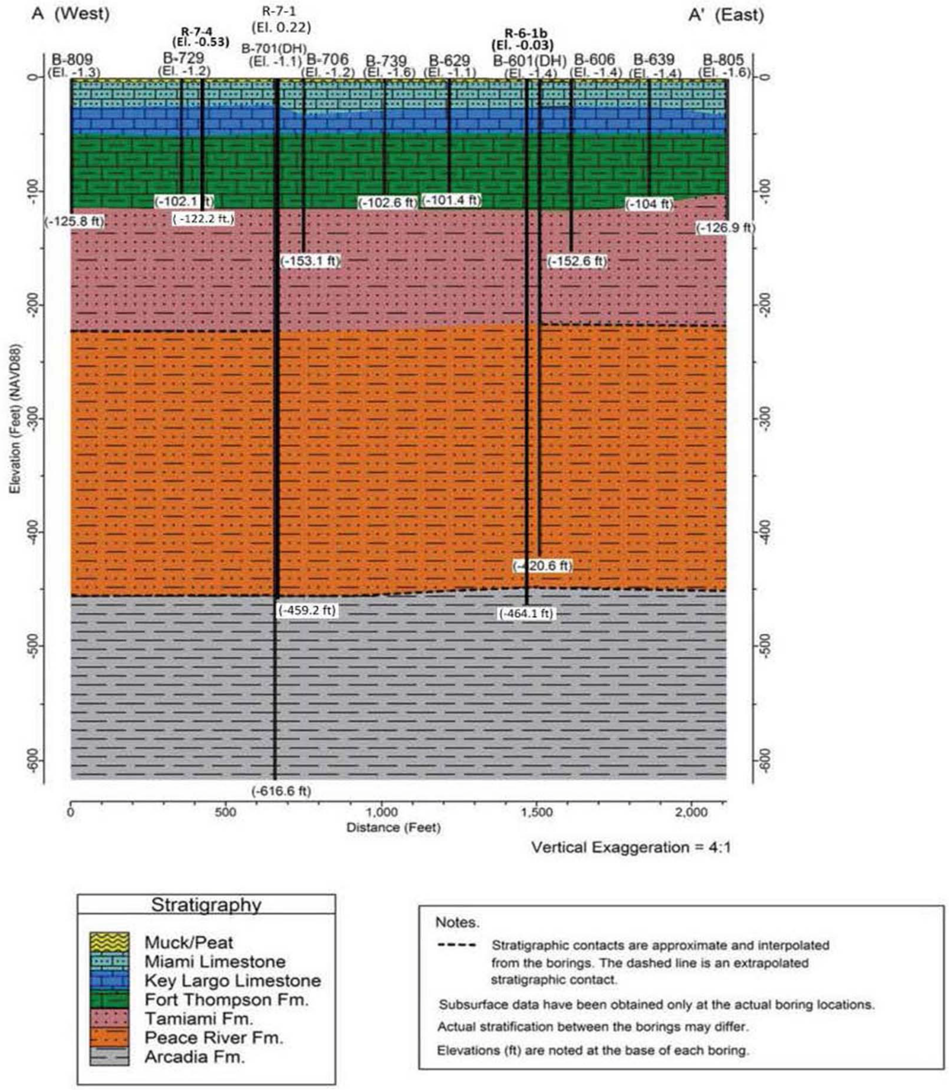



**Figure 2.5AA-215 Cross-Section A-A' (Vertical Exaggeration = 4:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-386**

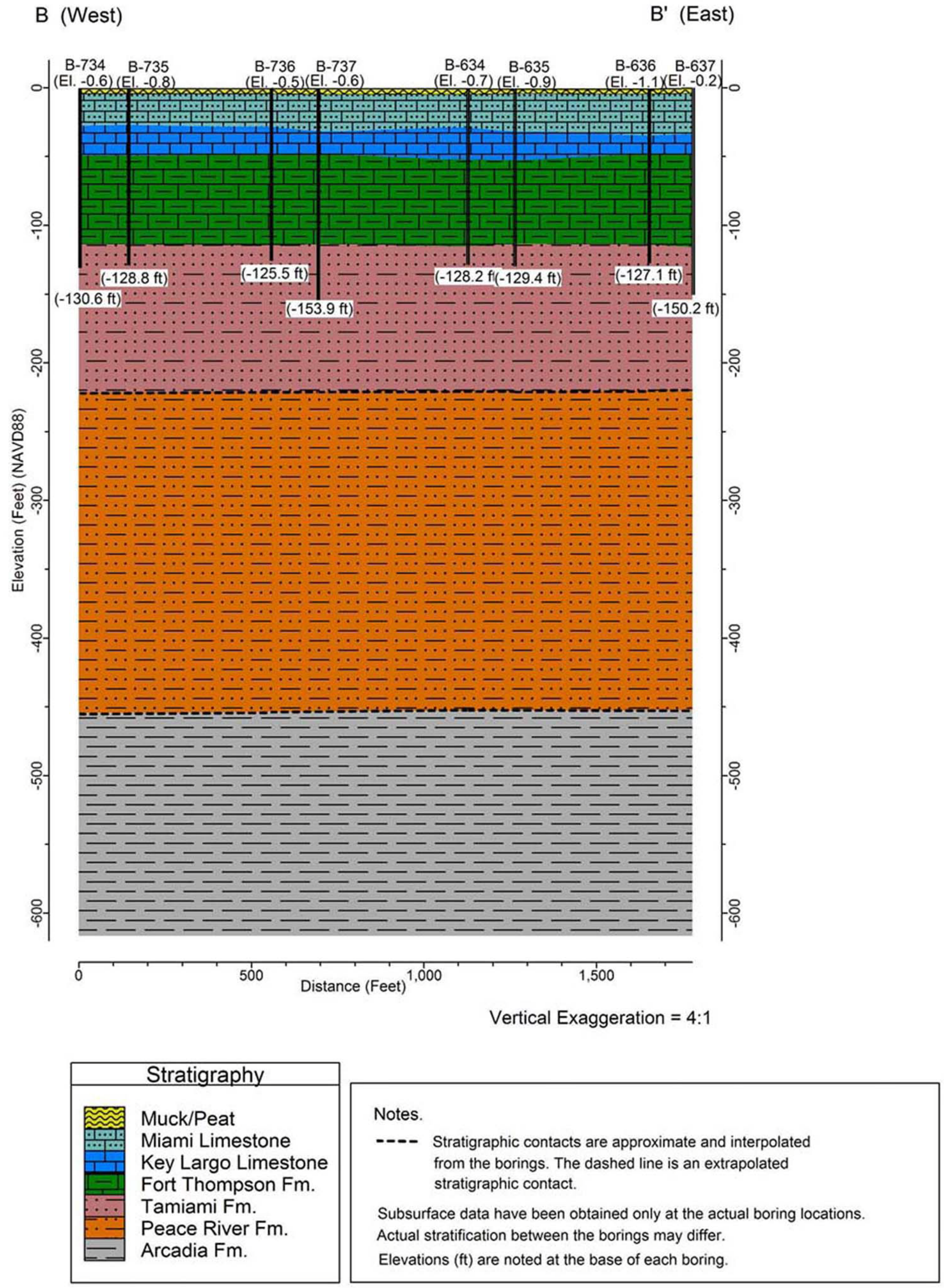



**Figure 2.5AA-216 Cross-Section B-B' (Vertical Exaggeration = 4:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-387**

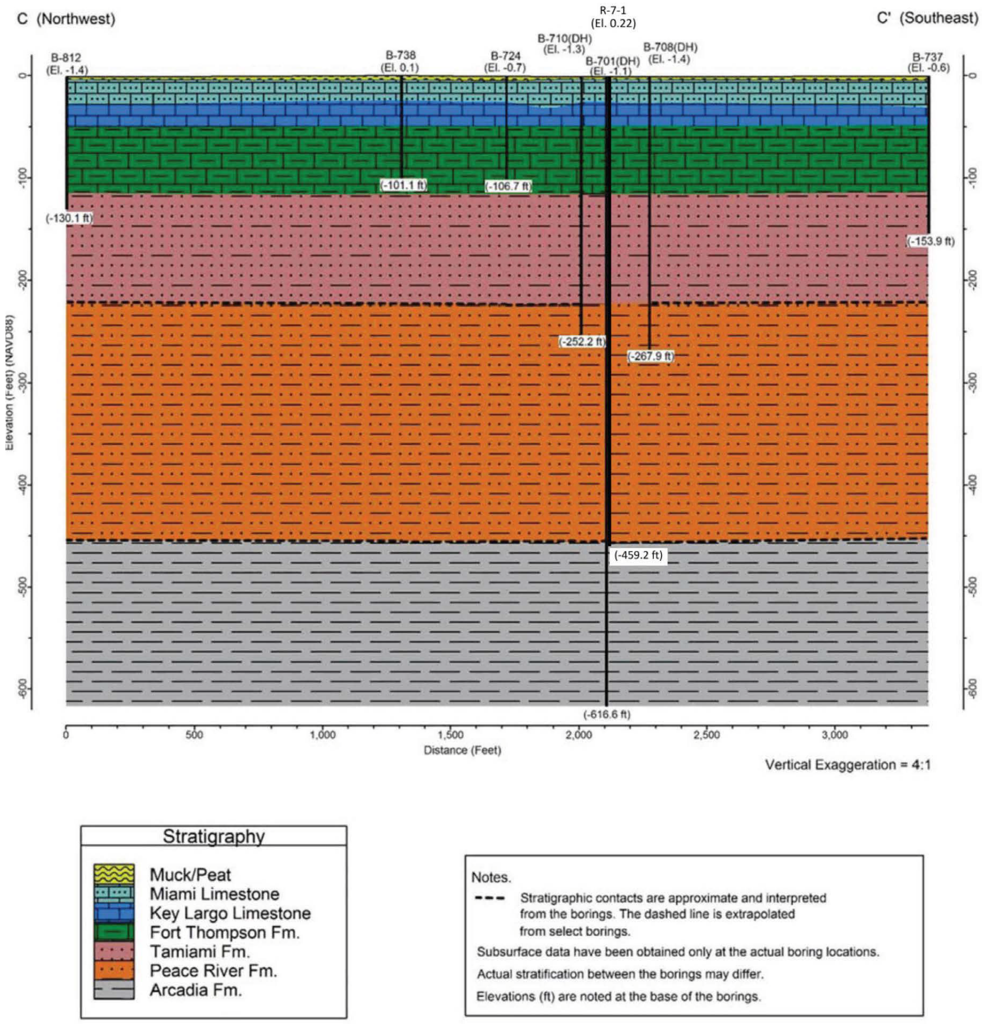



**Figure 2.5AA-217 Cross-Section C-C' (Vertical Exaggeration = 4:1)**

**This figure appears in Subsection 2.5.1 as Figure 2.5.1-388**