NRC RAI Letter No. PTN-RAI-LTR-041

SRP Section: 02.05.01 - Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 2 (RGS2)

NRC RAI Number: 02.05.01-17 (eRAI 6024)

FSAR Figures 2.5.1-342, -343, and -344 illustrate isopach and structure contour maps of the Key Largo Limestone and Fort Thompson Limestone stratigraphic units. The staff notes, however, that additional information is needed on the maps to understand the nature of the Key Largo and Fort Thompson limestone units.

In order for the staff to evaluate depositional structures or potential tectonic deformation in the bearing layer formation within the site area and in support of 10 CFR 100.23, please address the following:

a) Indicate the elevation on the structure contour maps and thickness values on the isopachs.
b) Indicate thin areas on the isopachs and low areas on structure contours.
c) Plot the location of cross section lines A, B, C, and D on the isopach and structure contour maps.
d) Provide a structure contour for the Key Largo formation.
e) The FSAR describes the Fort Thompson Formation as vuggy, and solution riddled. In light of this characteristic in the underlying Fort Thompson, discuss the implication of the numerous closed circles shown on the Key Largo isopach.

FPL RESPONSE:

a) Indicate the elevation on the structure contour maps and thickness values on the isopachs.

Revised structure contour maps showing the elevations of the top of the Fort Thompson Formation and the top of the Key Largo Limestone are provided in Figures 1 and 2, respectively. Revised isopach maps including thickness values of the Fort Thompson Formation and the Key Largo Limestone are provided in Figures 3 and 4.

b) Indicate thin areas on the isopachs and low areas on structure contours.

A relatively thin area in the Fort Thompson Formation is shown on Figure 3 in the vicinity of boring B-805. Relatively thin areas in the Key Largo Limestone are shown on Figure 4 in the vicinity of borings B-636, B-727, and B-737. Relatively low areas in the top of the Fort Thompson Formation are shown on Figure 1 in the vicinity of borings B-625, B-634, B-712, and B-728. Relatively low areas in the top of the Key Largo Limestone are shown on Figure 2 in the vicinity of borings B-636, B-706, and B-727, B-737, and B-738.

c) Plot the location of cross section lines A, B, C, and D on the isopach and structure contour maps.

The locations of cross section lines A, B, C, and D are shown on Figures 1, 2, 3, and 4.

d) Provide a structure contour for the Key Largo formation.

A structure contour map of the top of the Key Largo Limestone is provided in Figure 2.

e) The FSAR describes the Fort Thompson Formation as vuggy, and solution-riddled. In light of this characteristic in the underlying Fort Thompson, discuss the implication of the numerous closed circles shown on the Key Largo isopach.

Comparison of Figure 4 (Isopach Map of the Key Largo Limestone) and Figure 1 (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 co-located 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 2 to 3 feet (0.6 to 0.9 meters) of relief shown on the top of the Fort Thompson Formation in the vicinity of borings B-634 and B-729 (Figure 1) 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 4. 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 1 and Figure 2 (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 2.5 feet (0.8 meters), whereas the topographic relief in the depression on the surface of the overlying Key Largo Limestone in the same area is approximately 10 feet (3 meters). It seems unlikely that subsidence of about 2.5 feet (0.8 meters) in the Fort Thompson Formation due to collapse of a hypothetical solution cavity would induce corresponding subsidence of about 10 (3 meters) 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 one or two feet (0.3 to 0.6 meters). 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) in the vicinity of boring B-706, where the topographic relief is approximately 6 feet (1.8 meters). Comparison with the isopach map of the Key Largo Limestone (Figure 4) 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) does not correlate strongly with the locations of the vegetated depressions ("mangroves" on FSAR Figure 2.5.4-223) onsite. 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) 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 (Figures 2.5.4-226 and -227). This finding suggests that the depressions on Figure 2 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 lowest depressions on Figure 2 (-32 to -35 feet) (-9.8 to -10.7 meters) NAVD88 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) 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, respectively, 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 rose again.

Two versions of each of four cross-sections are provided. Cross-sections in the first set (Figures 5, 6, 7, and 8) are truncated at the elevation of -200 feet NAVD88 (-61 meters NAVD88) and depict the subsurface stratigraphy with a vertical exaggeration of 12 to 1. Figures 9, 10, 11, and 12 depict a thicker section of the subsurface stratigraphy on the same cross-sections with a vertical exaggeration of only 4 to 1. The locations of the surface traces of the cross sections are shown on Figures 1, 2, 3, and 4.

Geologic cross section A-A' (Figures 5 and 9) extends east-west through the power blocks and thirteen borings, including the four deepest borings R-6-1b, B-601, R-7-1, and B-701. Cross section B-B' (Figures 6 and 10) extends west-east through the southern edge of the site and includes eight borings, the deepest at 153 feet (46.7 meters) bgs. Cross section C-C' (Figures 7 and 11) extends diagonally northwest-southeast through the entire site and passes through the western power block. Cross section C-C' includes eight borings including two of the deepest borings, B-701(DH), at a depth of 615.5 feet (187.7 meters) bgs and R-7-1, at a depth of 459 feet (140 meters) bgs. Cross section D-D' (Figures 8 and 12) also extends diagonally northwest-southeast through the entire site but passes through the eastern power block. Cross section D-D' includes six borings; the deepest at a depth of 215 feet (65.6 meters) bgs.

The cross sections indicate that geologic contacts beneath the site are relatively flat and undeformed. This stratigraphy reflects the environment of deposition and subsequent erosion of the paleosurface. The flat and undeformed nature of the geologic contacts is reflected in the isopach maps of the Key Largo Limestone (Figure 4) and the Fort Thompson Formation

(Figure 3) that indicate a relatively uniform thickness across the site with no abrupt changes. Structure contour maps of the top of the Fort Thompson Formation and the top of the Key Largo Limestone (Figures 1 and 2, respectively) show a relatively flat paleosurface. Boring logs and descriptions of the lithology are included in the geotechnical data reports in FSAR 2.5.1 References 708 and 995.

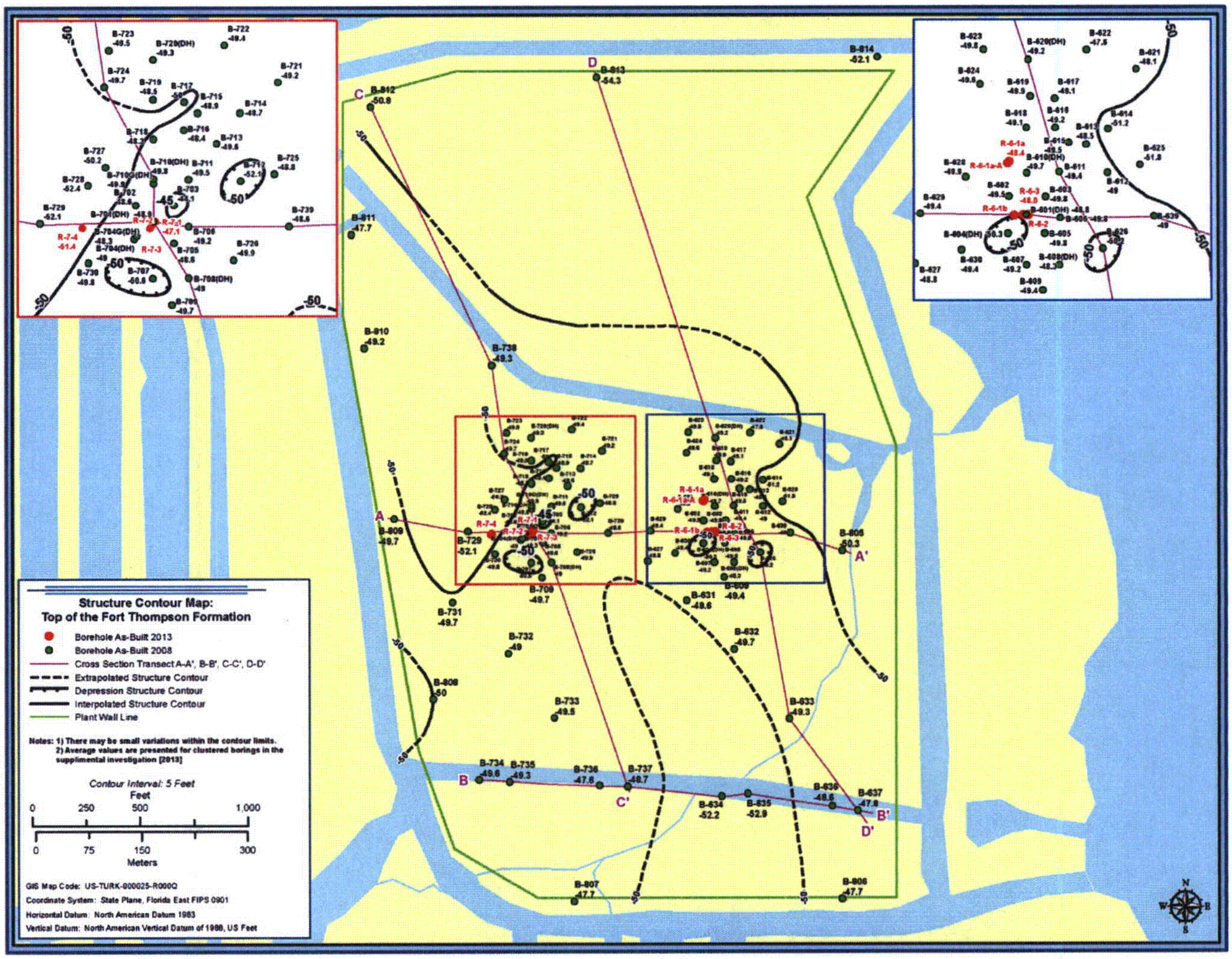

Figure 1 Structure Contour Map of the Top of the Fort Thompson Formation

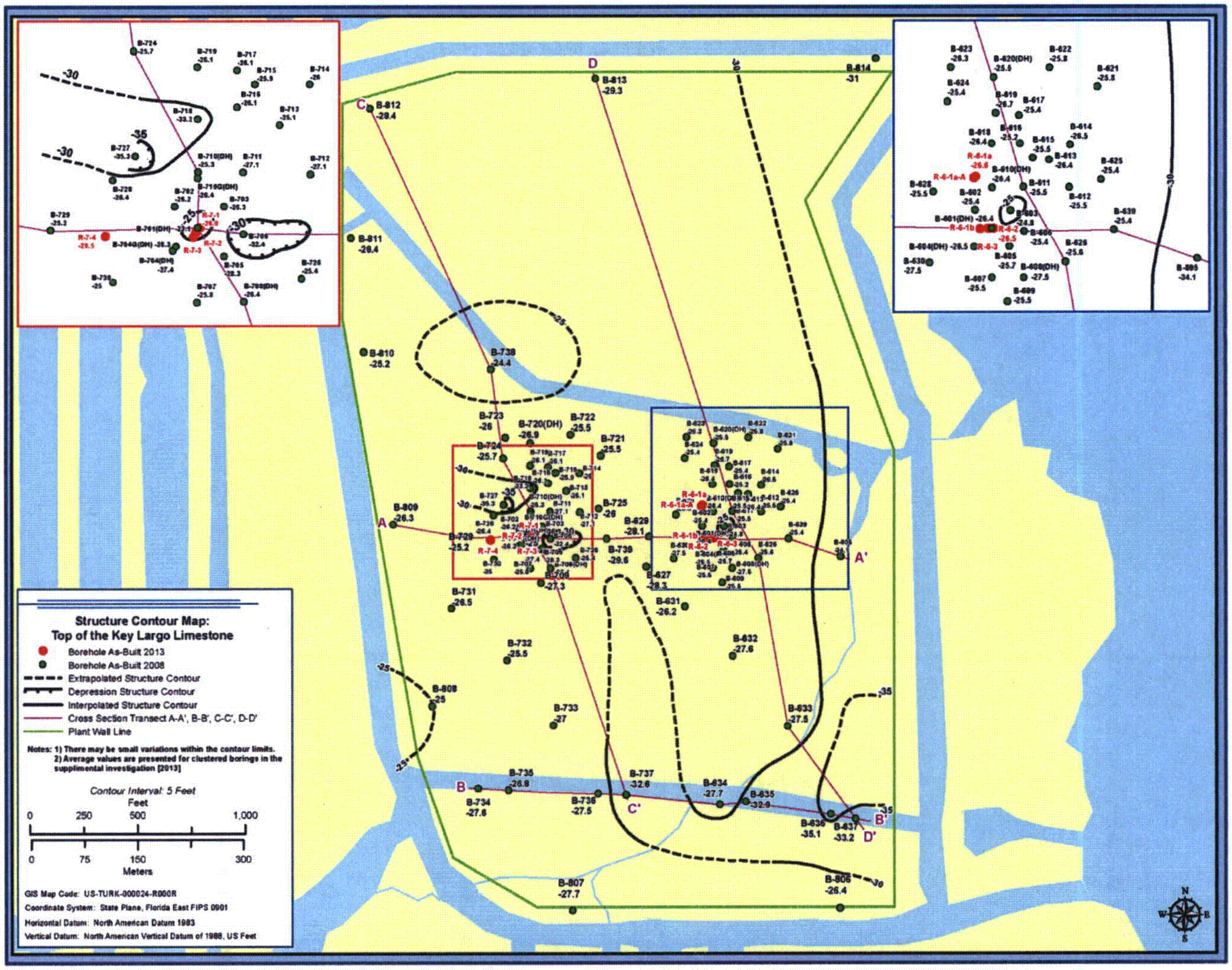

Figure 2 Structure Contour Map of the Top of the Key Largo Limestone

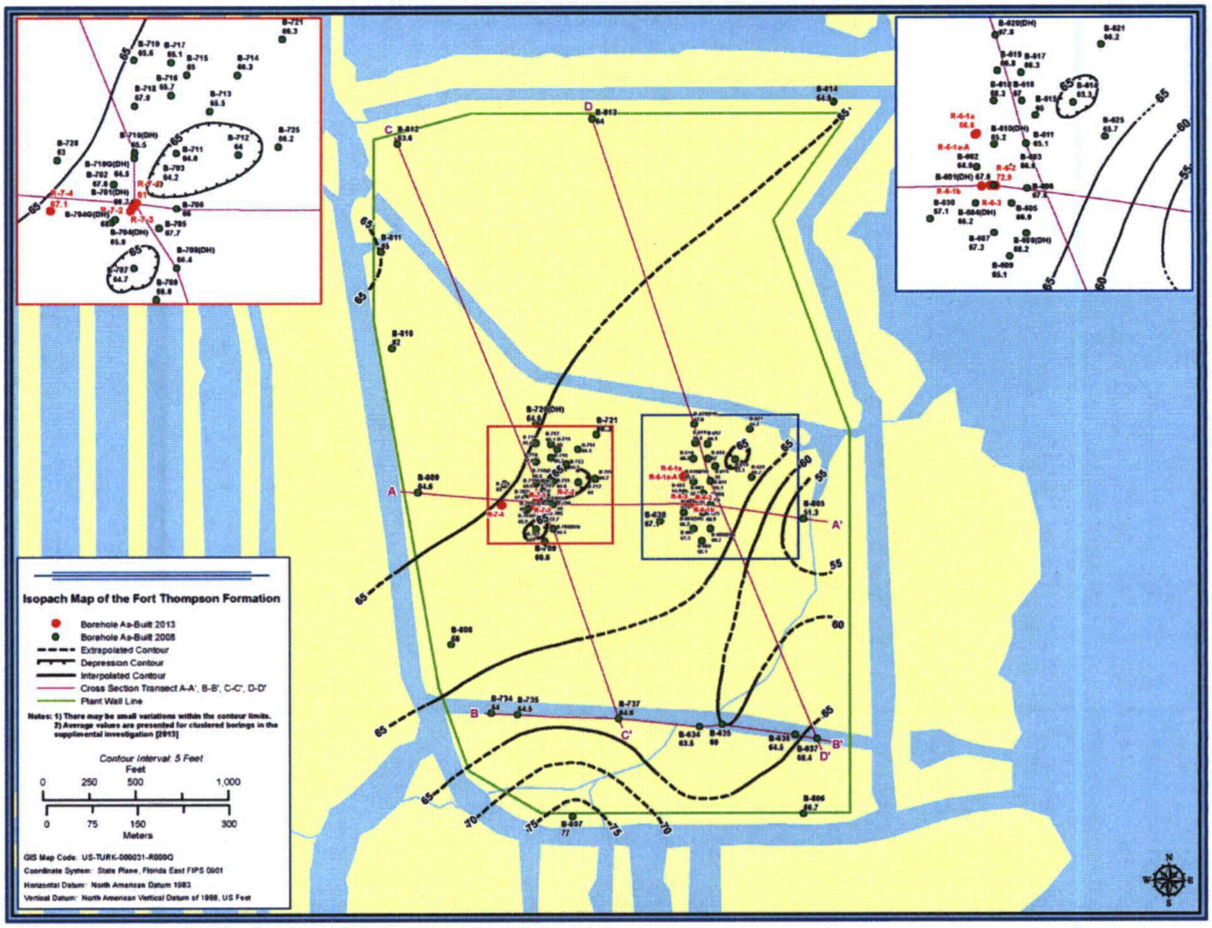

Figure 3 Isopach Map of the Fort Thompson Formation

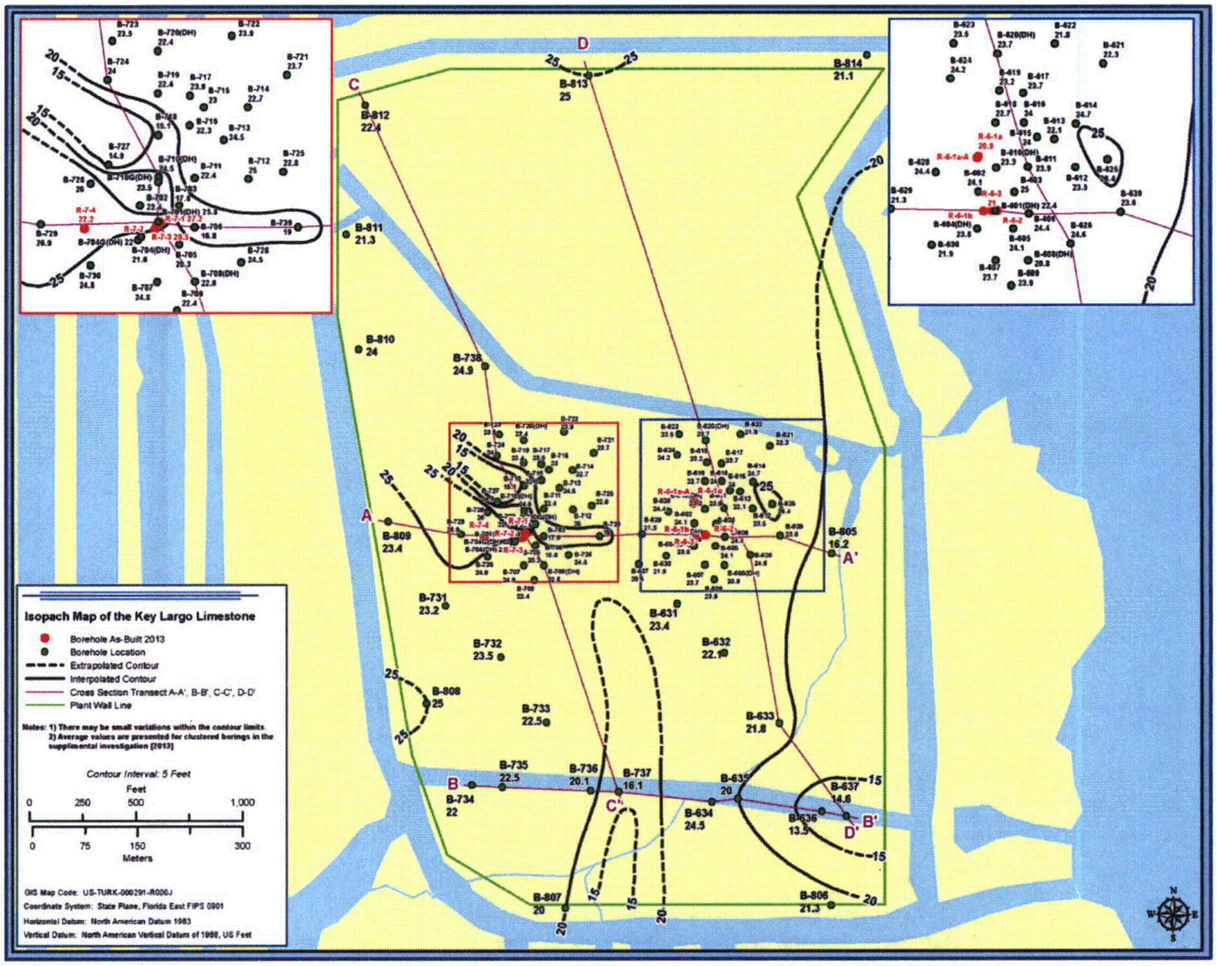

Figure 4 Isopach Map of the Key Largo Limestone

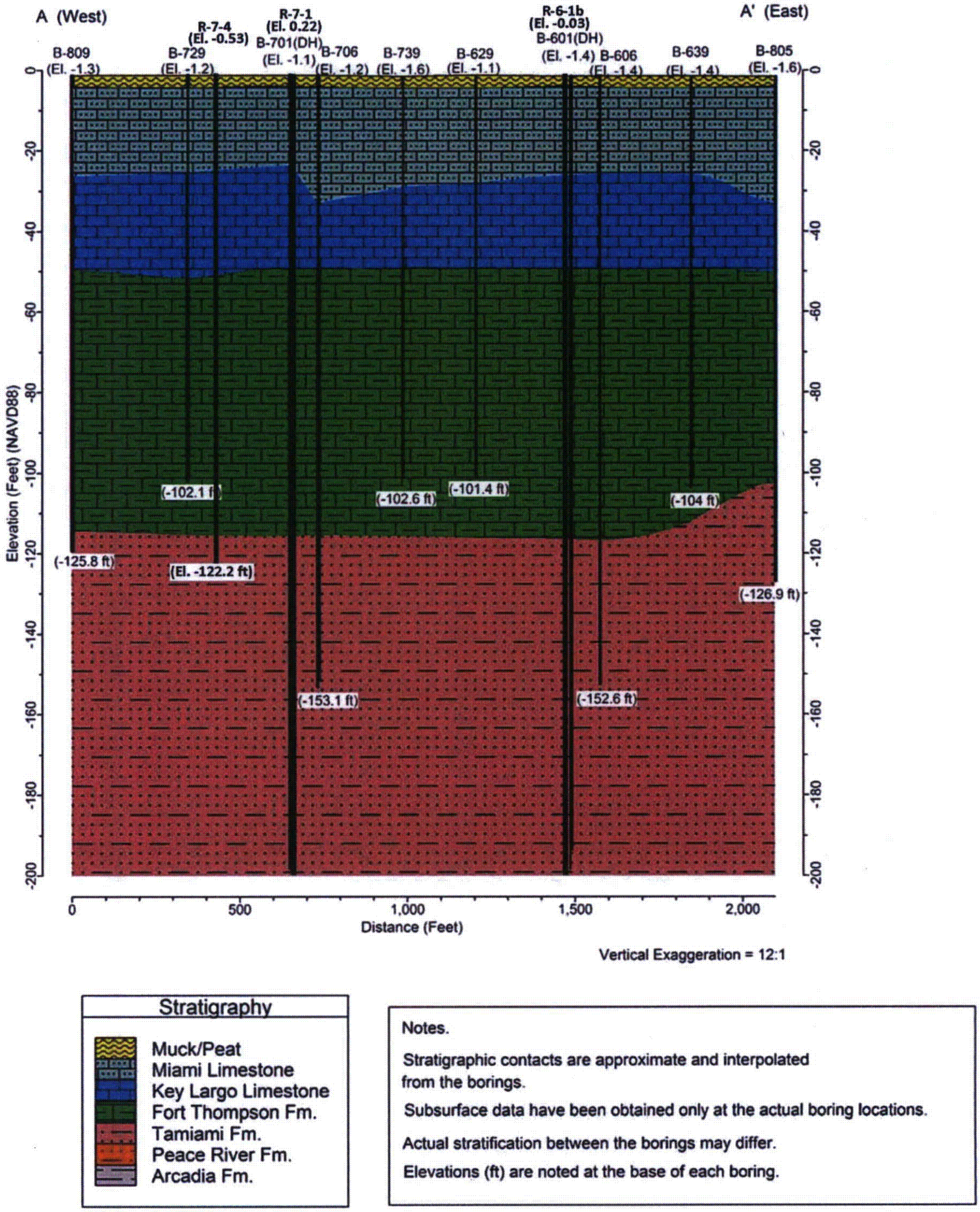

Figure 5 Cross-Section A-A′ Truncated (Vertical Exaggeration = 12:1)

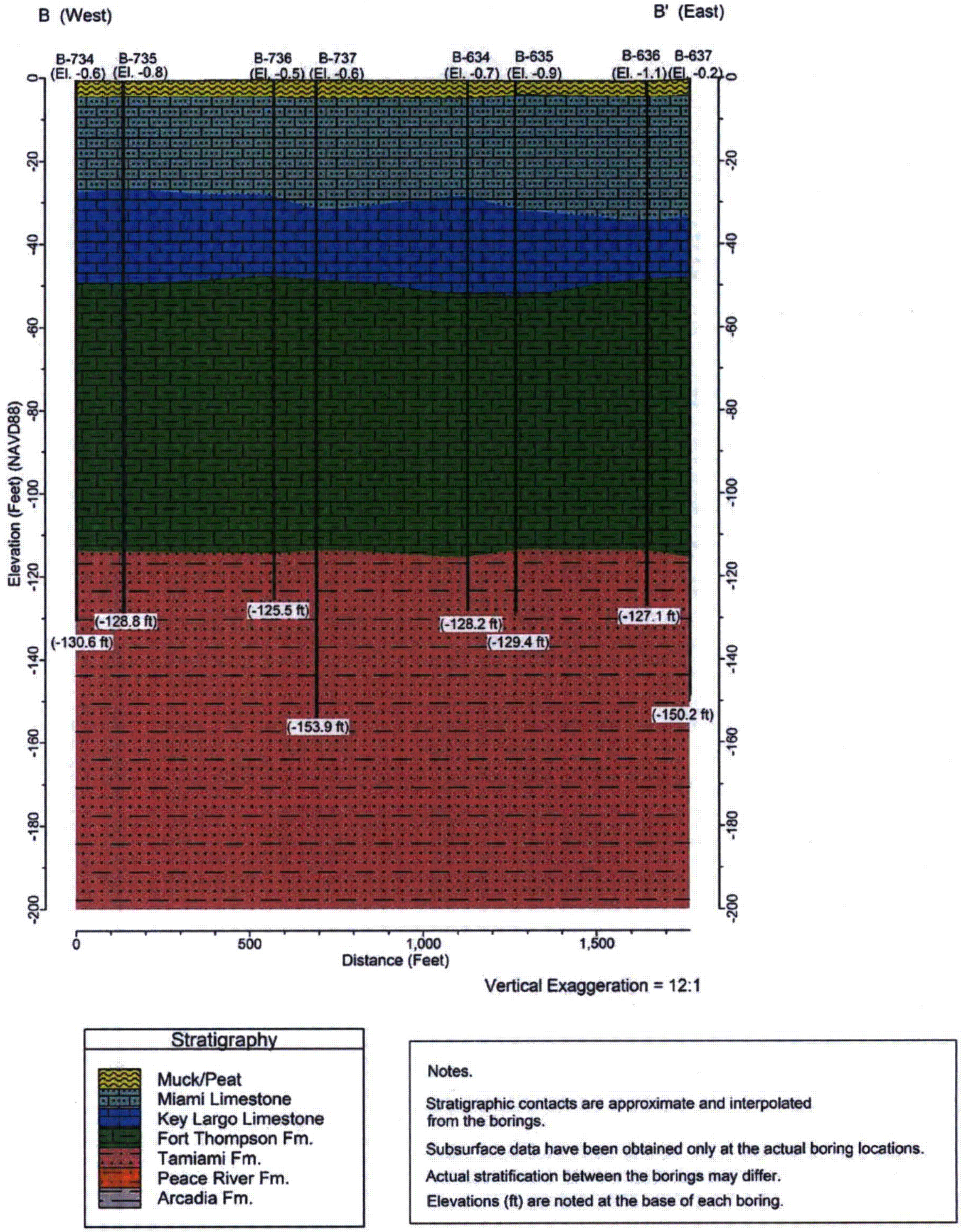

Figure 6 Cross-Section B-B′ Truncated (Vertical Exaggeration = 12:1)

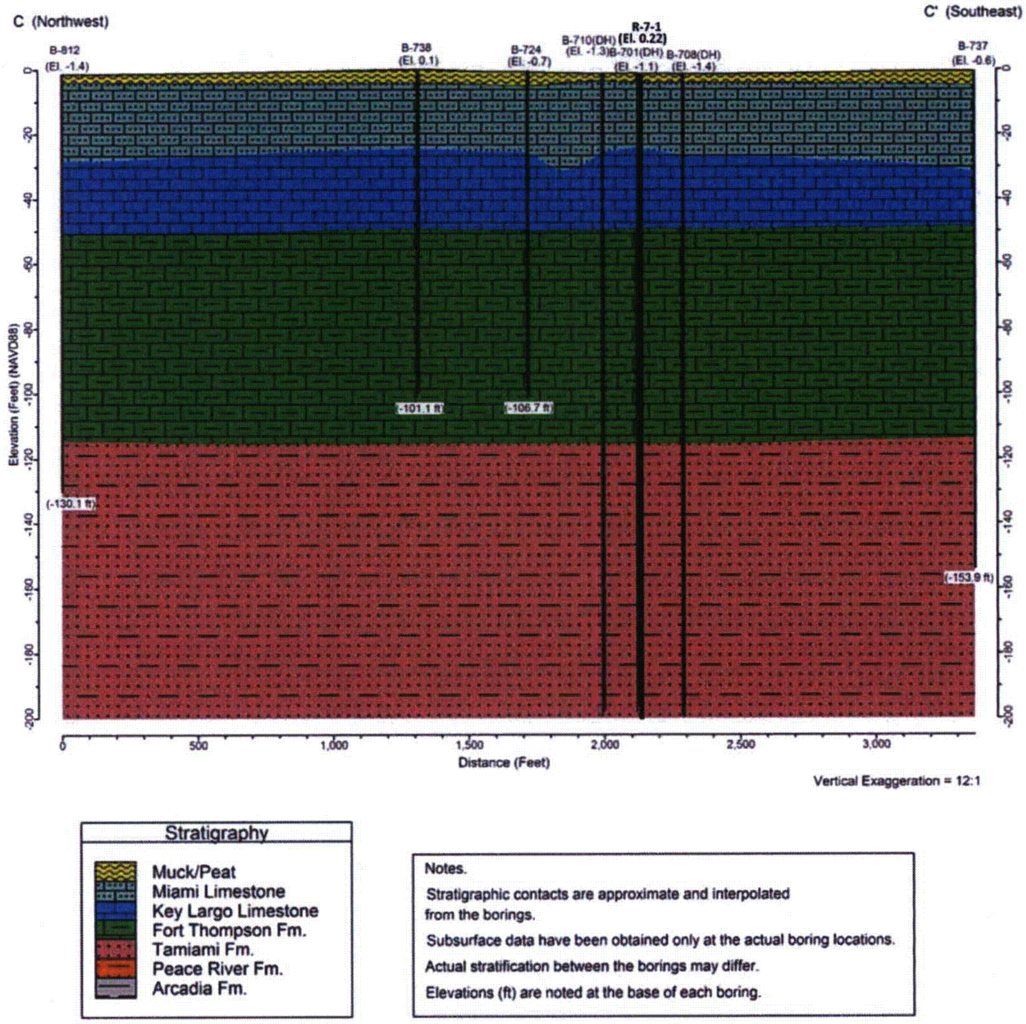

Figure 7 Cross-Section C-C′ Truncated (Vertical Exaggeration = 12:1)

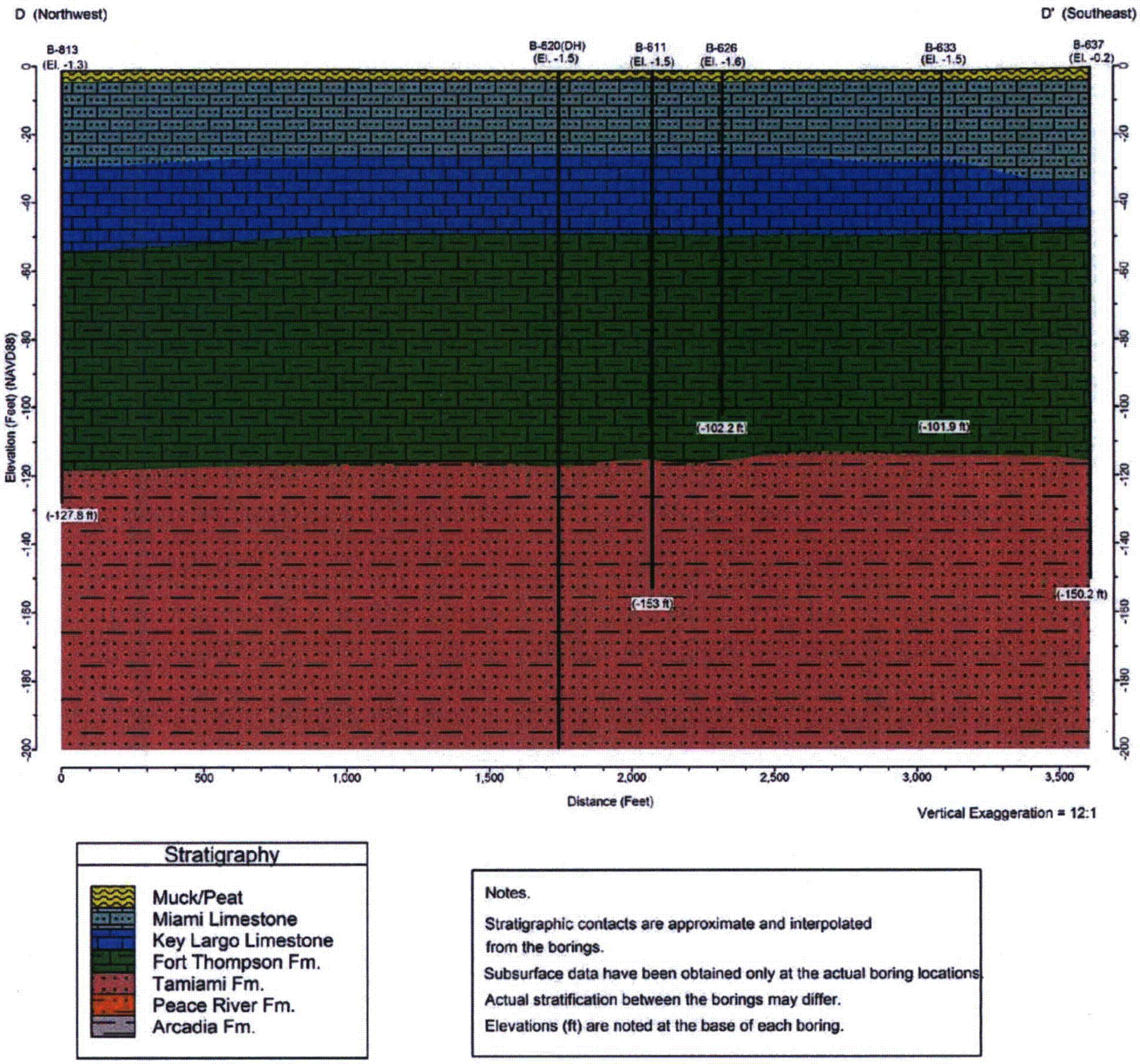

Figure 8 Cross-Section D-D` Truncated' (Vertical Exaggeration = 12:1)

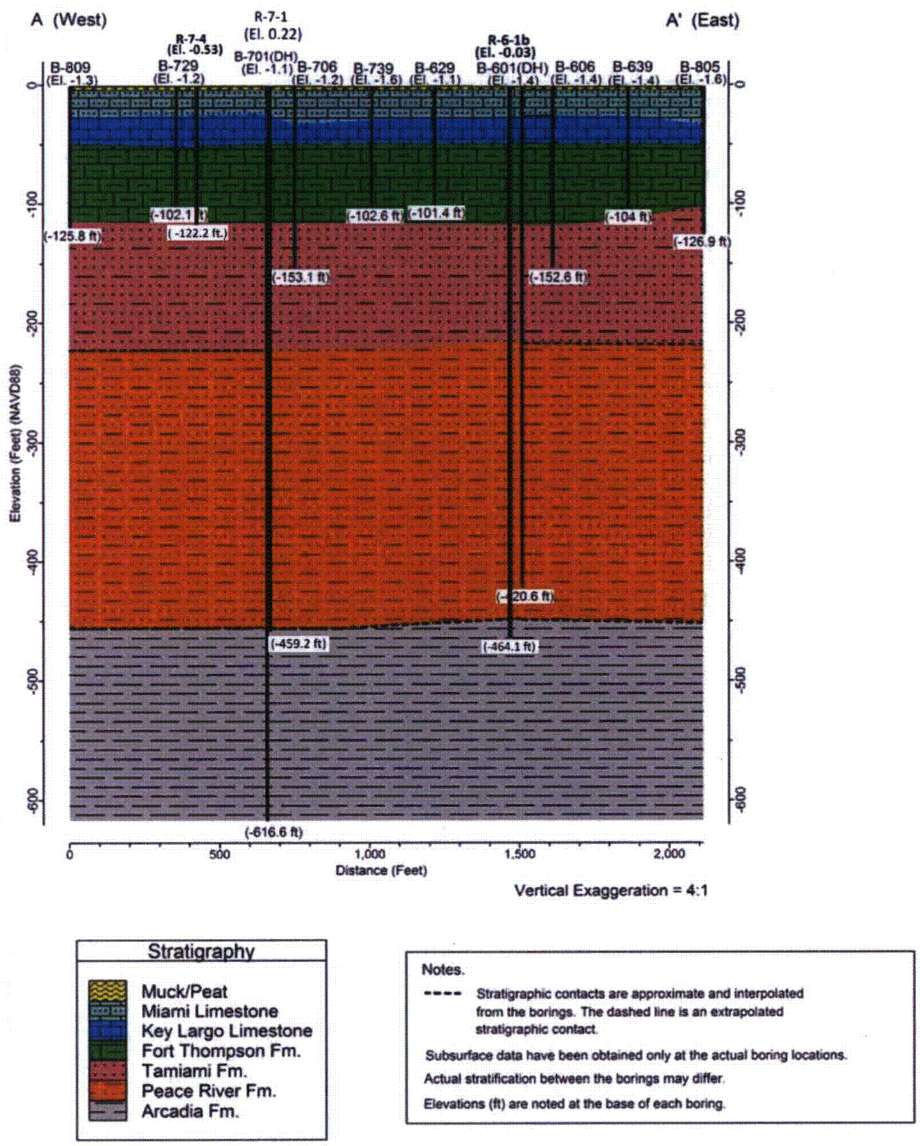

Figure 9 Cross-Section A-A′ (Vertical Exaggeration = 4:1)

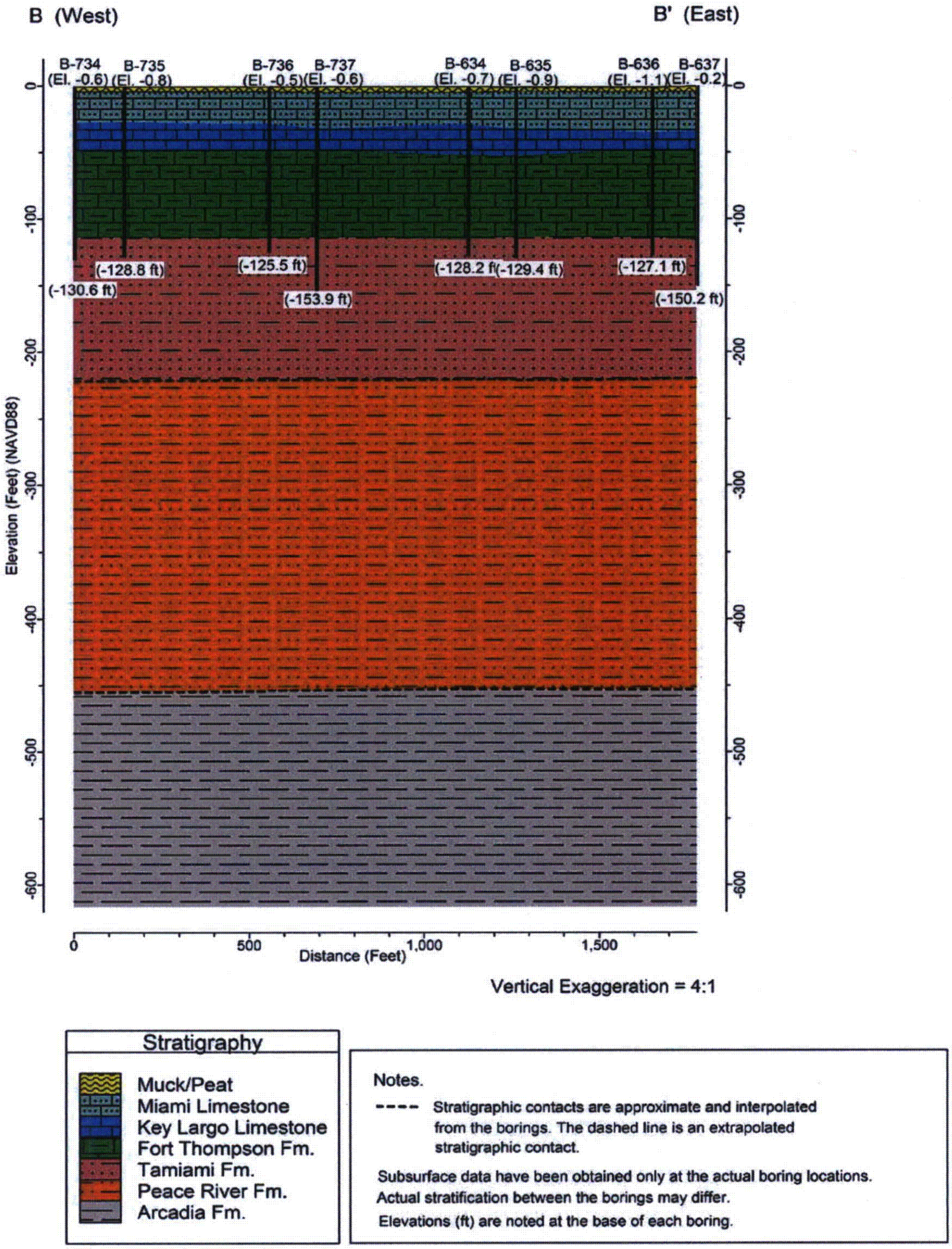

Figure 10 Cross-Section B-B′ (Vertical Exaggeration = 4:1)

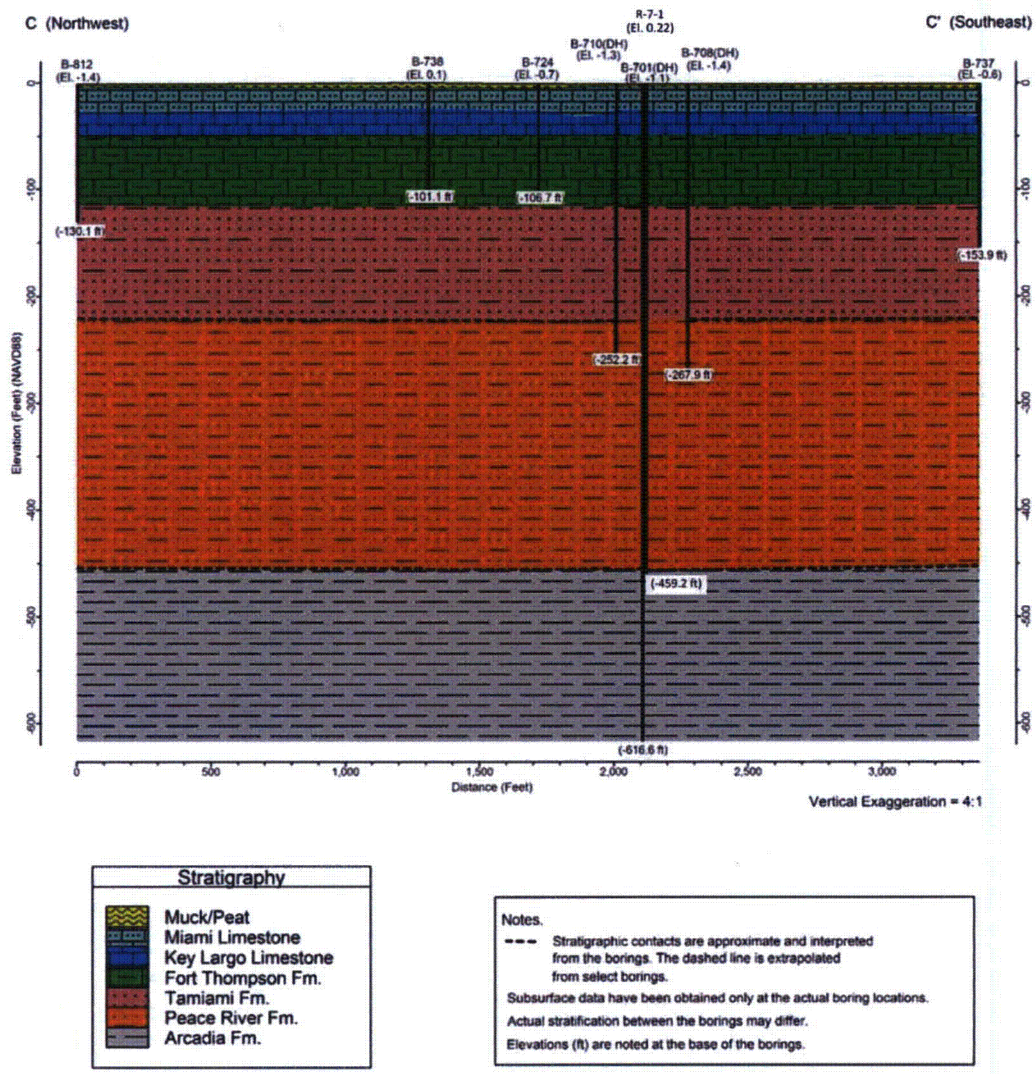

Figure 11 Cross-Section C-C′ (Vertical Exaggeration = 4:1)

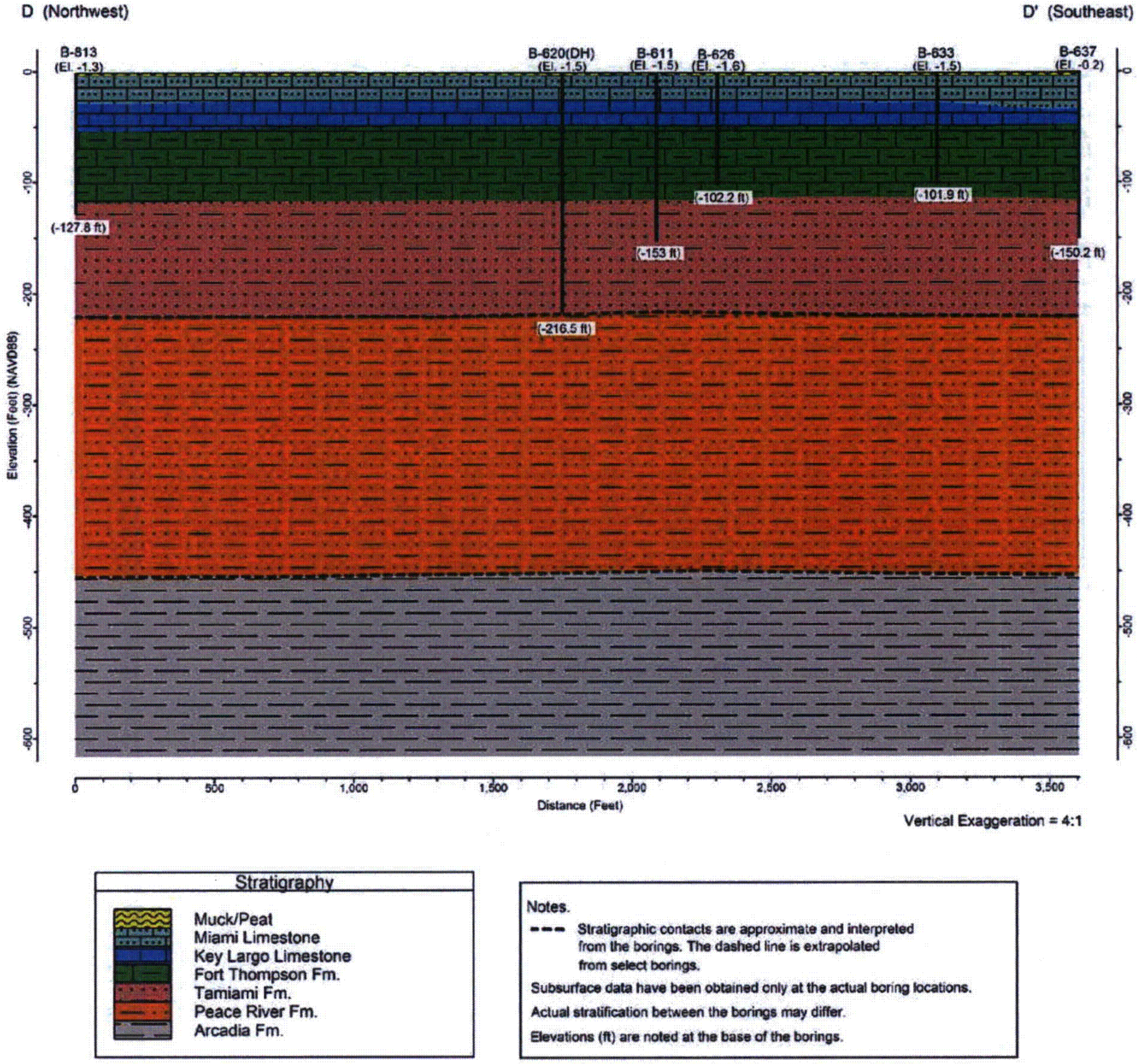

Figure 12 Cross-Section D-D′ (Vertical Exaggeration = 4:1

In addition to clarifications regarding the maps and cross-sections requested by the NRC during an April 25, 2013 teleconference, a summary of the potential for carbonate dissolution and karst development at the Turkey Point Units 6 & 7 site was also requested. That summary is provided as Appendix 2.5AA of this response. The appendix and associated revisions of the COLA are provided in this response in the section titled "Associated COLA Revisions".

This response is PLANT SPECIFIC.

References:

None

ASSOCIATED COLA REVISIONS:

The following revised text in FSAR Subsection 2.5.0.4, Stability of Subsurface Materials and Foundations, will be included in a future revision of the COLA.

2.5.0.4 Stability of Subsurface Materials and Foundations

The locations of the Units 6 & 7 nuclear islands are shown in Figure 2.5.4-201.

A combination of drilling, geophysics, and laboratory testing was used to characterize the subsurface. The **results of** the **initial** subsurface investigations and testing are presented in Reference 201. **The results of the supplemental subsurface investigations and testing are presented in References 202 and 203.**

On average, limestone strata extend from **4** feet below the surface to a depth of approximately 115 feet and are in turn underlain by sandy silty strata that extend to a depth of approximately 450 feet. Below this depth, ~~evaporate~~ **evaporite**-capped carbonate strata continue to basement volcanics at a depth of approximately 15,000 feet.

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. As further discussed in Section 2 of Appendix 2.5AA, 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. Carbonate dissolution in paleo-mixing 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 sea level and allowed mixing of fresh 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 paleo-mixing 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 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 terrane 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 longterm 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 (Subsection 2.4.5, Reference 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 of deep pore water upwelling in or near the site region is also discussed in Subsection 2.5.1.1.1.1.1.1. This process occurs within the sea bed on the offshore continental shelf where a layer of relatively impermeable rocks or sediments overlying a confined aquifer is breached by erosion or tectonic action, allowing upwelling of fresh groundwater into the ocean. 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 more likely. For this reason, carbonate dissolution associated with deep pore water upwelling 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 201 and 202, including a multi-method surface geophysical survey designed to detect subsurface cavities, offer 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.

The following text will be added after paragraph 7 of FSAR Subsection 2.5.1.1.1.1.1.1, Florida Peninsula Physiographic Subprovinces and will be included in a future revision of the COLA.

Carbonate Dissolution at Freshwater/Saltwater Interfaces

The freshwater/saltwater interface is defined as the location where seawater intrudes into a coastal aquifer and mixes with the discharging freshwater in a zone of mixed groundwater composition. The chemical reactivity of the mixing zone stems from the marked undersaturation with respect to carbonate minerals that develops from mixing a carbonate saturated freshwater with near surface seawater in a system closed with respect to carbon dioxide (Reference 945). Dissolution occurs when the two fluids of different salinities combine, even though both fluids are initially saturated with calcium carbonate (Reference 951). Because seawater saturated with calcium carbonate contains far less calcium carbonate than fresh groundwater saturated with calcium carbonate, the combined fluids become undersaturated with respect to calcium carbonate. This condition promotes dissolution of carbonate rocks.

Dissolution of limestone generally occurs where fresh, weakly acidic groundwater circulates through soluble carbonate rock or within zones of mixing fresh and seawater (References 263 and 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), groundwater at the site is saline (Table 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 (Subsection 2.4.5). 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.

Rising 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 (Subsection 2.4.5), 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 Turkey Point Units 6 & 7. 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 operating lifetime of Turkey Point Units 6 & 7 (Subsection 2.4.5). 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.

Several researchers (References 946, 947, 948, 949, and 950) indicate that carbonate dissolution associated with the mixing of freshwater and saltwater occurs predominantly at groundwater discharge sites or seafloor discharge zones. Mixing can also occur in surface water. The dissolution mechanisms are point source discharge and submarine groundwater discharge (SGD).

Point Source Discharge

Point source discharge is a concentrated flow of spatially constricted fresh surface water into a saltwater body. The discharge 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 its vicinity. An example of a point source discharge is surface water released to Biscayne Bay through drainage canal discharge.

The freshwater/saltwater interface at the base of the Biscayne Aquifer is located approximately 9.6 kilometers (6 miles) inland of Turkey Point Units 6 & 7, as shown on Figure 2.4.12-207. The migration of saltwater inland along the base of the aquifer occurs along the entire coastal zone and is the result of the aquifer's high permeability, the lowering of inland groundwater levels from groundwater pumping and surface drainage, and rising sea level (Subsection 2.4.5). As shown on Figure 2.4.12-207, the position of the freshwater/saltwater interface was relatively consistent between 1984 and 1995 and, in fact, provisional data from the USGS (Reference 960) showing the 2008 freshwater/saltwater interface in southeast Florida indicates a similar pattern.

Under natural conditions and before anthropogenic activity (e.g. construction of canals and enlargement of the Miami River) (References 267, 722, 955, 961, 962, and 963), the freshwater/saltwater interface in southeastern Florida was close to the coastline and freshwater discharged from springs on the floor of Biscayne Bay. In the late nineteenth century construction of flood control levees, drainage canals, and urbanization changed the position of the freshwater/saltwater interface. Canals were first dug through the Everglades to drain water from the area south of Lake Okeechobee to enable agriculture to develop (Reference 267). These canals roughly follow the transverse glades (i.e., narrow valleys or channels in which the soils (marl and sand) and vegetation are similar to those in the Everglades). By the late 1920s, major canals were constructed and rivers in the transverse glades were modified to connect Lake Okeechobee with the Gulf of Mexico and Atlantic Ocean (Figure 2.4.12-207) (References 267 and 964). In the 1930s, the government initiated flood control measures including levee construction and drainage channel modification. By the 1970s, gated control structures were installed at the coastal end of the primary drainage canals to discharge excess water during the wet season and impede the landward

movement of saltwater during the dry season. The final phase of canal development of the Everglades-South Dade conveyance system in the 1980s was constructed to meet agricultural water supply needs, control flooding, and mitigate saltwater intrusion (Reference 267).

The increased fresh surface water discharge from the Everglades to Biscayne Bay and the Atlantic Ocean through the drainage canals and increased pumping from the freshwater aquifer has probably had an impact on coastal groundwater hydrology by contributing to inland migration of the freshwater/saltwater interface as shown in Figure 2.4.12-207. Point source discharge also may have increased the potential for dissolution of carbonate rocks in the immediate vicinity of the drainage canal outfalls. However, stratification of freshwater near the surface of the canal outfalls may limit carbonate dissolution to the near surface.

Outfalls of drainage canals closest to the site are the Model Land Canal (C107) outfall near the southeast corner of the Turkey Point cooling water canals, approximately 8 kilometers (5.0 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, the possible effect of freshwater stratification near the outfalls, 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.

Submarine Groundwater Discharge

SGD is defined as the "phenomenon that forces groundwater to flow from beneath the seafloor into the overlying ocean regardless of its composition, whether freshwater, recirculated seawater, or a combination of both" (References 946 and 952). SGD can be subdivided into "shoreline flow" (i.e., fresh groundwater flow through an aquifer to the nearshore ocean that is driven by an inland hydraulic head) and "deep pore water upwelling" (DPU) (i.e., fresh groundwater flow beyond the shoreline on the continental shelf through deeper confined permeable shelf sediments and rocks, driven by buoyancy and pressure gradients (Reference 946). Reference 953 states "SGD per unit length of coastline could be very significant as a discharge process, due to the length of coastline where SGD occurs; whether or not rivers are present." The extent of SGD or saltwater intrusion at a given location is an issue of balance between hydraulic and density gradients in groundwater and seawater along a transect perpendicular to the shoreline (Reference 953). The two possible modes of submarine groundwater discharge, shoreline flow and deep pore water upwelling, are discussed below.

Shoreline Flow

As stated above, shoreline flow to the sea occurs when fresh groundwater flow through an aquifer is driven by an inland hydraulic head. As the shoreline flow nears the sea, it encounters the saltwater that has infiltrated from the ocean. The density of freshwater is lower than that of saltwater and therefore it tends to flow

above the saltwater. The freshwater flowing toward the sea encounters an irregular interface where mixing of the fluids is driven by diffusion and dispersion enhanced by ocean forces (i.e., tidal pumping, wave setup, storms, buoyancy, and thermal gradients). This freshwater/saltwater circulation pattern and mixing is similar to that in surface estuaries, leading to the term subterranean estuaries. Tidal forces operating in a mixed medium (i.e., bedrock) may enhance dispersion along the freshwater/saltwater interface and the permeability and preferential flow paths may be changed by chemical reactions within the aquifer. Precipitation of solids can restrict or block some paths, while dissolution will enlarge existing paths or open new ones (Reference 946). Examples of shoreline flow are:

- **Freshwater springs along Biscayne Bay (approximately 25 kilometers [16 miles] northeast of the site)**
- **Cave development along the Atlantic Coastal Ridge (approximately 17 kilometers [11 miles] north-northeast of the site)**
- **Submarine paleokarst sinkhole in the Key Largo National Marine Sanctuary (approximately 13 kilometers [8 miles] south of the site)**
- **Blue holes of the Bahamas in eastern South Andros Island (approximately 190 kilometers [120 miles] southeast of the site)**
- **Karst development on emergent carbonate islands in the Bahamas (approximately 320 kilometers [200 miles] southeast of the site)**
- **Karst development on the Yucatan Peninsula, Quintana Roo, Mexico (approximately 560 kilometers [350 miles] southwest of the site)**

Freshwater Springs along Biscayne Bay

Fresh groundwater had discharged along the Atlantic Coastal Ridge shoreline and offshore as submarine springs before the drainage canals were built and before substantial lowering of surface water and groundwater levels in southeast Florida. The groundwater flow conduits still exist and are dissolution features within the Biscayne Aquifer. Springs reportedly discharged near shore as freshwater boils in the shallow waters of Biscayne Bay (References 721, 954, and 955). In the late 1800s and early 1900s, springs within the Biscayne Aquifer provided a source of freshwater for sailing ships in Biscayne Bay. Parks (Reference 956) describes a freshwater spring off Coconut Grove (south of Miami) that was first documented in 1838 by Dr. Jacob Rhett Motte. Later a pump and platform was constructed to enable dories to tie up while filling wooden kegs with freshwater. This spring was marked as "freshwater" on Coast and Geodetic Survey Navigation Chart No. 166 (1896) (Reference 954). However, while many shoreline springs still exist in the bay and were formed by freshwater dissolution, salinity levels of 8 to 31 g/L (8 to 31 parts per thousand) indicate that the water quality is beyond the range for drinking water and, therefore, these groundwater discharges are no longer freshwater springs. The discharge rates from these springs are low, most likely due to blockage by sand in the conduits (Reference 954). 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 prior to redistribution of the groundwater flow.

Langevin (Reference 948) suggested that the drainage canals are the present focal points for groundwater discharge into Biscayne Bay, intercepting fresh groundwater that would have discharged directly to the bay. Field observations by Langevin (Reference 948) suggest that Biscayne Bay has changed from a system controlled by widespread and continuous submarine discharge and overland sheet flow to one controlled by episodic releases of surface water at the mouths of drainage canals. The canals and pumping from the freshwater aquifer have lowered the water table and, thus, submarine groundwater discharge has decreased. The Turkey Point Units 6 & 7 groundwater model is consistent with Langevin's model (Reference 948).

Cave Development along the Atlantic Coastal Ridge

Today, there are no freshwater springs discharging into Biscayne Bay. However, what do remain are the currently dry channels of past groundwater flow that were formed by freshwater dissolution. These are the caves of Miami-Dade County (Reference 955) (Figure 2.5.1-354). The 19 air-filled caves and one water-filled cave in Miami-Dade County found by Alan Cressler (Reference 955) are located along the eastern and western flanks of the Atlantic Coastal Ridge. Most caves of southeastern Florida occur on or along the eastern flanks of the ancient Atlantic Coastal Ridge, or along the edges of transverse glades that cut through the Atlantic Coastal Ridge. According to Cressler's (Reference 955) field observations and descriptions, the caves within the Pleistocene limestones fall into four categories: (1) at least one is oriented along fractures, (2) some caves are concentrated along the margins of transverse glades, (3) some caves are composed of stratiform lateral passages, and (4) some caves have entrances along the margins of cave-roof collapse. Most of the caves discovered by Cressler (Reference 955) fall into the second category. The caves are concentrated along the margins of transverse glades. Cressler (Reference 955) hypothesized that slightly acidic water from the Everglades could be a potent agent for dissolving limestone and forming the caves in the transverse glades in the Miami Limestone.

The most extensive karst development in Miami-Dade County lies within the boundaries of the Deering Estate County Park and Preserve (Reference 955) on the eastern flank of the Atlantic Coastal Ridge. The Deering Estate County Park and Preserve is located approximately 17.6 kilometers (11 miles) north-northeast of the site. Of the 19 air-filled caves identified by Cressler (Reference 955), seven are located in the Deering Estate. Observations in the Deering Estate indicate that variations in Pleistocene stratigraphy (i.e., Miami Limestone) may have played an

important role in the origin of many small caves, including the 36.6-meter (120-foot)-long Fat Sleeper Cave. At Deering Estate, cave passages are commonly low, wide and sandwiched between crossbeds of oolitic limestone. These stratiform passages seem confined to a zone of rock with many centimeter-scale vugs related to complex burrow systems. It is hypothesized that the burrow-related porosity provided early preferential pathways for groundwater flow and concentrated dissolution. In some caves, solution pipes penetrate the upper cross-bedded limestone and connect to the land surface (References 954 and 955).

One of the most well known caves in Miami-Dade County, Palma Vista Cave, is located on Long Pine Key in the Everglades National Park (Figure 2.5.1-355). The entrance of the Palma Vista Cave probably formed by the collapse of a thin roof that spanned a stratiform cave (Reference 954). The speleothems in the cave that are underwater are important because their presence implies that they developed in Palma Vista Cave during a previous, extended dry period (i.e., sea level low stand). Such a condition would have existed when sea levels were much lower, such as the period between approximately 80,000 and 6,000 years ago (Reference 957).

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), shoreline flow at the Turkey Point Units 6 & 7 site is brackish to 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 (Subsection 2.4.5). 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.

Submarine Paleokarst Sinkhole in the Key Largo National Marine Sanctuary

A large submarine, sediment-filled paleosinkhole in the Key Largo National Marine Sanctuary off Key Largo, Florida (Figure 2.5.1-360) is described as having a 600-meter (1970-foot) diameter with a depth likely to exceed 100 meters (328 feet) (Reference 959). The Key Largo submarine paleosinkhole lies beneath 5–7 meters (16-23 feet) of water, and is bordered by Holocene reefs to the east and marine grass and carbonate sand to the west. Shinn et al. (Reference 959) jet probed to 54.5 meters (179 feet) and did not reach the bottom of the sinkhole. Patches of marine grass grow on the carbonate sands in the circular feature, but corals are absent (Reference 959). The sediments as observed from the sediment cores consist of monotonous gray aragonite mud visually lacking sedimentary laminations and fossils. The composition of the sediment as analyzed by X-ray diffraction is approximately 95 percent aragonite and 5 percent calcite. The oldest ^{14}C age (from the bottom of the jet probe sampler) is 5650 +/-90 years before

present. The youngest ^{14}C age (just below the overlying carbonate sand cap) is 3260 +/-60 years before present. The high percentage of aragonite and near absence of low-magnesium calcite indicate the sediment is of marine origin and the ^{14}C dates indicate rapid deposition (Reference 959).

Shinn et al. (Reference 959) postulate that the Key Largo sinkhole is a cenote that formed during the Pleistocene. Fluctuations in sea level related to advance and retreat of continental glaciers raised and lowered the fresh groundwater/seawater shoreline mixing zone in the area of the sinkhole and facilitated dissolution of carbonate rocks to a depth near the sea level low stand. As the Wisconsinan ice sheet began to retreat and sea level began to rise 15,000 years ago, the shelf off Key Largo was at least 100 meters (328 feet) above sea level. A shallow freshwater lake would have formed at the bottom of the sinkhole. The lake would have gradually deepened as the groundwater level adjusted to the rising sea level. By 6000 years ago, just before marine flooding of the shelf, the sinkhole would have been surrounded by wetlands. Infilling of the sinkhole most likely began with precipitated freshwater calcite muds (i.e., marl). As sea level continued to rise, fresh and brackish water were replaced by saline waters. Marine sediment began to settle into the sinkhole, at which time the sinkhole would have functioned like a giant sediment trap. The ^{14}C dates indicate that pulses of rapid sedimentation at 4.1 ka and 4.8 ka (thousand years before present) punctuated marine sedimentation. These pulses were likely the result of tropical hurricanes, which reworked and deposited the lime mud on the Florida reef tract. The lime mud sedimentation ceased and was replaced by sedimentation with skeletal carbonate sands approximately 3 ka. The eastern rim of the sinkhole is dominated by coral reefs which are assumed to be the major source of the carbonate sands that cap the muddy sediment (Reference 959).

In summary, the Key Largo submarine paleosinkhole began to form during the Pleistocene. Infilling of the sinkhole began approximately 15,000 years ago when sea level began to rise. The environment at the bottom of the sinkhole at that time was essentially that of a freshwater lake that became brackish and eventually evolved to the current marine environment, at which point conditions conducive for continued limestone dissolution and sinkhole formation no longer existed. At approximately 6 ka the sinkhole was inundated by seawater and became a sediment trap. Rapid pulses of sedimentation occurred approximately 4.1 ka and 4.8 ka. At approximately 3 ka, coral reefs began to accumulate on the seaward side of the sinkhole.

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 (Table 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 (Subsection 2.4.5), 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 of the Bahamas, Eastern South Andros Island

The blue holes of the Bahamas beneath South Andros Island lead to an extensive system of underwater caves along nearshore fracture systems (Figure 2.5.1-365). Formation of the blue holes, which reach depths exceeding 100 meters (328 feet), began during a previous eustatic sea level low stand associated with advance of continental glaciation during the Pleistocene. Groundwater circulation to the blue holes is facilitated by the fracture permeability that exists within the fracture systems in the carbonate rock. Investigations into groundwater-seawater circulation in some of the holes offshore of South Andros Island indicate a brackish mixture in the caves that readily dissolves aragonite but not calcite, producing secondary porosity. The depletion of calcium in the saline groundwater indicates precipitation of calcite cement. Bacterial processes possibly due to submarine groundwater discharge also play a significant role in driving carbonate dissolution in the Bahamas (References 946 and 950).

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 (Table 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 (Subsection 2.4.5), 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 Emergent Carbonate Islands in the Bahamas

In the Bahamas, flank margin caves (Figures 2.5.1-361 and 2.5.1-362) form on emergent carbonate islands due to the mixing of fresh and saltwater in the presence of organic matter. The presence of organic matter allows oxidation to produce carbon dioxide, which in turn produces carbonic acid that drives carbonate dissolution. This carbonate dissolution results in anoxic conditions in the mixing zone of the fresh groundwater lens. Complex oxidation/reduction reactions involving sulfur produce acids that lead to further dissolution (Reference 263). The morphology of the flank margin caves includes large, globular chambers, bedrock spans, thin bedrock partitions between chambers, tubular passages that end abruptly, and curvilinear phreatic dissolution surfaces. The flank margin caves are not conduits, but rather mixing chambers (Figure 2.5.1-362). They receive freshwater from the fresh groundwater lens in the island interior as diffuse flow, and discharge that water, after mixing, as diffuse flow to the sea. The caves develop without an external opening to the sea or the land. Current

entry is possible due to surface erosion breaching into the cave (Reference 263). Examples of flank margin caves are Lighthouse Cave, San Salvador Island, Bahamas and Salt Pond Cave, Long Island, Bahamas (Reference 263).

In addition to flank margin caves, there are banana holes in the Bahamas (Figure 2.5.1-362). Banana holes form inland from the flank margin caves at the top of the fresh groundwater lens where the vadose and phreatic freshwaters mix. They are smaller phreatic dissolution voids that form due to collapse of a relatively thin bedrock roof resulting in a broad, vertical-walled depression up to 10 meters (33 feet) across (Reference 263). Both the flank margin caves and banana holes are found in the Bahamas at elevations of 1 to 6 meters (3.3 to 20 feet) above sea level. These caves formed during a glacioeustatic sea level high stand that reached elevations above modern sea level. According to Mylroie and Carew (Reference 263), these caves formed approximately 125,000 years ago. The duration of this high stand above modern sea level lasted approximately 15,000 years, during which time the Bahamas consisted of islands even smaller than today because all land below 6 meters (20 feet) in elevation was below sea level. Therefore, these phreatic caves formed in small freshwater lenses in as little as 15,000 years (Reference 263).

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 (Table 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 (Subsection 2.4.5). Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist.

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 shoreline flow and, therefore, is discussed here. In the Yucatan Peninsula, dissolution features intermediate in size between flank margin and epigenetic continental caves form along the margin of the discharging fresh groundwater lens as a result of freshwater/saltwater mixing. Fresh groundwater discharges are very substantial on the Yucatan carbonate platform, as they are fed by a large volume of allogenic recharge (i.e., recharge of the groundwater from an outside location) from the Yucatan interior (Reference 965). Smart et al. (Reference 965) believe that the Quintana Roo caves (Figure 2.5.1-363) represent a new cave type intermediate in size between flank-margin and epigenetic continental systems.

The Quintana Roo caves located several kilometers interior from the coast may display elements of a dendritic tributary pattern (typical of epigenetic continental

caves). Downstream, this drainage passes into an extended zone characterized by a cross-linked anastomosing passage pattern that extends inland from the coast for maximum distances of 8 to 12 kilometers (5 to 7.5 miles) (Reference 965). Large isolated mixing chambers characteristic of the flank margin type caves are absent. Instead, large chambers occur as an element in the anastomosing zone and are generally associated with collapse. Rectilinear maze patterns are generally absent from the caves located in the interior; however, they do appear to be characteristic of some of the coastal caves where fractures have developed parallel to the flank margin (Reference 965).

The passage types in the Quintana Roo caves are horizontal elliptical tubes and canyon-shaped passages and are extensively modified by collapse, but many retain dissolutional wall morphology. The caves are actively enlarging because of undersaturation with respect to calcium carbonate, resulting from the mixing of fresh and saline water. However, according to Smart et al. (Reference 965), many caves in the interior are above the present mixing zone and are characterized by collapse and infill with surface-derived clays, speleothem deposits, and calcite raft sands. Cave sediment fill, speleothem, and ceiling-level data indicate multiple phases of cave development. These multiple phases are associated with glacioeustatic changes in sea level, and alternate in individual passages between active phreatic enlargement and vadose incision and sedimentation. Due to 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 formerly closer to the coast and have gone through multiple phases of cave development. Collapse of the cave roofs is extensive and ubiquitous, which results in the 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 (Reference 965).

Two critical conditions that control the development of multiphase Quintana Roo caves following glacioeustatic variations in sea level are:

1. **When the passage segments remain connected to the underlying deep cave systems and are occupied by the present mixing zone, substantial inflow of saline water maintains the rate of mixing-driven carbonate dissolution, and the predominantly carbonate rock is removed, allowing active passage enlargement to continue.**
2. **When the links between cave passages are absent, rates of dissolution are low, and passage enlargement ceases (Reference 965).**

If the flow of freshwater through a passage is maintained by tributaries, the velocity may be sufficient to prevent accumulation of further sediments or to flush uncemented sediments from the passage and the cave void will remain open. If such freshwater flows are limited or absent due to blockage of the feeders, the passage segment will gradually become occluded by infill and roof collapse (Reference 965).

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 terrane 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 965). The absence of a more developed karst topography or 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 Table 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.

Deep Pore Water Upwelling

DPU takes place beyond the shoreline on the continental shelf through advection of water through deeper, confined permeable shelf sediments and rocks driven by buoyancy and pressure gradients. Evidence of DPU is provided by the existence of offshore submarine springs. In this case, the flow may be driven by an inland hydraulic head through highly permeable confined aquifers or by the large-scale cyclic movement of water due to thermal gradients (Reference 946). Examples of deep pore water upwelling are:

- **Submarine paleokarst sinkholes beneath Biscayne Bay (approximately 13 kilometers [8 miles] northeast of the site)**
- **Crescent Beach Spring and Red Snapper Sink, both off the coast of Crescent Beach, Florida (approximately 320 kilometers [200 miles] north of the site)**

Submarine Paleokarst Sinkholes Beneath Biscayne Bay

Cunningham and Walker (References 958 and 989) conducted a study east of the Miami Terrace using high-resolution, multichannel seismic-reflection data (Figure 2.5.1-356). The data exhibit 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 (Figure 2.5.1-357). The disturbances in the seismic reflections are indicative of deformation in carbonate rocks of Eocene to middle Miocene age. This deformation is interpreted to be related to collapsed paleocaves or collapsed paleocave systems and includes fractures, faults, and seismic-sag structural systems (Figure 2.5.1-358) (References 958 and 989).

In general, the seismic-sag structural systems exhibit one or more zones of vertically stacked, concave-upward arrangements of generally parallel seismic-reflection patterns (Figure 2.5.1-358) (References 958 and 989). Twelve seismic sag structural systems have been delineated on the seismic profiles of Cunningham and Walker (Reference 958). Two types of seismic-sag structural systems they have identified are "narrow" and "broad." The type of system is defined based on the measured differences in the inner sag width of the deformed seismic reflectors. The inner sag width is defined as "the distance between inflection points (i.e., where the shape of the subsidence profile changes from concave to convex) on both sides of the structural trough" (Reference 958).

Collapse related to the "narrow," seismic-sag structural systems is multistoried as shown in Figure 2.5.1-358 (Reference 958). The uppermost termination of zones of concave upward reflections displayed in many of the narrow sag structures may correspond to paleotopographic expression of the upper surface of paleosinkholes, since many are filled in with onlapping reflections. The onlapping reflections indicate passive sedimentary fill at the top of sagging reflections. This relationship is shown in zones 2 and 3 in the N1 profile in Figure 2.5.1-358. These two zones are indicative of cave collapse and suprastratal deformation during the Eocene. Cunningham and Walker (Reference 958) hypothesize that the association of narrow, seismic-sag structural systems with a possible single fault, in some cases, likely indicates a structural fabric and associated fracture/fault permeability. Although the more recent work by Cunningham and Walker confirms the existence of the seismic-sag structural systems in Biscayne Bay, the authors indicate that both faults and karst collapse systems that might cause disruption in confinement have only been imaged in the middle Eocene to Oligocene part of the Floridan Aquifer system (Reference 989). These faults may have a substantial control on the geographic distribution of some of the narrow seismic sag structural systems (References 958 and 989).

A major collapse event associated with the "broad," seismic-sag structural system is shown in Figure 2.5.1-359. This collapse event occurred in the Eocene based on the deformation of seismic-reflection stratigraphic layer 8 (SS8) reflections which are assigned to Eocene-age rocks. These SS8 reflectors appear to have downlapping relations onto the upper surface of the zone 2 sag structures and truncate reflectors at the top of the zone 2 structure (Reference 958).

There are three possible mechanisms for the formation of the seismic sag structures: (1) "corrosion" or dissolution by an Eocene mixed freshwater/saltwater zone associated with regional groundwater flow, (2) upward groundwater flow during the Eocene driven by Kohout convection (the circulation of relatively warm saline groundwater deep in carbonate platforms and subsequent mixing with meteoric water as it rises), and (3) upward ascension of hydrogen sulfide-charged groundwater, with the hydrogen sulfide derived from the dissolution and reduction of calcium sulfates in the deeper Eocene or Paleocene rocks (Reference 958). The

potential link between the seismic sags and submarine paleosinkholes suggests the seafloor sinkholes began to form as early as the Eocene.

Regardless of the mechanism of formation, the geophysical data indicate the absence of deformation in rocks younger than middle Miocene (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 middle Miocene would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, Tamiami Formation and Peace River Formation. The total thickness of this section at the site is approximately 137.2 meters (450 feet) (Figure 2.5.1-332). Deformation of rocks below this depth is not likely to pose a threat of surface collapse at the site.

Crescent Beach Spring and Red Snapper Sink, Off the Coast of Northeast Florida

Crescent Beach Spring and Red Snapper Sink are located outside of the 200-mile radius site region, but the spring and sink are evidence of deep pore water upwelling and warrant discussion here. Crescent Beach Spring, a freshwater spring, is located approximately 4 kilometers (2.5 miles) east of Crescent Beach, Florida (Figure 2.5.1-364) and is considered a first-order magnitude spring with a flow rate of greater than 40 cubic meters/second (greater than 1400 cubic feet/second) (Reference 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 (Reference 946).

The Red Snapper Sink (Figure 2.5.1-364) is located approximately 42 kilometers (26 miles) off 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 site observed that seawater was flowing into small caves at the base of the hole, indicating possible recharge of the Floridan Aquifer, and that the water in the bottom of the hole was similar in salinity and sulfate content to ambient seawater. According to Moore (Reference 946), Red Snapper Sink was similar to Crescent Beach Spring before the piezometric head was lowered along the coast, and preservation of the feature suggests that a freshwater spring was active at this site in the recent past.

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 (Table 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 off shore, 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.

The following revised text in the last paragraph of FSAR Subsection 2.5.1.2.2, Site Area Stratigraphy, and additional paragraphs will be included in a future revision of the COLA.

Four geologic cross sections, two isopach (thickness) maps, ~~one~~**two** structure contour map**s**, and a site geologic map were prepared from the information obtained from the site subsurface investigation (Figure 2.5.1-33~~6~~**4**). Geologic cross section A-A' (Figure**s** 2.5.1-338 **and 2.5.1-386**) extends east-west through the power blocks and ~~eight~~ **13** borings, including the ~~two~~**four** deepest borings B-601**, B-701, R-7-1,** and **R-6-1b**. Cross section B-B' (Figure**s** 2.5.1-339 **and 2.5.1-387**) extends west-east through the southern edge of the site and ~~includes~~ eight borings, the deepest at ~~153 feet (~~46.6 meters (153 feet) bgs. Cross section C-C' (Figure**s** 2.5.1-340 **and 2.5.1-388**) extends diagonally northwest-southeast through the entire site and passes through the western power block. Cross section C-C' includes ~~seven~~ **eight** borings including **two of** the deepest boring**s**, B-701(DH), at a depth of ~~615.5 feet (~~187.6 meters~~)~~ (615.5 feet) bgs **and R-7-1, at a depth of 140 meters (459 feet) bgs**. Cross section D-D' (Figure**s** 2.5.1-341 **and 2.5.1-389**) also extends diagonally northwest-southeast through the entire site but passes through the eastern power block. Cross section D-D' includes six borings; the deepest at a depth of 215 feet (66 meters) bgs.

The locations of the surface traces of the cross sections are shown on Figures 2.5.1-342 and 2.5.1-344 (isopach maps of the Key Largo Limestone and the Fort Thompson Formation, respectively) and Figures 2.5.1-349, and 2.5.1-343 (structure contour maps of the top of the Key Largo Limestone and the Fort Thompson Formation, respectively). Two versions of each of the four cross- sections are provided. Cross-sections in the first set (Figures 2.5.1-338, 2.5.1-339, 2.5.1-340, and 2.5.1-341) are truncated at the elevation of -61 meters-(-200 feet) NAVD88 and depict the subsurface stratigraphy with a vertical exaggeration of 12 to 1. Figures 2.5.1-386, 2.5.1-388, and 2.5.1-389 depict a thicker section of the subsurface stratigraphy on the same cross-sections with a vertical exaggeration of only 4 to 1.

The cross sections indicate that geologic contacts beneath the site are relatively flat and undeformed. This **stratigraphy** reflects the environment of deposition and subsequent erosion of the paleosurface. ~~This is represented by~~ **The flat and undeformed nature of the geologic contacts is reflected in the** isopach maps of the Key Largo Limestone (Figure 2.5.1-342) and the Fort Thompson Formation (Figure 2.5.1-344) that indicate a relatively uniform thickness across the site with no abrupt changes. **The** structure contour map**s** of the top of the **Key Largo Limestone (Figure 2.5.1-349) and the** Fort

Thompson Formation **(Figure 2.5.1-343)** show a relatively flat paleosurface ~~(Figure 2.5.1-343)~~. Boring logs and descriptions of the lithology are included in the geotechnical data report in References 708 **and 995. Section 5.3 of Appendix 2.5AA provides a discussion of the isopach and structure contour maps and reasons for concluding that they provide no strong evidence for the presence of large collapse features in the Key Largo Limestone or Fort Thompson Formation at the site.**

The following revised text will be included in a future COLA revision to replace paragraphs 7 through 14 of FSAR Subsection 2.5.1.2.4, Site Geologic Hazards.

Seventh paragraph and onward:

An FGS investigation (Reference 724) concludes that most of Miami-Dade County is underlain by limestone containing solution cavities. ~~It indicates that a few localities in the Homestead/Turkey Point area may be underlain by open and sand-filled cavities in a zone occurring between depths of about 18 to 31 feet (5 to 9 meters). Information collected during the course of Units 6 & 7 subsurface investigations include rod drops, loss of drill fluid circulation, rock recovery, and Rock Quality Designation (RQD).Analysis of this information indicates that, while individual boreholes showed variation, data collected during the drilling of boreholes qualitatively points towards the existence of two preferential secondary porosity flow zones in the areas beneath and in the immediate vicinity of the Units 6 & 7 site:~~

~~An upper zone from approximately -25 feet to -35 feet NAVD 88 located predominantly within the Key Largo limestone (the start of this zone correlates roughly with the boundary between the overlying Miami Limestone and the underlying Key Largo Limestone).~~

- ~~A lower zone from approximately -65 feet to -75 feet NAVD 88 that correlates with a sandy zone within the Fort Thompson Formation.~~

~~Analysis of the caliper, suspension velocity, and acoustic televiewer data collected from 10 borings during the Units 6 & 7 subsurface investigation provides additional evidence supporting the existence of these secondary porosity flow zones beneath Units 6 & 7. As stated in the MACTEC site subsurface investigation report (Reference 708), the location of cavities and weathered zones on the televiewer logs correspond precisely with increases in caliper log diameter and suspension P- and S-wave velocity drops. Study of the downhole geophysical data logs confirms that such cavities and weathered zones are commonly observed within the elevation ranges proposed for the upper and lower secondary porosity flow zones. A downhole video survey conducted in pilot hole MW-1, located on the Turkey Point Peninsula, also supports the existence of these secondary porosity zones. The downhole video shows evidence of highly permeable zones containing interconnected vugs between the elevations of approximately -21 feet to -43 feet NAVD 88 and -62 feet to -72 feet NAVD 88.~~

Zones of secondary porosity have formed in limestone beneath the site where microkarst features have developed (Subsections 2.4.12.1.3.1 and 2.5.1.2.4). These zones of secondary porosity provide areas of preferential groundwater flow. The microkarst features are thought to have formed by solution enlargement of sedimentary structures when fresh groundwater formerly flowed from inland areas, mixed with sea water, and facilitated dissolution as it flowed through the zone to the sea. The zones of secondary porosity can be subdivided into two categories: touching-vug porosity and moldic porosity.

The two zones of secondary porosity were identified at the site following review of the geophysical logs, the geotechnical boring logs, and the shear wave velocity logs. In general, the zones of secondary porosity were identified based on increases in borehole diameter on the caliper logs, darkened areas on the acoustic televiewer images, typically lower P-S wave velocity values, rod drops, and in the case of touching-vug porosity, loss of drilling fluid circulation. Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353 show the approximate locations of the two zones of secondary porosity on three example-boring logs, B-604 (DH), B-608 (DH), and B-710 G (DH), and their locations at the Turkey Point Units 6 & 7 site are shown on Figures 2.5.1-228 and 2.5.4-202. Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353 were compiled using the lithology, caliper, natural gamma, acoustic televiewer, and velocity (Vs and Vp) logs.

Recent studies by Cunningham et al. (References 404 and 723) suggest vuggy porosity is common within the Biscayne Aquifer (Miami Limestone, Key Largo Limestone, and Fort Thompson Formation) and that typical solution features associated with the touching-vug porosity include solution-enlarged fossil molds up to pebble size, molds of burrows or roots, irregular vugs surrounding casts of burrows or roots, and bedding plane vugs. Cunningham et al. (Reference 404) show images of vugs in the Miami Limestone and Fort Thompson Formation, with cavernous vugs approximately 4 feet in height (Figure 2.5.1-385). The results of extensive site investigation for Turkey Point Units 6 & 7 (Subsections 2.5.1.2.2 and 2.5.4.2.2, and Reference 708) offer no evidence that karstification of the area has developed cavernous limestone with the potential for collapse and formation of sinkholes.

Touching-vug porosity occurs on the site within the approximate depth interval of 20 to 35 feet (Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353) near the contact of the Miami Limestone and Key Largo Limestone (the "Upper Zone" of secondary porosity discussed in Subsection 2.4.12.1.4). Because the elevation of ground surface at the site is approximately 0 feet NAVD 88 (Reference 708), this depth interval corresponds approximately to -20 to -35 feet NAVD 88. The origin of this porosity is solution enlargement of burrows, inter-burrow vugs, moldic fossils, root molds, and vugs between root casts (References 404, 723 and 969). These structures are sufficiently numerous and closely spaced to form a laterally continuous zone of interconnected voids. Results of drilling and coring within the zone of touching-vug porosity during the site subsurface investigation have shown

the feature to be laterally persistent, generally of centimeter scale, with very few indications of possible larger voids such as a rod drop.

Moldic porosity occurs in pockets within the approximate depth interval of 60 to 75 feet (-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 discussed in Subsection 2.4.12.1.4. The origin of this feature is preferential dissolution of fossil shells and other organic structures rather than the matrix rock within which they are contained, resulting in void spaces of generally centimeter scale within molds of the structures (References 404, 723, and 969). Results of drilling and coring within the zone of moldic porosity during the site subsurface investigation have shown the feature not to be laterally persistent but occurring in isolated sandy pockets with very few indications of possible larger voids such as a rod drop.

As seen from the cores taken during the subsurface investigation and photos of the cores (References 708 and 995), the potential origin of the touching-vug porosity within the upper zone is associated with original reef structure and, based on Cunningham et al. (References 404 and 723), solution enlargement. The potential origin of the lower zone of secondary porosity is moldic porosity resulting from dissolution on in situ bivalve shells.~~The "cavities" described in the MACTEC report (Reference 708) are considered to represent both touching-vug porosity and moldic porosity. The potential origin of touching-vug porosity within the upper zone of secondary porosity is solution enlargement and original reef structure. The potential origin of the lower zone of secondary porosity is moldic porosity resulting from dissolution on in situ bivalve shells.Recent studies by Cunningham et al. (References 404 and 723) suggest vuggy porosity is common in the Biscayne Aquifer (Miami and Key Largo Limestones and Fort Thompson Formation) and that typical solution features associated with the touching-vug porosity include solution-enlarged fossil molds up to pebble size, molds of burrows or roots, irregular vugs surrounding casts of burrows or roots, and bedding plane vugs.~~

As further discussed in Appendix 2.5AA, dissolution of the limestone in the upper zone of secondary porosity likely occurred during the Wisconsinan glacial stage of the Pleistocene Epoch when sea level was lower than during the preceding interglacial stages when the Miami Limestone and Key Largo Limestone were formed (Figures 2.5.1-372 and 2.5.1-373) and fresh groundwater from the Everglades mixed with seawater and discharged through the zone to the sea. The coralline vugs within the Key Largo Limestone typically exhibit evidence of precipitation of secondary minerals such as 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 6 miles (9.6 kilometers) inland from the site (Figure 2.4.12-207), groundwater within the zone of touching-vug porosity is saline (Table 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 0.78 foot (0.2 meter) per century (Subsection 2.4.5), 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).

Dissolution of the limestone in this zone of secondary porosity likely occurred during the early to 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 6 miles (9.6 kilometers) inland from the site (Figure 2.4.12-207), groundwater within the zone of moldic porosity is saline (Table 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 0.78 foot (0.2 meter) per century (Subsection 2.4.5), 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.

While touching-vug and moldic porosity similar to that noted by Cunningham et al. (References 404 and 723) and Lucia (Reference 969) occur at the Turkey Point Units 6 & 7 site, it should be noted that only occasional small rod drops were noted during the site investigation (References 708 and 995) (Subsections 2.5.1.2.4, 2.5.4.1.2.1 and 2.5.4.4.5.5 (Table 2.5.1-208)). 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 an SPT when the weight of the string of drill rods is sufficient to advance the SPT 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 inter-bedded 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.

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). The geotechnical logs of the boreholes in which the rod drops occurred indicate that, except for the two drops that occurred in the Miami Limestone, the drops occurred as the drill or sampler advanced from relatively competent rock into a more sandy zone. 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.

The evaluation of all data (References 708 and 995) indicate 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 7918.4 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 708 and 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 feet 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 708 and 995).

Cavities observed during rock core operations were relatively small. The overall data collected during the Units 6 & 7 subsurface investigations are consistent with a communication with the FGS, which indicates that dissolution present in the site area is generally considered to be **microkarst** with numerous small cavities. **This information is consistent with investigations by Cunningham (References 404 and 723) in the Biscayne Aquifer in southeastern Florida.**

An investigation of small surface depressions identified within the site (Figure 2.5.1-333) and site area is discussed in Subsection 2.5.3. The UFSAR for Turkey Point Units 3 & 4 concludes that "[s]uch depressions are not sinkholes associated with collapse above an underground solution channel, but rather potholes, which are surficial erosion or solution features" (Reference 712). These solution potholes are not expected to form large voids beneath the surface that would pose a hazard to the site (Reference 264).

An integrated geophysical survey focused on the Units 6 & 7 power block area and the small surface depressions identified within the site is discussed in Subsection 2.5.4.4.5. Based on ~~all of the site characterization data collected from the site~~ **an integrated interpretation of the boring data (Subsection 2.5.4.1.2.1) and the integrated site geophysical survey data,** there is no **apparent** evidence for sinkhole hazards or for the potential of surface collapse due to the presence of large underground openings. **The origin and significance of the surface depressions as well as the interpretation of the geophysical survey data are discussed further in**

Appendix 2.5AA. The locations of the vegetated depressions correlate well with results of the geophysical surveys (Figures 2.5.4-223 and 2.5.4-228). The presence of peat within the vegetated depressions, as well as the soft zones within the Miami Limestone (indicated by relatively low SPT "N" values recorded in logs of soil borings drilled on the geophysical survey lines), correlate well with low-gravity anomalies.

The MASW data indicate that the vegetated depressions at the site are underlain by continuous Key Largo Formation (Figures 2.5.4-227 and 2.5.4-241). These two figures show MASW data along survey lines 9 and 10 that intersect at a prominent vegetated depression. Within the limits of survey resolution, the microgravity data do not indicate the presence of large subsurface voids. To address uncertainties in the resolution of the geophysical data away from survey lines and at depth beneath the foundation, a microgravity survey will be conducted at the base of the Unit 6 and Unit 7 nuclear island excavations (Subsection 2.5.4.4.5).

What can be interpreted as karst or sinkhole-like features similar to the small surface depressions on site have been noted in aerial photographs of the nearby portion of Biscayne Bay (Appendix 2.5AA). The Bay has been modified and dredged and has an average water depth that ranges from 6 to 13 feet (Reference 991). Assuming the water level in the bay is 0 feet NAVD 88, the bottom of the bay ranges in elevation from approximately -6 to -13 feet NAVD 88. According to Reich et al. (Reference 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, the elevation of the bedrock surface within which the "karst/sinkhole-like features" occur on the floor of the bay (or alternatively the "vegetated depressions," "local depressions," and "potholes" described in Subsection 2.5.3) ranges from -6.5 to -43 feet NAVD 88. The 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 (Subsection 2.5.1.2.4). The Lower Zone of secondary porosity is located within the Fort Thompson Formation at an approximate elevation of -65 feet NAVD 88 (Subsection 2.5.1.2.4). Based on site stratigraphic data (Subsection 2.5.1.2.2), the units are relatively flat and it appears that the Upper Zone of secondary porosity at the Turkey Point Units 6 & 7 site occurs within the stratigraphic interval within which the "karst/sinkhole-like features" occur on the floor of Biscayne Bay. That level is the stratigraphic interval of the Miami Limestone and Key Largo Limestone (Figure 2.5.1-332). Results of the site subsurface investigation (References 708, 995, and 996) have demonstrated the absence of large solution cavities at this stratigraphic interval on the site.

While the touching-vug porosity exhibited in the Upper Zone of secondary porosity and the "karst/sinkhole-like features" on the bottom of Biscayne Bay may be in the same stratigraphic interval, the formation of these dissolution features is somewhat different. Dissolution features such as vugs are typically post-depositional features that occur in a freshwater phreatic system in which groundwater has filled open spaces and causes dissolution. The "karst/sinkhole-

like features" on the bottom of the bay appear to be paleo-dissolution features that formed during the Wisconsinan (most recent) glacial stage of the Pleistocene when sea level was approximately 100 meters (328 feet) lower than the modern ocean (Reference 262) and at an elevation favorable for dissolution by rainwater of subaerial limestone in what is now the bay. More information on the development of the "karst/sinkhole-like features" on the bottom of Biscayne Bay is provided in Appendix 2.5AA and in the following paragraph, together with a summary of the evolution of the bay.

The process of limestone deposition in Florida was variable during the Pleistocene Epoch due to fluctuations in glacial runoff and the corresponding sea level. The Sangamon interglacial corresponds to the Q5e interglacial stage that occurred between approximately 125,000 and 75,000 thousand years ago (Reference 928). During this time, sea level rose globally and in Florida resulted in an increase in marine carbonate deposition. Sea level was approximately 20 feet higher than today (References 993 and 994) and covered the entire Florida peninsula south of Lake Okeechobee (Reference 994). The marine sediments (i.e. the Miami Limestone and Key Largo Limestone) that accumulated during the Sangamon and the previous interglacial high sea level stands (Reference 928) were lithified and their depositional morphology preserved. Two elongated sediment ridges that formed the Key Largo Ridge and the Atlantic Coastal Ridge resulted in the limestone basin that is now filled by Biscayne Bay, Card Sound, and Barnes Sound.

During lower sea level stands of the Wisconsinan glacial stage, the Florida platform became emergent (sea level was approximately 100 meters (328 feet) lower than today) and the sea floor of Biscayne Bay was exposed (Reference 262). The exposed sea floor of the Bay was altered by rainwater. Dissolution, re-precipitation, and vegetative soil formation cemented the calcareous surface and slowly produced a very hard reddish limestone "soil crust" over the surface. Carbonate dissolution resulting from infiltration of rain water produced solution holes and pipes into the underlying limestone and solution-hole drainage, in particular dendritic drainage patterns, developed on the limestone of Biscayne Bay and its vicinity, including the Turkey Point Units 6 & 7 site. This process of surface dissolution ended in Biscayne Bay when sea level rose and flooded the Bay but continued on emergent areas, including the Turkey Point Units 6 & 7 site. The depositional morphology and paleo-dissolution morphology resulting from the Sangamon interglacial high sea level stand and Wisconsinan glacial low sea level stand are preserved on the sea floor of Biscayne Bay (References 993 and 994).

The position of the freshwater/saltwater interface is approximately 6 miles inland from the bay in the vicinity of the site (Figure 2.4.12-207), groundwater beneath the site is saline (Tables 2.4.12-210 and 2.4.12-211), sea level is rising (Subsection 2.4.5.2.2.1), and there is no fresh groundwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote further dissolution of the limestone underlying the Turkey Point Units 6 & 7 site or the

dissolution features on the floor of Biscayne Bay does not exist. These features on the floor of Biscayne Bay do not appear to have the capacity for development of large underground caverns with the potential for collapse and formation of sinkholes.

The following text in FSAR Subsection 2.5.3.8.2.1, Potential Sources of Non-Tectonic, Geologic Deformation, last paragraph, will be revised in a future revision of the COLA.

Geologic reconnaissance and aerial photo analysis identified numerous ellipsoidal or circular features. These features consist of vegetation and water-filled areas that are generally less than 1 foot lower in elevation than the surrounding areas within the site and site area. Many of these surficial depressions observed on preconstruction photographs have been obliterated by construction of the Turkey Point Units 3 & 4 cooling canals (Figures 2.5.1-333 and 2.5.3-202). The underlying Miami Limestone is covered by recent deposits of **peat, with interpreted thickness of up to** approximately **11 feet thick (3.4 meters)** (Subsection 2.5.1.2.2). In **these vegetated depressions** geotechnical work investigations **(References 248, 249, and 250)** have confirmed that the deposits of ~~mud~~ **peat** ~~and silt~~ reach thicknesses exceeding **1.8 meters (6 feet)** and appear to ~~be~~ **remain** wetter than the surrounding areas. These karst features were formed after the deposition of the Pleistocene Miami Limestone, but their exact timing is not known. The formation and significance of the vegetated depressions are discussed further in Appendix 2.5AA.

The Florida Geological Survey generally ~~assesses~~ **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 (Reference 229) (Figure 2.5.1-222). In these cases, such solution potholes are generally expected to be shallow and broad and to develop gradually, rather than in a single, sudden collapse event. Additionally, these solution potholes are not expected to form large voids beneath the surface that would pose a hazard to the site (Reference 229). Based on information developed in this subsection and in Subsection 2.5.1.2.5.2, the possibility of dissolution features similar to the one reported southeast of Key Largo (Reference 228) **existing at depth beneath this site area is unlikely** ~~existing at depth beneath this site area is unlikely~~ (Subsection 2.5.4.4.5). No collapse or settlement problems associated with karst-type dissolution of underlying limestones have been associated with Turkey Point Units 3 & 4 (Reference 209). An integrated geophysical survey focused on the Units 6 & 7 power block area and several of the surficial depressions identified within the site was conducted as part of this application and is discussed in Subsection 2.5.4.4.5. **Although subject to spatial resolution and detection limits inherent in a subsurface investigation, the**~~Based upon~~ available **borehole and geophysical** data **indicate** there is minimal hazard posed by sinkholes and no evidence for potential surface collapse due to the presence of large underground openings **at the site**.

The following references will be added to FSAR Subsection 2.5.1.3 in a future COLA revision.

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