PMTurkeyCOLPEm Resource

From:	Comar, Manny
Sent:	Thursday, June 04, 2015 4:43 PM
To:	TurkeyCOL Resource
Subject:	FW: L-2015-156: Response to NRC Request for Additional Information Letter No. 081 (eRAI 7804) SRP Section 02.05.01 - Basic Geologic and Seismic Information
Attachments:	L-2015-156 Signed 05-19-2015 RAI Response for NRC RAI Letter No 81 (eRAI 7804).pdf

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From: Burski, Raymond [mailto:RAYMOND.BURSKI@fpl.com]
Sent: Tuesday, May 19, 2015 1:08 PM
To: Williamson, Alicia; Lieto, Amanda; Segala, John; Maher, William; Comar, Manny; Hoeg, Tim; Terry, Tomeka; McCree, Victor
Subject: L-2015-156: Response to NRC Request for Additional Information Letter No. 081 (eRAI 7804) SRP Section 02.05.01 – Basic Geologic and Seismic Information

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

Re: Florida Power & Light Company
Proposed Turkey Point Units 6 and 7
Docket Nos. 52-040 and 52-041
Response to NRC Request for Additional Information Letter No. 081 (eRAI 7804)
SRP Section 02.05.01 – Basic Geologic and Seismic Information

References:

1. NRC Letter to FPL dated February 18, 2015, Request for Additional Information Letter No. 081 Related to SRP Section 02.05.01 – Basic Geologic and Seismic Information for the Turkey Point Nuclear Plant Units 6 and 7 Combined License Application
2. FPL Letter L-2015-069 to NRC dated March 26, 2015, Schedule for Response to NRC Request for Additional Information Letter No. 081 (eRAI 7804) SRP Section 02.05.01 – Basic Geologic and Seismic Information
3. FPL Letter L-2015-123 to NRC dated April 10, 2015, Updated Schedule for FSAR Chapter 2 RAI Responses and FSAR Chapter 19

Florida Power & Light Company (FPL) provides, as attachments to this letter, its responses to the Nuclear Regulatory Commission's (NRC) requests for additional information (RAIs) 02.05.01-36 and 02.05.01-37 provided in Reference 1. In References 2 and 3 FPL provided schedule information for the responses to these RAIs. The attachments identify changes that will be made in a future revision of the Turkey Point Units 6 and 7 Combined License Application (if applicable).

Ray Burski
Licensing Supervisor-Nuclear, working on behalf of
Florida Power & Light Company
raymond.burski@fpl.com

(O) 561-694-4496
(C) 504-909-6436

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Subject: FW: L-2015-156: Response to NRC Request for Additional Information Letter No. 081 (eRAI 7804) SRP Section 02.05.01 - Basic Geologic and Seismic Information
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"TurkeyCOL Resource" <TurkeyCOL.Resource@nrc.gov>
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FPL.

L-2015-156
10 CFR 52.3

May 19, 2015

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

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If you have any questions, or need additional information, please contact me at 561-691-7490.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on May 19, 2015.

Sincerely,

William Maher
Senior Licensing Director – New Nuclear Projects

WDM/RFB

Attachment 1: FPL Response to NRC RAI No. 02.05.01-36 (eRAI 7804)
Attachment 2: FPL Response to NRC RAI No. 02.05.01-37 (eRAI 7804)

cc:
PTN 6 & 7 Project Manager, AP1000 Projects Branch 1, USNRC DNRL/NRO
Regional Administrator, Region II, USNRC
Senior Resident Inspector, USNRC, Turkey Point Plant 3 & 4

NRC RAI Letter No. PTN-RAI-LTR-081

SRP Section: 02.05.01 - Basic Geologic and Seismic Information

Questions from Geosciences and Geotechnical Engineering Branch 2 (RGS2)

NRC RAI Number: 02.05.01-36 (eRAI 7804)

In Cunningham et al, 2012, approximately 210 km of high resolution marine seismic data reveal normal and reverse faults in Biscayne Bay, within 25 miles of the site. One of these faults is identified on 5 seismic lines and extends about 10 miles, striking N, NE. The authors interpret this fault as a vertical normal fault offsetting the top of Arcadia formation. The fault appears to project directly to the TPNPP. Staff also notes that because the fault appears to offset the top of Arcadia Formation, the age of movement would be about middle Miocene, but might be as young as early Pliocene (5.3 Ma). Staff also notes that this tectonic structure is not included in the TPNPP FSAR.

a) In support of 10 CFR 100.23 please provide a discussion of this tectonic feature with respect to TPNPP and integrate into the regional tectonic setting for the TPNPP COLA.

b) Does this fault fit the characteristics of a strike-slip fault with component of dip slip? If the fault is strike-slip how would you constrain age of latest movement?

c) What is the possibility that this fault underlies the TPNPP site? If this feature underlies the site, what impact does this have on potential surface deformation?

d) Update any RAI responses and associated COLA revisions that pertain to this topic.

FPL RESPONSE:

Reference 1 (Cunningham et al., 2012) maps an unnamed, north-northeast-striking fault based on interpretation of offshore seismic reflection data obtained from five survey lines in Biscayne Bay. At its nearest approach, this fault is mapped to approximately 7 miles (11 kilometers) north of Turkey Point Units 6 & 7. This RAI requested more information about the geometry, kinematics, and timing of this structure than was available in Reference 1, which is an expanded abstract. Thus, FPL contacted the lead author, Kevin Cunningham, for additional information. Kevin Cunningham provided his recent peer-reviewed publication, Reference 2 (Cunningham, 2015), which includes additional information about this fault.

The fault was mapped on five seismic-reflection profiles with a trace length of approximately 10 miles (16 kilometers) in Reference 1, and extended as an uncertain (dashed) fault an additional 20+ miles (30+ kilometers) northward through a data gap to connect with a possible offset identified in seismic profiles at the Miami-Dade North District Boulder Zone Water Field in Reference 2. Reference 2 provides more recent and more detailed mapping and information about this structure (Figure 1), and hence much of the discussion that follows is based on updated and more detailed data presented in that more-recent publication. The remainder of this response is divided into four parts, a through d, to address each part of the RAI.

a) Three of the five seismic-reflection profiles that image the strike-slip fault identified in Biscayne Bay are presented in References 1 and 2 and are shown in Figures 2, 3, and 4. Figure 2 indicates that strata at depths of 120-600 milliseconds (ms) two-way travel time (TWTT) exhibit up-to-the-east separations. The authors interpret these faulted strata as the Avon Park and Arcadia Formations, which are as young as middle Eocene to middle Miocene (Reference 2, Figure 2). Reference 2 interprets reflections that represent the top of the Peace River and Tamiami Formations (of Pliocene age) as unfaulted. Figure 3 also indicates that strata below depths of approximately 120 ms and greater are offset up-to-the-east. Overlying Peace River, Tamiami and younger strata are less coherent, but not depicted as faulted (Figure 3). Figure 4, reproduced from Plate 1 of Reference 2, indicates only strata below the top of the Arcadia Formation (of Miocene age) are faulted on seismic-reflection profile C1.

   Reference 2 reports that typically the fault vertically separates reflectors up to about 10 ms in TWTT, or approximately 40 feet (12 meters), in an east-side-up sense. Larger TWTT offsets of up to 30 ms on the top of the Arcadia Formation (Figures 2 and 3), are interpreted by Reference 2 to result from the juxtaposition of displaced paleotopography on the upper surface of the Arcadia Formation. Regionally, the upper contact of the Arcadia Formation is an irregular surface with paleotopographic relief of up to 300 feet (91 meters) (see discussion in response to RAI 02.05.01-12). The fault offset at the top of the Arcadia Formation is downlapped by undeformed siliciclastics of late Miocene to early Pliocene age (Peace River Formation), thus fault movement has been interpreted to be within the middle Miocene to early Pliocene epochs (References 1 and 2). Cunningham interprets this faulting to be related to regional transform fault systems responsible for the opening of the Atlantic Ocean during the Mesozoic (Reference 2). A summary of this fault will be added to FSAR Subsection 2.5.1.1.1.3.2.1, Florida Peninsula and Platform Tectonic and Structural Features.

b) Reference 1 indicated that this structure is a steep normal fault, whereas the more-recent and peer-reviewed Reference 2 indicates that the fault is a strike-slip structure with a range of apparent dips from 89° W to 85°E observed on the five seismic-reflection profiles. Reference 2 interprets strike-slip motion for the fault based on the change in dip direction between profile lines and the overall steep dips interpreted from the seismic reflection profiles. The apparently consistent vertical separations of the reflections within the Arcadia Formation and older units show that the fault has some vertical component of slip and indicates that if the fault extended upwards through younger strata, some vertical offset of those strata would be detected. It would require a very special case of perfectly strike-slip motion on perfectly horizontal, tabular beds to not be able to recognize any offset in faulted Pliocene or younger strata imaged in the seismic reflection profiles. If this structure is a strike-slip fault, it appears to have some component of dip-slip offset given that (1) all of the imaged strata are flat-lying and/or conformable and (2) with the exception of the aforementioned top-Arcadia paleotopography, there is a consistent east-side-up sense of separation on the strata from the middle Arcadia down to at least 500 ms. Reference 2 interprets that the lack of this east-side-up separation on

Figures 2-4 above the top of Arcadia to indicate a lack of displacement on this structure, and hence no fault movement in post-Arcadia time (Middle Miocene to early Pliocene, approximately the last 3.6 Ma).

c) The fault as mapped by Reference 1 and Reference 2 projects towards the Turkey Point Units 6 & 7 site. The southern extent of the fault as mapped by Reference 2 is roughly coincident with the location of seismic line C1, the southernmost profile that images the fault (Figure 1). Thus, the southern extent of faulting is not constrained by the data presented in Reference 2. Evaluating whether the fault projects beneath the site location is difficult given that the depths of site explorations are generally shallower than the top of the Arcadia Formation, which is the stratigraphically highest unit interpreted as faulted in Reference 2. Insufficient information exists to definitively exclude the possibility that this fault underlies the Turkey Point Units 6 & 7 site.

   Appendix A to Regulatory Guide 1.208, defines a capable tectonic source as a structure that can generate both vibratory ground motion and tectonic surface deformation in the present seismotectonic regime. It should have at least (1) the presence of near-surface deformation of a recurring nature within the last 500,000 years or at least once in the last 50,000 years, (2) an association with one or more moderate to large earthquakes or sustained earthquake activity that are usually accompanied by significant surface deformation, or (3) a structural association with a capable tectonic source having characteristics of either (1) or (2) such that movement on one could be reasonably expected to be accompanied by movement on the other. Reference 2 indicates this fault does not cut post-Arcadia Formation strata and based on the site investigations there is no evidence of faulting in the post-Arcadia Formation strata (Pliocene and younger, approximately last 3.6 Ma) at the site (see FSAR Subsection 2.5.1.2.2 and Figures 2.5.1-343, 2.5.1-386, 2.5.1-387, 2.5.1-388, and 2.5.1-389). There are no earthquakes associated with the fault trace (see FSAR Figure 2.5.3-203), and no nearby potential Quaternary tectonic structures or capable faults (see FSAR Figure 2.5.3-205). Thus, even with an unverified assumption that the fault underlies the Turkey Point Units 6 & 7 site, this fault is not a capable tectonic source and does not pose a surface rupture hazard at the Turkey Point Units 6 & 7 site.

d) The Turkey Point Units 6 & 7 FSAR Subsection 2.5.1.1.1.3.2.1 will be revised to include a discussion of the fault from Reference 1 and Reference 2. A markup of these COLA revisions is provided below. Figure 2 provided as part of this RAI response will be added to the COLA and FSAR Figures 2.5.1-229 and 2.5.1-331 will be revised to include this recently mapped fault. This RAI response provides added information, and does not require the revision of any previous RAI responses.

Figure 1: Map of fault from Reference 2 and associated seismic profiles

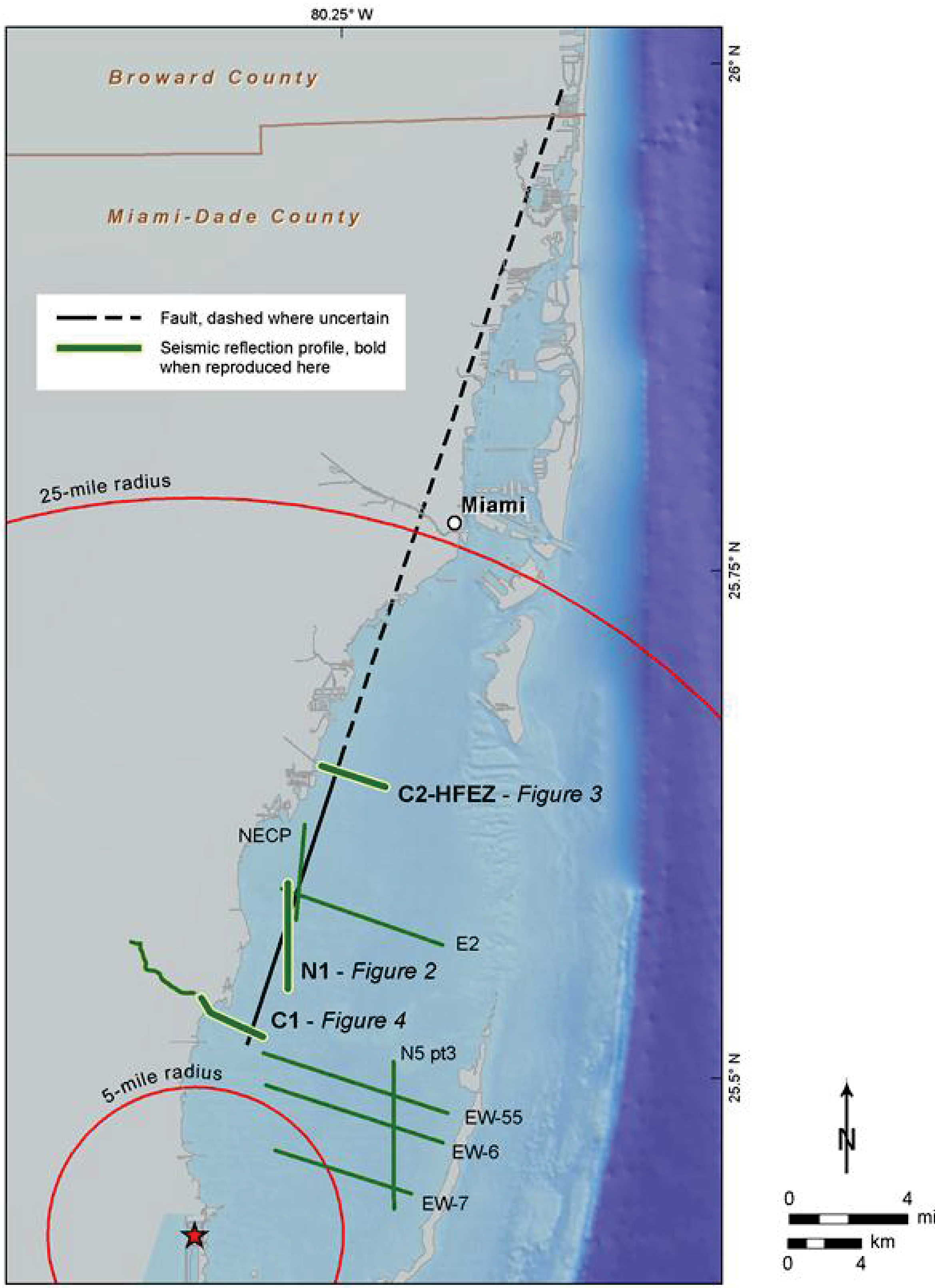


Figure 2: Seismic-reflection profile N1 from Reference 2

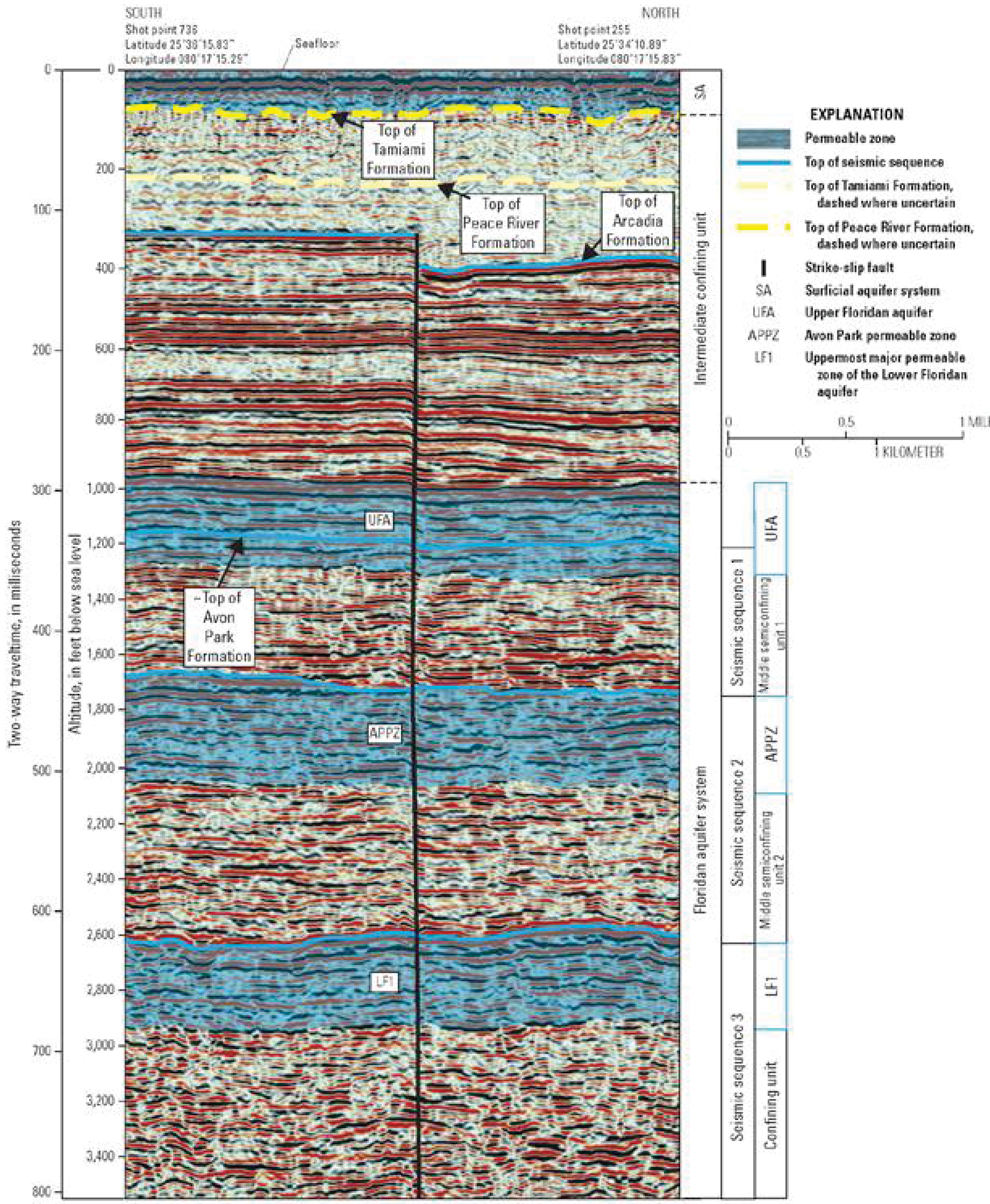


Figure 3: Seismic-reflection profile C2-HFEZ from Reference 2

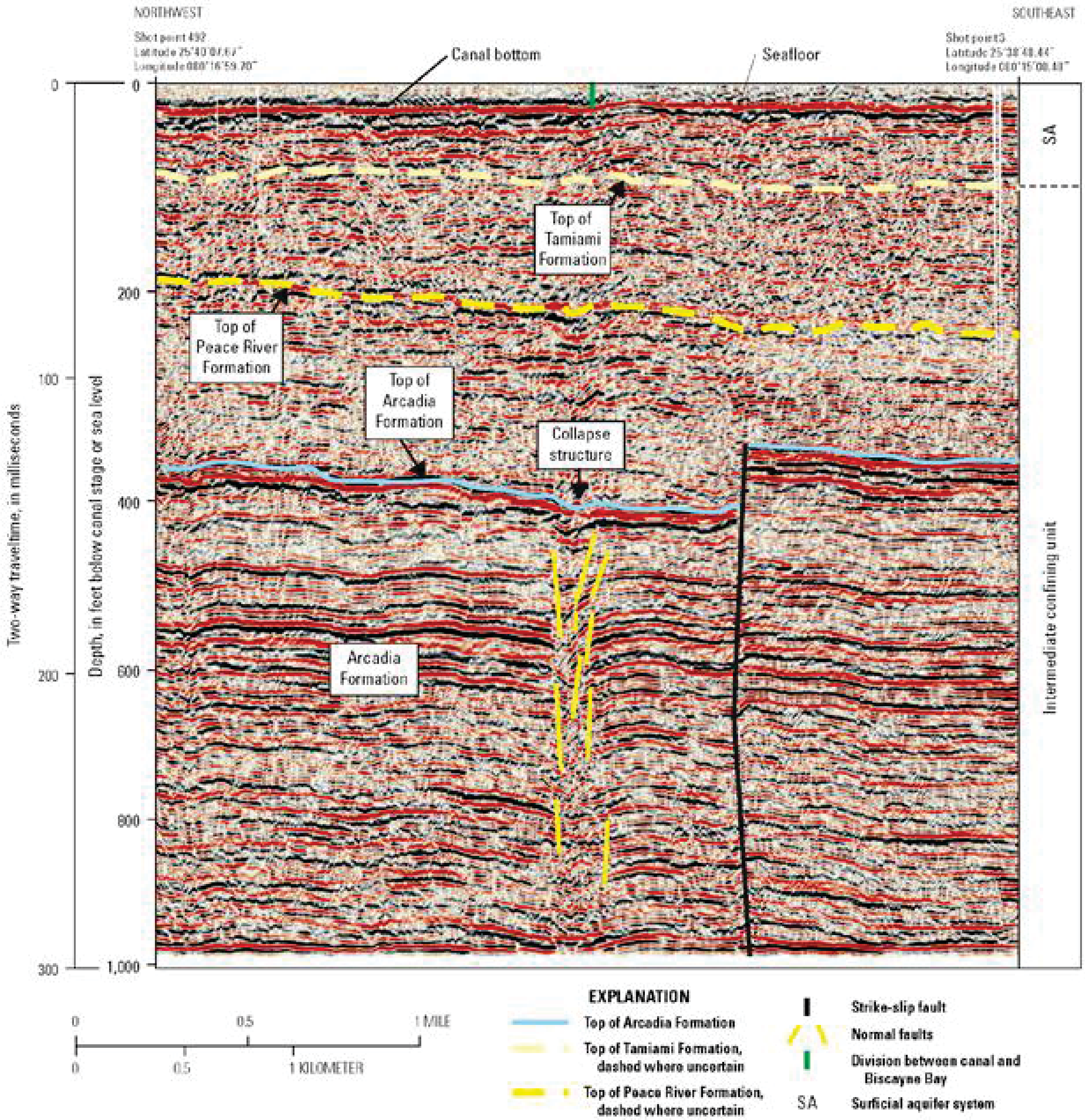
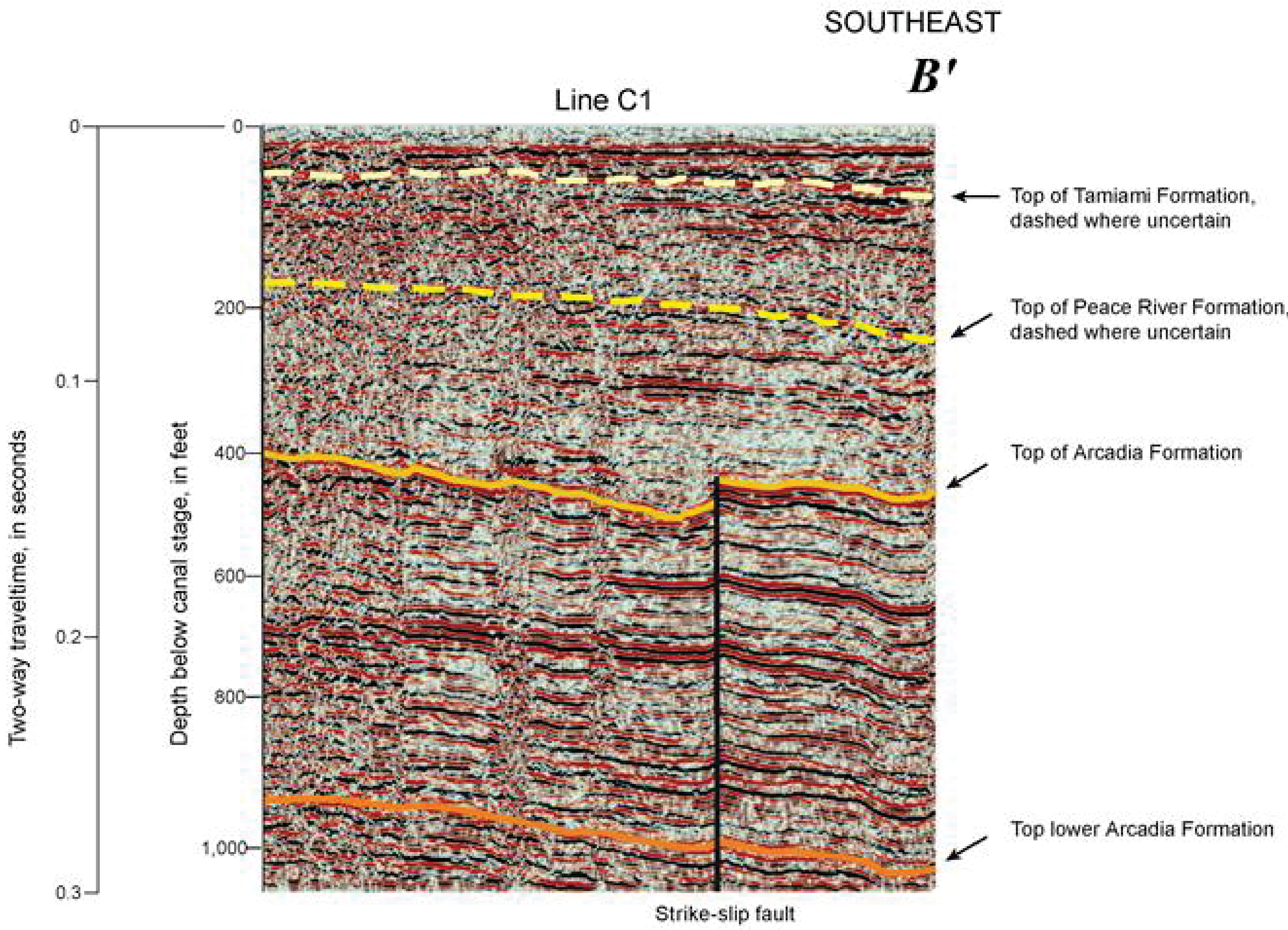


Figure 4: Seismic-reflection profile C1 from Reference 2



This response is PLANT SPECIFIC.

References:

1. Cunningham, K. J., Walker, C, and Westcott, R. L., 2012, Near-Surface Marine Seismic-Reflection Data Define Potential Hydrogeologic Confinement Bypass in the Carbonate Floridian Aquifer System, Southeastern Florida: SEG Las Vegas 2012 Annual Meeting, 6 p.

2. Cunningham, K. J., 2015, Seismic-Sequence Stratigraphy and Geologic Structure of the Floridan Aquifer System Near “Boulder Zone” Deep Wells in Miami-Dade County, Florida: U.S. Geological Survey Scientific Investigations Report 2015–5013, 28 p.

ASSOCIATED COLA REVISIONS:

The first paragraph in FSAR Subsection 2.5.1.1.1.3.2.1 will be revised in a future COLA revision as follows:

2.5.1.1.1.3.2.1 Florida Peninsula and Platform Tectonic and Structural Features

Structures of the Florida Peninsula and Platform

The Florida Peninsula exposes only flat, unfaulted strata at the surface (Figure 2.5.1-201), so all tectonic features are identified with subsurface methods, usually from drilling or seismic reflection data. Tectonic and structural features identified within the Florida Platform province (which includes the emergent peninsula and the submerged carbonate platform) are mostly a series of gentle highs and lows in the regional stratigraphy. In some cases, these may be reflecting original basement topography (such as the Peninsular Arch) or may reflect changes in sedimentation later in time (Figures 2.5.1-259, 2.5.1-260, and 2.5.1-261). Both surface exposures and well data indicate that Cretaceous and younger strata on the Florida Platform are generally gently dipping to horizontal (Figures 2.5.1-261, 2.5.1-240, 2.5.1-242, and 2.5.1-232). Local and regional seismic data and high-resolution bathymetric data indicate that the shallow stratigraphy in southern Florida is undeformed by tectonic faulting (e.g., References 798, 799, and 398). ~~While occasional~~ **In a few instances,** variations in pre-Miocene stratigraphy recorded in boreholes **and seismic-reflection data have** ~~due to erosional paleotopography or karst have sometimes~~ been interpreted as possible faulting (for example, the queried fault on Figure 2.5.1-234 **[Reference 373] or the fault from Cunningham [Reference 999]**), **and erosional paleotopography or karst may complicate these interpretations. More typically,** local and regional seismic data and high-resolution bathymetric data indicate that the shallow stratigraphy in southern Florida is undeformed by tectonic faulting (e.g., References 798, 799, and 398). Similarly, continuous, unfaulted prograding strata drape the edges of the Florida and Bahama Platforms along the Straits of Florida (Figure 2.5.1-262) (Subsection 2.5.1.1.1.2.2 provides a discussion of the prograding strata).

The following text will be inserted after the 20th paragraph in FSAR Subsection 2.5.1.1.1.3.2.1 before the subheading "Seismicity of the Florida Peninsula and Platform" in a future COLA revision as follows*:*

Tectonic Fault from Cunningham

Cunningham et al. (Reference 989) and Cunningham (Reference 999) identified a buried, north-northeast-striking fault beneath Biscayne Bay approximately 11 km north of Turkey Point Units 6 & 7 (Figures 2.5.1-229 and 2.5.1-331). This feature is identified on five seismic-reflection profiles and is interpreted to have vertical separations of approximately 40 feet of the tops of the Avon Park and Arcadia Formations (Reference 999) (Figure 2.5.1-393). Greater separation at the top of the Arcadia Formation surface is due to offset paleotopography (Reference 999; Figure 2.5.1-393). A range of dips from 89° W to 85°E is observed on the 5 seismic profiles, and the change in dip direction and steepness of the fault dips is cited

by Cunningham (Reference 999) as evidence for strike-slip faulting. Cunningham (Reference 999) indicates that the latest movement occurred in the middle Miocene to early Pliocene epochs based on the absence of offset reflectors in the overlying Miocene Peace River, Pliocene Tamiami and younger strata (Figure 2.5.1-393). Therefore, this fault does not represent a capable tectonic fault or pose a fault rupture hazard for Turkey Point Units 6 & 7. Cunningham (Reference 999) suggests this strike-slip fault could be related to the buried regional transform fault systems related to the opening the Atlantic Ocean.

The first paragraph of FSAR Subsection 2.5.1.2.3 will be revised in a future COLA revision as follows:

2.5.1.2.3 Site Area Structural Geology

This subsection provides a review of the structural setting from published maps and literature and the Units 3 & 4 UFSAR (Reference 712), which is supplemented by new information from the 2008 geologic mapping and exploration program performed as part of this investigation (Reference 708), the supplemental field investigation (Reference 995), and sampling performed in surficial muck deposits using a McCauley Sampler (Reference 996). The site lies on the stable Florida carbonate platform; no faults or folds are mapped **at the surface** within more than 25 miles (40 kilometers)**, and the nearest fault identified by Cunningham (Reference 999) is buried by Pliocene and younger strata** **(**Figure 2.5.1-331**, Figure 2.5.1-393**). New data include geologic mapping and bedding attitudes interpreted from lithologic contacts in boreholes. Taken together, these data indicate generally flat, planar bedding in Pleistocene and older units and an absence of geologic structures within the site area.

A new reference will be added to FSAR Subsection 2.5.1.3 in a future COLA revision as follows:

2.5.1.3 References

999 Cunningham, K. J., 2015, *Seismic-Sequence Stratigraphy and Geologic Structure of the Floridan Aquifer System Near “Boulder Zone” Deep Wells in Miami-Dade County, Florida*: U.S. Geological Survey Scientific Investigations Report 2015–5013.

The first paragraph of FSAR Subsection 2.5.3.2 will be revised in a future COLA revision as follows:

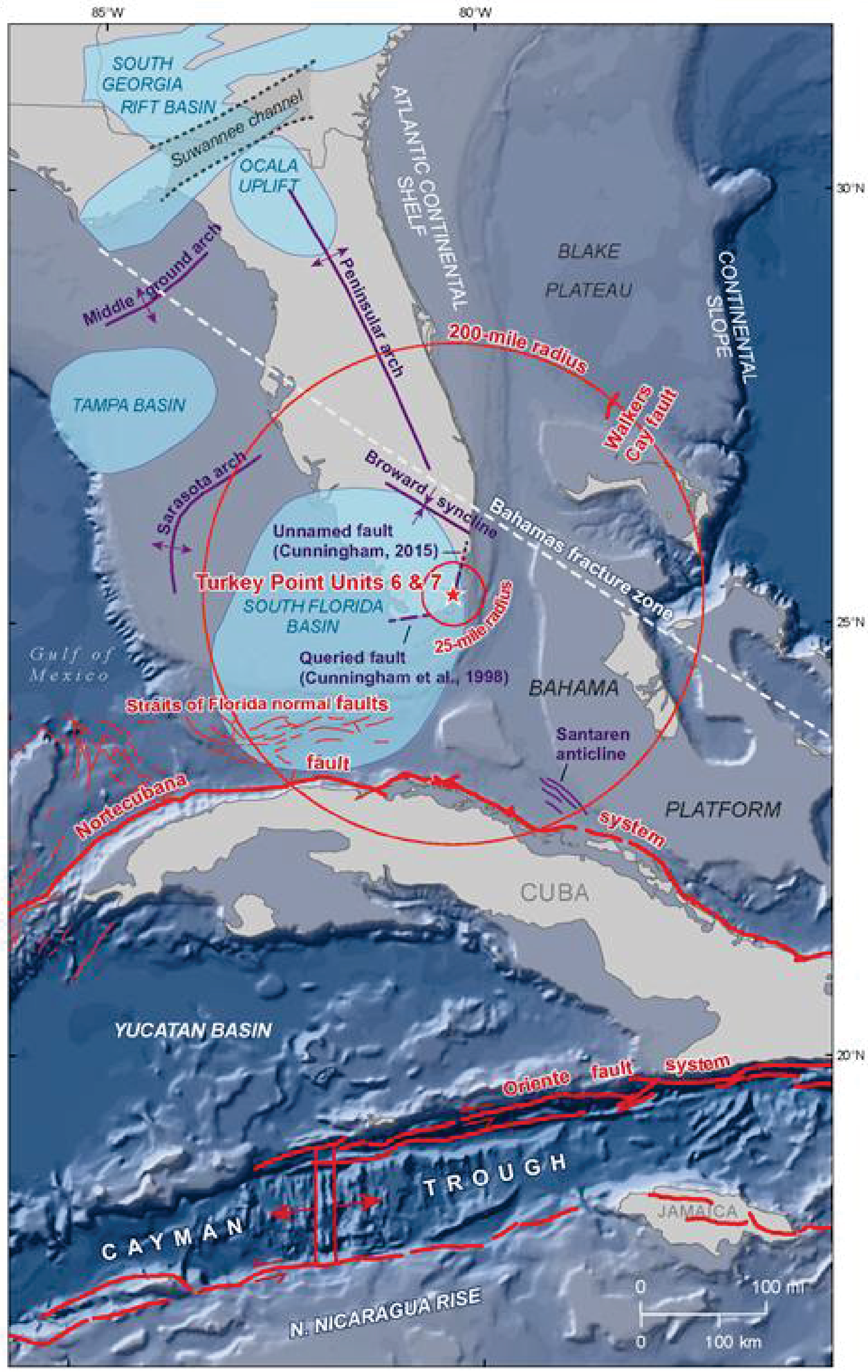
2.5.3.2 Geological Evidence, or Absence of Evidence, for Surface Deformation

Field reconnaissance, review and interpretation of aerial photography, and review of published literature did not reveal any evidence for active tectonic deformation within the site vicinity or site area. No active faults or geomorphic features relating to active faulting have been mapped in the site vicinity, site area, or the site (Figures 2.5.1-334, 2.5.1-336, 2.5.1-337, 2.5.1-338, 2.5.1-339, 2.5.1-340, 2.5.1-341, and 2.5.1-342). Although ~~a basement~~ fault**s** ~~has~~ **have** been interpreted to exist within the site vicinity

(Figure**s 2.5.1-229 and** 2.5.1-253), there is no evidence to suggest that ~~this~~ **these** buried pre~~-Cretaceous~~ **Quaternary** ~~fault is~~ **faults are** active or represent~~s~~ a surface faulting hazard (Figures 2.5.1-261 and 2.5.1-263) (Subsection 2.5.1.1.1.3.2.1). Therefore, no capable faults are known to exist within the site vicinity. In addition, no seismic activity has been reported within the site vicinity (Subsection 2.5.2), and bedding is horizontal and undisturbed (Subsection 2.5.1.2.3). No salt domes, Quaternary volcanic features, or glacial sources of deformation occur in the site vicinity (Figures 2.5.1-201 and 2.5.1-237) (Subsections 2.5.3.8.2.1, 2.5.1.1.2.1.1, 2.5.1.1.1.2.1.1, 2.5.1.2.4, and 2.5.1.2.3). Non-tectonic deformation features in the site area are interpreted to be “potholes” caused by surficial dissolution (Subsections 2.5.1.2.4 and 2.5.4.4.5).

FSAR Figure 2.5.1-229 will be replaced with the following revised figure in a future COLA revision:

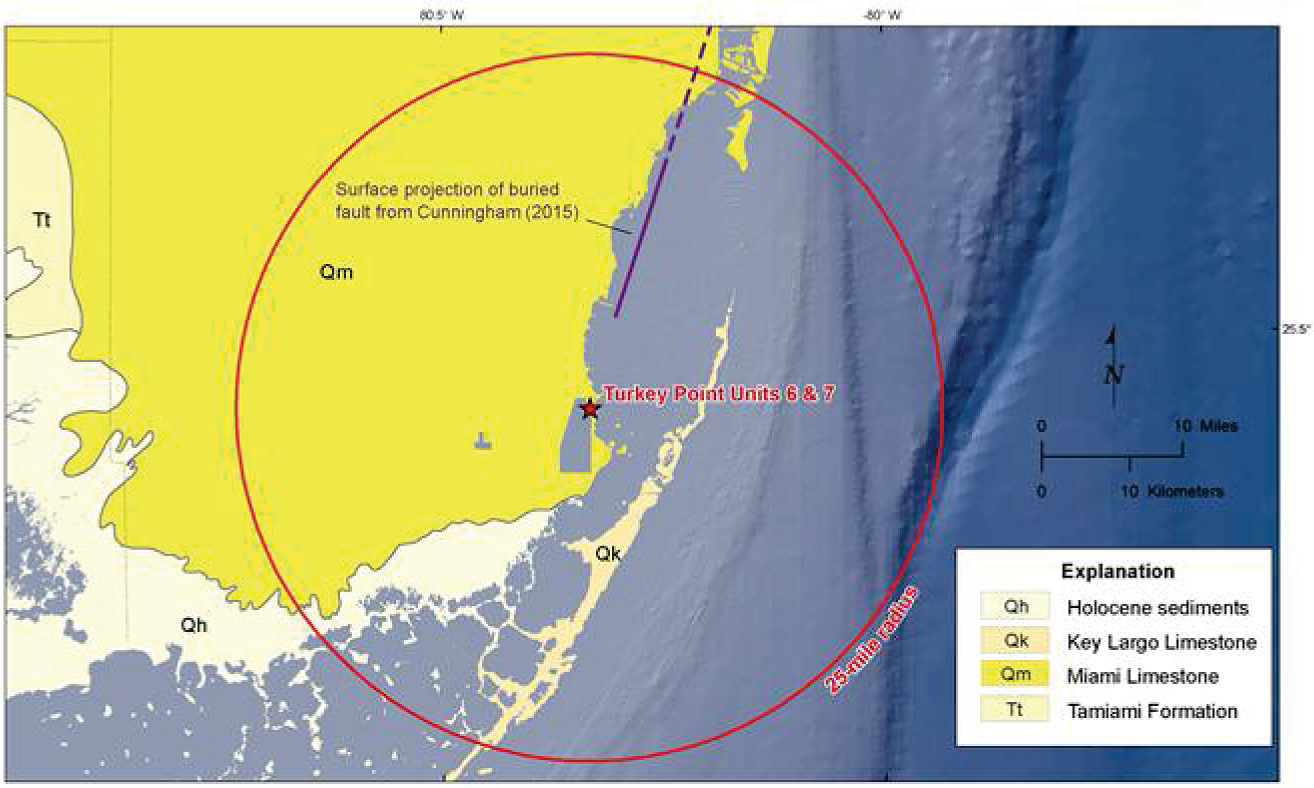
Figure 2.5.1-229 Regional Tectonic Features



Sources: References 822, 482, 823, 457, 212, ~~and~~ 421**, and 999**

FSAR Figure 2.5.1-331 will be replaced with the following revised figure in a future COLA revision:

Figure 2.5.1-331 Site Vicinity Geologic Map

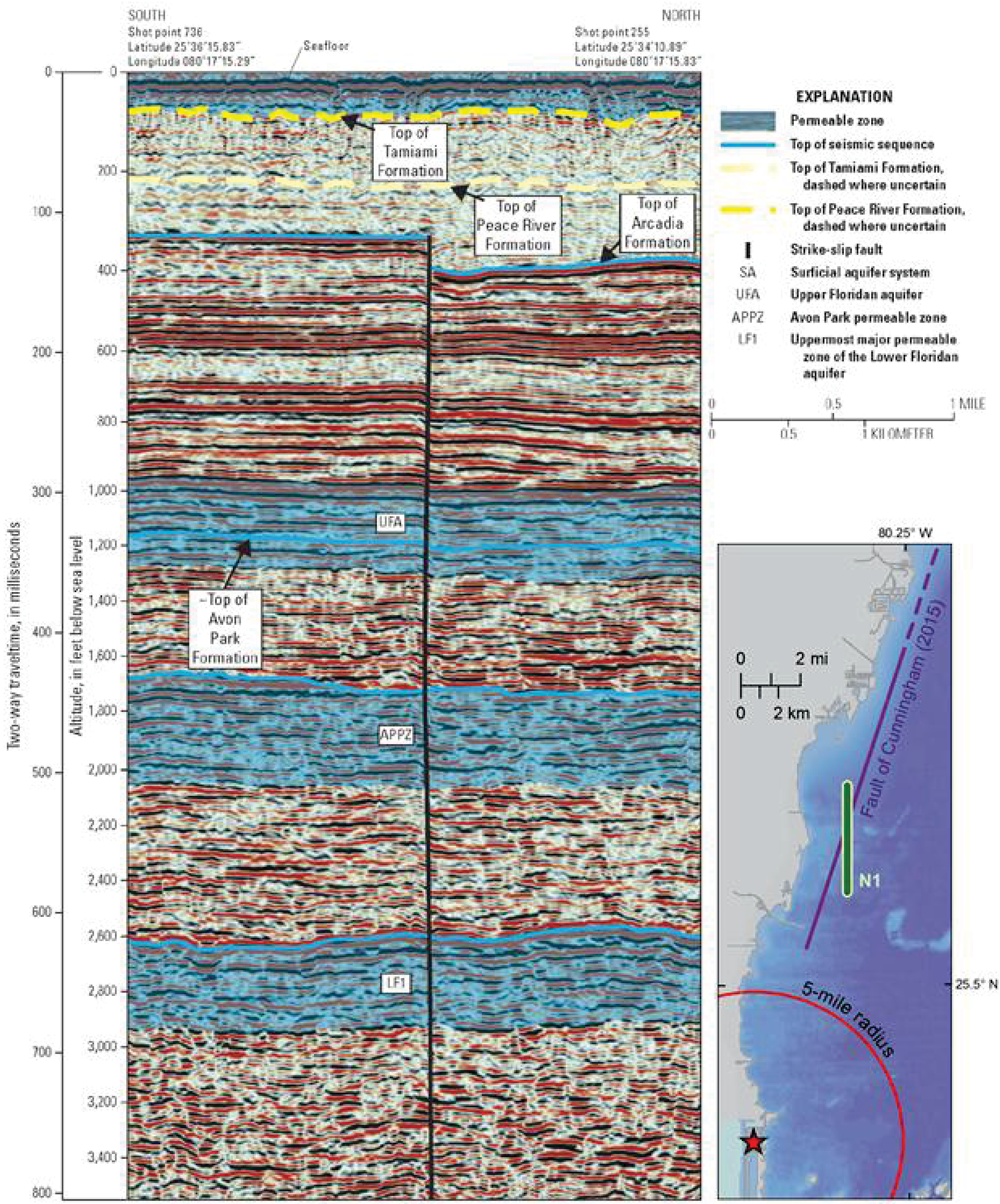


Base sources: Reference 435

Source of geologic information: References 827 and 999

A new FSAR Figure 2.5.1-393 will be added in a future COLA revision:

Figure 2.5.1-393 Seismic Reflection Profile N1 from Cunningham (2015)



Source: Reference 999

ASSOCIATED ENCLOSURES:

None

NRC RAI Letter No. PTN-RAI-LTR-081

SRP Section: 02.05.01 - Basic Geologic and Seismic Information

Questions from Geosciences and Geotechnical Engineering Branch 2 (RGS2)

NRC RAI Number: 02.05.01-37 (eRAI 7804)

The Technos 2009 Geophysical Survey for Karst Characterization at Proposed Units 6 and 7 Turkey Point Nuclear Power Plant describes a filled sinkhole at Jewfish Creek, within 10 miles of TPNPP. Technos describes the filled sinkhole: The sinkhole at Jewfish Creek is ~1900 ft across and estimated to be more than 600 feet deep, based upon seismic and microgravity data. Borings and geophysical logging indicated open cavities within this paleocollapse feature up to 9 feet in diameter. Staff notes that a 600 ft deep sinkhole is well below the -350 ft sea level lowstand from Late Pleistocene glacial maxima. Staff notes that the Jewfish Creek sinkhole is also in a similar setting to TPNPP with respect to current and paleo shorelines.

a. In support of 10 CFR 100.23, please provide other relevant details regarding the Jewfish Creek feature. What stratigraphic formations does the sink hole impact? At what depth and in what stratigraphic formation were the open cavities found? Does the Jewfish Creek sinkhole represent hypogenic limestone dissolution (as described in Klimchouk, 2009) in an onshore location, near TPNPP?

b. Klimchouk, 2009, describes process and features associated with hypogenic speleogenesis that fit dissolution features identified in southern Florida within the site vicinity and the Keys as described by various researchers such as: Cunninham and Walker, 2009; Cunningham et al, 2012; Land and Paull, 2000; Land et al, 1995; and possibly the feature at Jewfish Creek (Technos, 2009). Land et al, 1995 describes a Quaternary-aged, large, deep sink hole that formed under persistent submarine circumstances as hypogenic karst. Land and Paull found several more sinkholes all along the Keys and Miami. More recently and close to TPNPP, Cunningham and Walker, 2009, describe 12 seismic sags, capped by Miocene strata, in Biscayne Bay, close to shore, as derived from hypogenic processes. Klimchouk, 2009 describes hypogenic speleogenesis as occurring in semi-confined groundwater circumstances and forming vertically stacked or chimney-like voids; active over large spans of geologic time and demonstrating reactivation cycles. Dissolving mechanisms include both physical and chemical conditions.

You state in RAI response 2.5.1-2 that ‘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’. Staff notes that the seismic sags in Biscayne Bay and possibly the sinkhole at Jewfish Creek are near-shore or on-shore features (not out on the shelf break) that likely represent hypogenic karst that could affect TPNPP. In support of 10 CFR 100.23, please provide a discussion of hypogenic dissolution processes in southern Florida and include features in the site vicinity. Consider the uncertainty of the age of these features from onset to closure if the hypogenic process reactivates. Consider the possible locations where this might occur in the site vicinity.

c. Please provide a map showing all dissolution features found in the TPNPP site vicinity, include the locations of the 12 subsurface seismic sags from Cunningham and Walker and the young sinkholes identified by Land and Paull (1995 and 2000). Update any RAI responses and associated COLA revisions that pertain to this topic.

d. You state in response to RAI 2.5.1-1, with respect to the seismic sags in Biscayne Bay, that regardless of the mechanism of formation, the geophysical data indicate absence of deformation in rocks younger than middle Miocene. 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 (Miami, Key Largo limestones, Fort Thompson, Tamiami and Peace River Formations) would be deformed. At the site this section is approximately 450 feet (137 meters) and deformation below this depth is not likely to pose a threat of surface collapse at the site. Considering the diameter dimensions of the seismic sags identified in Biscayne Bay as published in the Cunningham and Walker paper, please provide a basis or reference to a calculation to support your statement that deformation below this depth (450 ft) is not a threat of surface collapse at the site

FPL RESPONSE:

a. Jewfish Creek and adjacent Lake Surprise (a shallow marine lake) are located approximately 27 kilometers (km) (17 miles [mi]) from Turkey Point Units 6 & 7 (Figure 1). Data from 34 geotechnical borings located along Jewfish Creek and in Lake Surprise (collected in 1994 to support design work for the Jewfish Creek Bridge) provided evidence for localized loose sand layers. Publishing as Benson et al. Technos Inc. (hereinafter referred to only as Technos) interpreted these loose materials as possible evidence for sediment transport (i.e., piping) into dissolution cavities (References 1 and 2). At some locations, drilling water (circulation) losses were also observed, suggesting voids and/or highly permeable sub-surface layers (locations of anomalous borehole data in Figure 1). For the most part, these water losses were concentrated at depths between 6 meters (m) and 30 m (20 feet [ft] and 100 ft).

   Microgravity surveys over the same area completed by Technos provided evidence for a 100 microgal (μGal) anomaly centered between Jewfish Creek and Lake Surprise (References 1 and 2). Generally, this gravity anomaly coincided with the aforementioned borehole locations showing evidence of cavities. Technos (References 1 and 2) also noted that extensive road maintenance was completed in the area due to surface settlement, likely resulting from soil piping.

   Supplemental sub-bottom profiling (i.e., seismic reflection surveys) in Lake Surprise completed by Technos (References 1 and 2) also provided evidence for downward dipping reflectors located near the aforementioned gravity anomaly center and edges. Technos (References 1 and 2) suggested that these dipping reflectors were cemented strata surrounding dissolution-enlarged joints, or chimneys associated with a deeper cavity. Technos (References 1 and 2) also noted that aerial imagery suggested a major northeast-southwest trending lineament within the gravity anomaly area and through at least five nearby lakes (Figure 1).

Later field investigations conducted by Technos (References 3 and 4) confirmed sub-surface karst conditions within the Jewfish Creek/Lake Surprise area. Specifically, Technos (Reference 4) conducted supplemental high-resolution and deep seismic reflection surveys and additional geotechnical drilling and geophysical logging that identified seven collapse (subsidence) structures beneath the Jewfish Creek/Lake Surprise feature, filled with sediments derived from overlying materials (Figure 2). Generally, these collapse structures ranged in width from 30 m to 60 m (100 ft to 200 ft) and were distributed over a 580 m (1900 ft) distance.

Jewfish Creek/Lake Surprise Anomaly Interpretations

Technos (References 1 and 2) initially concluded that the Jewfish Creek/Lake Surprise data indicated a large cave chamber or a large horizontal cave passageway and associated vertical joint system at some depth. Specifically, Technos (References 1 and 2) modeled the Jewfish Creek/Lake Surprise feature essentially as a spherical, water-filled cavity with a 40 m to 46 m (134 ft to 150 ft) radius, centered roughly 152 m to 172 m (500 ft to 565 ft) below ground surface. A conceptual model for this cave and joint system is provided in Figure 3, as developed by Technos (References 1 and 2).

Later, Technos (Reference 4) interpreted the largest subsidence structure at Jewfish Creek/Lake Surprise as a cavity collapse in a soluble limestone layer, the Arcadia Formation, at depths below approximately 213 m (700 ft). Corresponding subsidence in overlying Arcadia Formation layers, and in younger unconsolidated sands and capping limestone, inferred to be the Peace River, Tamiami, Caloosahatchee or possibly Fort Thompson, and Key Largo formations, was also interpreted from the seismic reflection data, at depths between approximately 21 m and 213 m (70 ft and 700 ft) (Figure 4). Density logs from geotechnical borings located adjacent to the collapse structure indicated voids and porous zones in the shallower formations, primarily between 6.1 and 21.3 m (20 and 70 ft). Technos (Reference 4) interpreted the seven structures as localized collapses, or collapse features associated with closely spaced and enlarged dissolution joints.

In a later work, Technos (Reference 5) described the Jewfish Creek/Lake Surprise feature as (at least) a 580 m (1900 ft) wide and 183 m (600 ft) deep sinkhole. Technos (Reference 5) also suggested that the Jewfish Creek/Lake Surprise feature was associated with open cavities (voids) up to 2.7 m (9 ft) in diameter. Specific evidence for these open cavities was not provided, and is not entirely supported by previous Technos/Benson et al. reports (References 1, 2, 3, and 4). Similarly, the massive (singular) sinkhole interpretation (Reference 5) is not consistent with suppositions for more localized collapse (as noted above).

Importantly, Technos (Reference 4) indicated that the Jewfish Creek/Lake Surprise feature collapsed and subsided “long ago” and noted that active void or cavity formation was no longer a concern. It was suggested that any remaining cavities were likely small and very deep, and that the overlying rock and sediment masses would thus inhibit surface subsidence or settlement. Consequently, Technos (Reference 4) concluded that the Jewfish Creek Bridge could be economically constructed with minimal risk. Construction for the bridge was completed in May 2008, and no structural damage or differential settlement has since been reported (Reference 6).

Possible Formation Mechanism

Technos (References 1, 2, 3, and 4) did not clearly indicate a formation mechanism for the Jewfish Creek/Lake Surprise feature, but did intimate an epigenetic (rather than hypogene) origin in mentioning void formation due to “flowing fresh groundwater” and subsequent dissolution in deeper limestones. Separately, it should be noted that the collapse structures at Jewfish Creek/Lake Surprise were interpreted by Technos (Reference 4) to be centered in the late Oligocene to early Miocene age Arcadia Formation. It is possible, then, that the collapsed cavities (or collapsed joints) were formed (or enlarged) via subaerial exposure and downward meteoric dissolution (i.e., epigenic or hypergenic dissolution) during middle to late Miocene sea level lowstands, estimated to be 300 m (985 ft) below modern sea level, with considerations/corrections for subsidence (FSAR Reference 2.5.1-951). Alternatively, void formation may be linked to eogenetic (or syngenetic) dissolution processes, namely submarine groundwater discharge during sea level highstands and consequent enhanced carbonate dissolution at a former freshwater/saltwater interface, as previously identified in the Response to RAI No. 02.05.01-1 (eRAI 6024).

Because the collapse structures (as inferred from dipping strata) at Jewfish Creek/Lake Surprise extend upward into the Key Largo Formation, void development and joint enlargement could also be attributed, in part, to epigenic dissolution by meteoric waters (at least in more near-surface layers) during Pleistocene sea level lowstands. It is important to note, however, that the deep collapse origination point (at least 152 m [500 ft] deep) inferred by Benson et al. and Technos (References 1, 2, 3, and 4) precludes subaerial exposure during the maximum estimated late Pleistocene sea level lowstand (125 m [410 ft]). Void collapse (and subsidence) at Jewfish Creek/Lake Surprise may instead represent cave or joint enlargement via phreatic dissolution, and subsequent (later) cave or joint collapse in the Pleistocene due to sea level lowering induced buoyancy losses (but not exposure) and corresponding load changes within overlying layers. Phreatic dissolution, in this case, would (again) likely have been associated with freshwater/saltwater mixing as previously described in RAI No. 02.05.01-1 (eRAI 6024).

Collapse structures at Jewfish Creek/Lake Surprise are also not entirely inconsistent with the narrow structural sag features described by Cunningham and Walker (FSAR Reference 2.5.1-958) and subsequently by Reese and Cunningham (Reference 7) and Cunningham (FSAR Reference 2.5.1-999 and References 8 and 9) in Biscayne

Bay and northeastern Miami-Dade and eastern Broward counties, as shown on Figure 5. However, these sag features are generally vertically stacked (multi-storied) and are not closely spaced or distributed horizontally as is the case at Jewfish Creek/Lake Surprise.

Although Cunningham and Walker (FSAR Reference 2.5.1-958) did not explicitly attribute the aforementioned sags to hypogene dissolution processes, the vertical stacking is consistent with collapse in a multi-story hypogene cave system, as described by Klimchouk (Reference 10) and illustrated in panels A3 and B3 (circled for emphasis) in Figure 6. Nevertheless, Cunningham (FSAR Reference 2.5.1-999) cites evidence (unspecified) for hypogenic karst collapse in just one southeast Florida location, a borehole (well) in the Miami-Dade Water and Sewer Department (MDWASD) northern wastewater injection field, at depths attributed to the much deeper and older Avon Park and Oldsmar formations. Moreover, Cunningham (FSAR Reference 2.5.1-999) has suggested that a different sag feature within the MDWASD's southern wastewater injection field could reflect subaerial exposure and sinkhole development (i.e., epigenetic dissolution) along a major sedimentation and subsidence stratigraphic/sequence boundary.

Accordingly, a hypogene dissolution mechanism is not necessarily required to explain the southeastern Florida structural sags or the Jewfish Creek/Lake Surprise collapse feature, although hypogene processes cannot be discounted as a formative mechanism.

b. Klimchouk (References 10 and 11) has generally described hypogene speleogenesis as dissolution-enlarged permeability (flow) structure development via ascending waters, driven by regional and/or more localized hydraulic potentials (i.e., hydrostatic pressures) or other convective circulation mechanisms. Given the vertical heterogeneity inherent in most sedimentary sequences, this upward groundwater flow implies some hydrological confinement (artesian conditions) rather than surface recharge. In southeastern Florida, confinement is largely provided by the Peace River and middle and upper (non-carbonate) Arcadia formations. Potential for ascending flow (and, by inference, hypogene speleogenesis) thus exists in the lowermost Arcadia Formation and the underlying Suwannee and Ocala limestones, and the Avon Park, Oldsmar, and upper Cedar Keys formations (i.e., the Floridan Aquifer system).

   In particular, Kohout (References 12 and 13) posited that thermally-induced convective circulation was occurring in the Floridan Aquifer system within southern Florida. Specifically, Kohout (References 12 and 13) suggested upward flow from the lower Floridan Aquifer through a middle, semi-confining unit in the aquifer (namely, the Avon Park Formation) and subsequent seaward flow within the upper Floridan Aquifer. In the Turkey Point Units 6 & 7 site vicinity, the aforementioned upper Floridan Aquifer includes the lower Arcadia, Suwanee, and uppermost Avon Park formations. Aquifer units ascribed to the Ocala limestones are missing in the site vicinity.

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

Meyer (Reference 14) noted that groundwater ages and radiocarbon (C-14) and uranium isotope concentration data within the Floridan Aquifer substantiate Kohout convection, and suggested that inland flows associated with the circulation pattern were as high as 52 m (172 ft) per year in the early Holocene, at least in the so-named boulder zone in the Oldsmar Formation. Meyer (Reference 14) estimated modern Kohout circulation inland flows to be only about 1.5 m (5 ft) per year. It is thus assumed that Kohout circulation (and, by inference, hypogene dissolution) has slowed over the Holocene, as sea levels stabilized. Morrissey et al. (Reference 15) argued that this decreased inland flow was associated with increased coastal groundwater levels (i.e., hydraulic head) from long-term Holocene sea level rise, and subsequent reduced hydraulic gradients (and thereby flow velocities) across the Florida platform.

Morrissey et al. (Reference 15) also suggested that the density difference between sea water and discharging freshwater (alone) could induce convection in the Floridan Aquifer system, as similarly asserted by Sanford et al. (Reference 16) and Hughes et al. (Reference 17).

Possible Hypogene Dissolution in Southeastern Florida

It is important to note that hypogene karst features do not necessarily manifest at the surface (or should not be expected to manifest at the surface) given that hypogene dissolution is not associated with meteoric recharge. Hypogene dissolution feature surface exposure typically occurs only via surface denudation (e.g., uplift and erosion). Direct (observational) evidence for hypogene dissolution (i.e., from cave morphology) is thus not readily available for southeastern Florida, as only epigenetic caves are known and accessible (see Part c).

Very few studies from southeastern Florida explicitly address (or invoke) hypogene dissolution processes as a cave or cavity/void forming mechanism. Most notably, Cunningham and Walker (FSAR Reference 2.5.1-958) proposed two hypogene mechanisms to possibly explain structural sags in Biscayne Bay and the Atlantic Ocean: (1) upward groundwater flow via Kohout convection and subsequent carbonate dissolution by mixed fresh and saline waters, and (2) dissolution associated with upward ascending hydrogen-sulfide-rich groundwater, sourced from calcium sulfates in deeper Eocene (or Paleocene) age rocks.

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

Cunningham and Walker (FSAR Reference 2.5.1-958) also suggested that submarine sinkholes located along the Pourtalès and Miami terraces as identified by Jordan (References 18 and 19) and Malloy and Hurley (Reference 20) and later by Land et al. (Reference 21) and Land and Paull (FSAR Reference 2.5.1-951) were potential evidence for fresh/salt water mixing and subsequent dissolution resulting from upward flow during Kohout circulation. It is important to note that Land et al. (Reference 21) and Land and Paull (FSAR Reference 2.5.1-951) (and others) only intimated that upward convective (Kohout) circulation could be responsible for the sinkholes, but did not completely discount epigenetic formation processes. Critically, though, it should be noted that Cunningham and Walker (FSAR Reference 2.5.1-958) present no real (i.e., tangible) evidence to support a hypogene origin for these features, either via Kohout circulation and fresh/salt water mixing or dissolution by hydrogen-sulfide-rich waters.

Additional data (including location information) related to the aforementioned sag and sinkhole features are provided in the associated response to Part c (below).

<u>Hypogene Speleogenesis Timing and Reactivation Potential</u>

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

Importantly, in the Turkey Point Units 6 & 7 site vicinity, deformation associated with the aforementioned structural sags does not seem to extend beyond (above) the Oligocene to Miocene age Arcadia Formation. Nevertheless, sag features with deformation extending upward into the Peace River and Tamiami formations have been imaged below the North New River and Hillsboro canals, located approximately 77 km and 101 km (48 mi and 63 mi) from the site, in Broward and Palm Beach counties (References 7, 8, and 9). It is possible then that cave formation and/or collapse occurred as late as the Pliocene.

As already noted, Meyer (Reference 14) and Morrissey et al. (Reference 15) (and others) have suggested that Kohout circulation remains active in southeastern Florida. Carbonate dissolution via hypogene mechanisms (mixing-induced dissolution or dissolution by ascending sulfide-rich waters) is thus possible in the lower and middle (semi-confining) Floridan Aquifer units (i.e., in areas wherein groundwater flow is predominantly upward). Existing cross-formational permeability structures (faults, fractures, cavities, etc.) could also drive upward flow (and corresponding hypogene speleogenesis) in localized areas. Consequently, various tectonic faults, folds, and fractures and the faults and fractures associated with the sag structures identified by Cunningham and Walker (FSAR Reference 2.5.1-958) and others (References 7, 8, and 9) could thus serve as vertical groundwater flow paths (FSAR Reference 2.5.1-958) and loci for active hypogene speleogenesis in southeastern Florida.

It is important to note that dissolution in Floridan Aquifer upward flow zones, or along cross-formational permeability structures, is likely minimal. In typical carbonate dissolution systems, maximum cave wall (or karst conduit wall) retreat rates have been reported to average 0.01 to 0.1 centimeters (cm) (0.004 to 0.04 inches [in]) per year (Reference 22). Conservatively assuming even a ten-fold increase in these rates, for example, dissolution-induced enlargement along existing flow conduits (joints, fractures, etc.) would equal only about 0.6 m (2 ft) over the expected Turkey Point Units 6 & 7 operational span.

Potential hypogene (and epigenetic) karst feature distributions and dissolution loci are further discussed in Part c (below).

c. Significant dissolution features within the Turkey Point Units 6 & 7 site vicinity and in adjacent central and eastern Broward County are identified on Figures 7 and 8, and include caves, sinkholes, and springs, as well as paleo-karst collapse and sag structures. Notably, the latter features include the previously described Jewfish Creek/Lake Surprise collapse structure, and the sag systems described by Cunningham and Walker (FSAR Reference 2.5.1-958). Major offshore dissolution features (namely submarine sinkholes) are also identified on Figure 7, and are described below.

<u>Caves and Surface Sinkholes</u>

Caves (as denoted by blue circles on Figures 7 and 8) are not particularly common in the Turkey Point Units 6 & 7 site vicinity or in the wider southeastern Florida region. Cressler (FSAR Reference 2.5.1-955) described only 19 air-filled caves and one water-filled cave in southeastern Florida, although an additional seven caves have since been mapped by Florea (Reference 23). Typically, these caves are located along the Atlantic Coastal Ridge or transverse glades (low relief, relict tidal channels) that cut across the Atlantic Coastal Ridge (Figures 7 and 8). At least 11 caves lie within the Deering Estate County Park and Preserve located roughly 17.6 km (11 mi) north-northeast from the site.

It should be noted that the Florida Sinkhole Research Institute (now defunct) and Florida Geological Survey (FGS) (Reference 24) have catalogued only five sinkhole openings (surface collapses) in Miami-Dade and Broward counties, as identified by the red circles on Figures 7 and 8. FGS subsidence incident reports (SIRSs) indicate that these features are not directly related to active rock dissolution and subsequent collapse, but instead to infrastructure issues, namely sediment piping associated with broken hydrants (FGS SIR 86-001) and water mains (FGS SIR 86-002) or leaky storm drain boxes (FGS SIR 86-004).

Jointly, the above data suggest that comparably active (recent) cave formation and epigenetic dissolution (or, by inference, near-surface collapse) is unlikely at Turkey Point Units 6 & 7 as the aforementioned caves are located significantly inland, along the Atlantic Coastal Ridge, and are restricted (vertically) to the Miami Limestone. Moreover, known sinkhole occurrences in the wider site vicinity appear to be unrelated to active dissolution processes, but instead are likely associated with urban development.

<u>Springs</u>

Currently, karst spring catalogues maintained by FGS (Reference 25) do not include entries for the Turkey Point Units 6 & 7 site vicinity or Broward or Miami-Dade counties. Evidence for spring flows (and inferred karst conduits) in the site vicinity (for example, at Coconut Grove and Devils Punch Bowl) is nonetheless provided by historical accounts (References 26 and 27). Anecdotal information suggests that submarine groundwater discharges into Biscayne Bay were particularly significant in the area between the Coral Gables Canal (near Coconut Grove) and the Mowry Canal, located approximately 5.1 km (3.2 mi) north from the site, at least prior to canal construction (FSAR Reference 2.5.1-949).

Aerial imagery for the shoreline near Turkey Point Units 6 & 7 from 1938 clearly captures an offshore spring and groundwater seepage only 1500 m (4921 ft) from the approximate site center-point (Figure 7). Gonzalez (Reference 28) relocated the seepage/discharge point in 2004, but did not observe flow. Generally though, the approximately relocated spring site was characterized by sediment-filled, seagrass-covered karst holes.

At least 21 additional offshore springs (identified by green circles on Figure 8) were located in 2006 by Gonzalez (Reference 28) in an area approximately mid-way between the aforementioned Mowry and Coral Gables canals. Generally, Gonzalez (Reference 28) classified these seepage points as small, ephemeral openings in soft sediment, typically less than 15 cm (6 in) across, or as more persistent, large diameter (1 m to 4 m [3 ft to 13 ft]) features. Discharge from the larger diameter features was described as strong with resulting exposure of the limestone surface and associated karst conduits, although dry season flow was apparently discernible only during low tide. Flow in the smaller, ephemeral springs was visible only in the wet season, or following precipitation events. Flow in all springs was diminished when nearby canal flood gates were opened.

Gonzalez (Reference 28) reported that the spring waters were slightly acidic, and ranged in salinity from approximately 8 to 31 grams per liter (g/L) (equivalent to 8 parts per thousand [ppt] to 31 ppt). Foraminiferal assemblages associated with the springs were thus reported to include both brackish and fresh water species. Significantly, Gonzalez (Reference 28) indicated that foraminifera tests recovered from the springs exhibited extensive pitting, and thus suggests that some carbonate dissolution occurs at the discharge sites.

Because offshore spring flow (shallow submarine groundwater discharge) in the immediate site vicinity is relatively low, it is likely that associated dissolution is limited. Moreover, the karst conduits feeding these springs are most likely confined to depths corresponding to the Miami Limestone, and thus will be excavated (if present) prior to construction.

Submarine Sinkholes

More significantly, Land et al. (Reference 21) and, later, Land and Paull (FSAR Reference 2.5.1-951) mapped nine submarine sinkholes in the Florida Straits, on the Pourtalès and Miami terraces (purple circles, Figure 7) at depths between 244 m and 575 m (800 ft and 1886 ft). Long and short axes and depths in the sinkholes average about 630 m (2065 ft) and 440 m (1444 ft) and 100 m (328 ft) respectively. Land et al. (Reference 21) (and Land and Paull [FSAR Reference 2.5.1-951]) interpreted the features as having formed underwater, and as rooted in Eocene and Oligocene limestones. Land and Paull (FSAR Reference 2.5.1-951) also suggested that some were possibly still active, given incomplete infilling.

Cunningham and Walker (FSAR Reference 2.5.1-958) suggested that the Pourtalès and Miami terrace sinkholes were evidence for fresh/salt water mixing resulting from upward flow driven by Kohout circulation, as described in Part b. Kohout (References 12 and 13) predicted mixing and upward flow in these areas, but did not explicitly recognize the sinkholes as direct evidence for discharges. Land et al. (Reference 21) and Land and Paull (FSAR Reference 2.5.1-951) only intimated that upward convective circulation could be responsible for the sinkholes, noting that the Pourtalès and Miami terrace sinkholes were laterally continuous with the Floridan Aquifer and thus could simply represent past (or even present) freshwater discharge and dissolution associated with freshwater/saltwater mixing in the immediate discharge zone (i.e., non-hypogene mixing zone dissolution).

A similarly large (610 m [2000 ft] diameter) and deep, but sediment-filled, submarine sinkhole was identified by Shinn et al. (FSAR Reference 2.5.1-959) in shallow waters in the Key Largo National Marine Sanctuary, centered approximately 31 km (20 mi) south-southeast from Turkey Point Units 6 & 7 and 115 km (71 mi) north-northeast and 40 km (25 mi) south-southwest from the Pourtalès Terrace and Miami Terrace sinkhole locales, respectively (Figure 7). Shinn et al. (FSAR Reference 2.5.1-959) did not provide a precise age for the collapse feature, although radiocarbon dates suggest that the sinkhole has accumulated sediment for at least the last 5700 years. Core material from the sinkhole included rock fragments resembling the Miami and/or Key Largo Limestone, thus suggesting that the sinkhole likely developed at latest during the Pleistocene.

Comparable submarine sinkholes with diameters between 30 m and 500 m (98 ft and 1640 ft) are also known from Cay Sal Bank (Figure 7) (Reference 29) and from various other locations in the westernmost Bahama Banks (Reference 30). Generally, filled sinkholes within the Florida Straits and adjacent areas (e.g., the Key Largo feature) are interpreted as epigenetic in origin, having developed during late Pleistocene sea level lowstands.

Collectively, the Pourtalès Terrace, Miami Terrace, and Key Largo submarine sinkholes are not suitable (relevant) analogues for dissolution or paleo-karst collapse feature development at Turkey Point Units 6 & 7. Surface and subsurface structures identified at the site do not, for example, exhibit morphologies consistent with the aforementioned submarine sinkhole features. Vegetated karstic depressions at the site (epigenetic in origin) are small, typically less than 50 m (164 ft) across, and shallow, less than 2.1 m (7 ft) deep, as surveyed via sediment coring and sampling (FSAR Reference 2.5.1-996). In contrast, the Pourtalès Terrace and Miami Terrace sinkholes and the Key Largo sinkhole are wide (over 190 m [623 ft] across) and deep (over 30 m [98 ft]).

Perhaps more importantly, the Turkey Point Units 6&7 location is inconsistent with groundwater discharge loci (and inferred enhanced dissolution zones) generally predicted by numerical groundwater circulation models for the southern Florida Platform (Reference 31). Under sea level highstand boundary conditions, these models predict increased saltwater encroachment (rather than discharge) and dissolution at depths exceeding 500 m (1640 ft) (i.e., near the Florida Platform base). Contrastingly, lowstand model conditions predict increased groundwater discharge, and suggest that mixing will occur along the upper platform margin, at shallower depths.

Land et al. (Reference 21) and Land and Paull (FSAR Reference 2.5.1-951) mapped only one sinkhole on the Pourtalès Terrace at depths greater than the aforementioned 500 m (1640 ft) sea level highstand model dissolution limit. Land et al. (Reference 21) noted that this karst feature, located near the base of the Pourtalès Terrace at a 575 m (1886 ft) water depth, is positioned in a Quaternary sediment drape, suggesting recent formation, and thus is consistent with highstand model predictions for persistent submergence. Land and Paull (FSAR Reference 2.5.1-951) mapped the remaining Pourtalès sinkholes at depths between approximately 350 m and 460 m (1148 ft and 1509 ft). Generally, then, these additional sinkholes are consistent with groundwater discharge during an earlier sea level lowstand (probably in the Miocene).

Turkey Point Units 6 & 7 are located well inland from the Florida Platform base and upper margin, and thus the site is not likely to have been a locus for Kohout circulation and corresponding freshwater/saltwater mixing induced dissolution under highstand or under lowstand conditions, as described above.

Sags and Paleo-Karst Collapse Structures

In total, Cunningham and Walker (FSAR Reference 2.5.1-958) and others (References 7, 8, and 9 and FSAR Reference 2.5.1-999) imaged and described 12 sag structures (karst collapse features) under Biscayne Bay and 24 onshore sag structures in northeastern Miami-Dade and eastern Broward counties (pink circles in Figures 7 and 8). Discussion related to these features (and to the Jewfish Creek/Lake Surprise structure) is provided in the responses to Parts a and b (above) and is not repeated here.

Another possible onshore paleo-collapse feature (not described previously) was identified by Technos (Reference 5) during geophysical and geotechnical investigations for a tunnel project in Miami Harbor, under the Government Cut shipping channel (Figure 7). Located approximately 42 km (26 mi) northeast from the Turkey Point Units 6 & 7 and 25 km (15 mi) north from the sag features in Biscayne Bay, this feature was described by Technos (Reference 5) as exhibiting "soft zones" and cavities exceeding 3 m (10 ft) diameter, at depths (below sea level) between 20 m and 30 m (65 ft and 100 ft). Because this structure occurs at relatively shallow depths, it is likely associated with subaerial exposure and epigenic dissolution during sea level lowstands.

Two other potential collapse features, described as sinkholes, have also been identified offshore from Broward County, approximately 90 km (56 mi) north-northeast from the site. Specifically, two large, depression features were identified by ENTRIX, Inc. during geophysical surveys conducted to support a now withdrawn application for the proposed Calypso liquefied natural gas (LNG) deep water port facility (Reference 32). Centered roughly 10 km and 16 km (6 mi and 10 mi) from the shore, as depicted in Figure 7, these features were estimated as 670 m (2200 ft) and 365 m (1200 ft) in diameter, respectively.

ENTRIX, Inc. (Reference 32) specified that the southernmost Calypso feature (Calypso Port 1 in Figure 7) exhibited surface expression and thus indicates possible continued subsidence. In contrast, the northern sinkhole feature (Calypso Port 2) was evident only in the sub-surface.

Given location and size, it is likely that the Calypso Port 1 and 2 features likely formed coincident with other submarine sinkholes in the Florida Straits described by Land and Paull (FSAR Reference 2.5.1-951) and Land et al. (Reference 21).

Collective Karst Feature Relevance to Deformation Predictions at the Site

Collectively, the aforementioned information related to caves, cover collapse sinkholes, springs, submarine sinkholes, paleo-karst collapses, and sag structures in the site vicinity (and in other areas in southeast Florida) suggests that while dissolution features are present, most are not currently active. Active dissolution is thus likely to be limited at Turkey Point Units 6 & 7, as is the potential for deformation due to collapses within existing (i.e., "paleo") dissolution features.

For example, caves and surface collapse sinkholes have not been identified at the site, and are not expected, given that active cave formation and surface collapses in southeastern Florida appear to be restricted to the Atlantic Coastal Ridge. Active dissolution associated with karst conduits at the site, as evident in past submarine groundwater discharges, is also likely insignificant (less than 0.1 cm [0.04 in] per year, as noted above, in Part b).

Although substantial in scale and extent, the numerous sag features described in Cunningham and Walker (FSAR Reference 2.5.1-958) and various others (References 7, 8, and 9) provide no evidence for post-Pliocene (relatively recent) deformation. Only the observed collapse structures at Jewfish Creek/Lake Surprise (References 1, 2, 3, and 4) and Key Largo (FSAR Reference 2.5.1-959) appear to have occurred in the Pleistocene, coincident with sea level lowstands. Given this sea level lowstand coincidence, the Jewfish Creek/Lake Surprise structures are not particularly relevant analogs for active (or future) surface collapse at (or near) the Turkey Point Units 6 & 7 site. Conditions are thus not favorable for comparable collapses at or near Turkey Point Units 6 & 7.

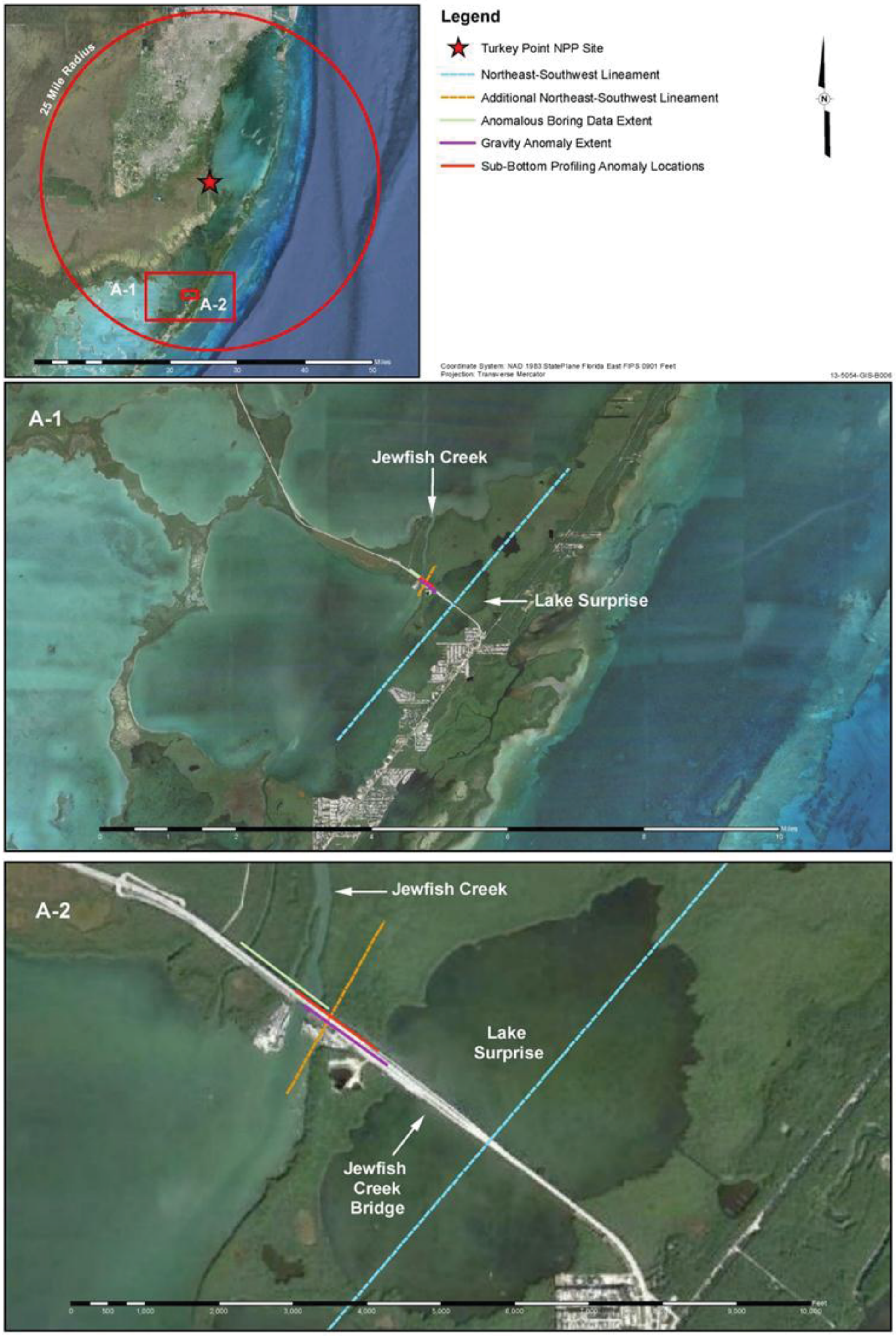
Importantly, it should be noted that isopach and structure contour maps for the Pleistocene Key Largo Limestone and Fort Thompson Formation at Turkey Point Units 6 & 7 provide no evidence for co-located or similarly oriented closed-contour depressions that would indicate surface subsidence. Moreover, the few closed-contour depressions that have been mapped generally are not deeper than 0.3 m to 0.6 m (1 ft to 2 ft). Consequently, these data suggest that large collapse structures do not underlie the site.

d) Collapse (i.e., sag) structures in the site vicinity described originally by Cunningham and Walker (FSAR Reference 2.5.1-958) and later by Cunningham (FSAR Reference 2.5.1-999) do not indicate post-Miocene deformation. Although there is no evidence to suggest that comparable structures underlie the Turkey Point Units 6 & 7 site, as noted in Part c, if present, these features would most likely be confined to the Arcadia Formation (or underlying rocks) and would already have collapsed. Consequently, active surface or near-surface deformation related to potential sag structures at the site is not expected. Supporting this expectation, geotechnical boring B-701 DH, located at the Unit 7 center-point, advanced to approximately 188 m (616 ft) below ground surface, well into the Arcadia Formation, presents no indications for cavities and/or collapses.

Finite element models for settlement presented in FSAR Subsection 2.5.4.10.3.2 do not consider the Arcadia Formation, given that the seismic sag related settlement contributions from this layer (and underlying layers), if they exist at all, are negligible. More explicitly, the depth to the Arcadia Formation at the Turkey Point Units 6 & 7 site (139 m [455 ft] on average) is much greater than the estimated 2*B* value for the site, assuming an extreme nuclear island foundation least lateral dimension (i.e., a *B* value) equal to 48.8 m (160 ft). At 139 m (455 ft) changes in effective vertical stress due to the nuclear island foundation load are less than 10 percent of the effective in situ stress.

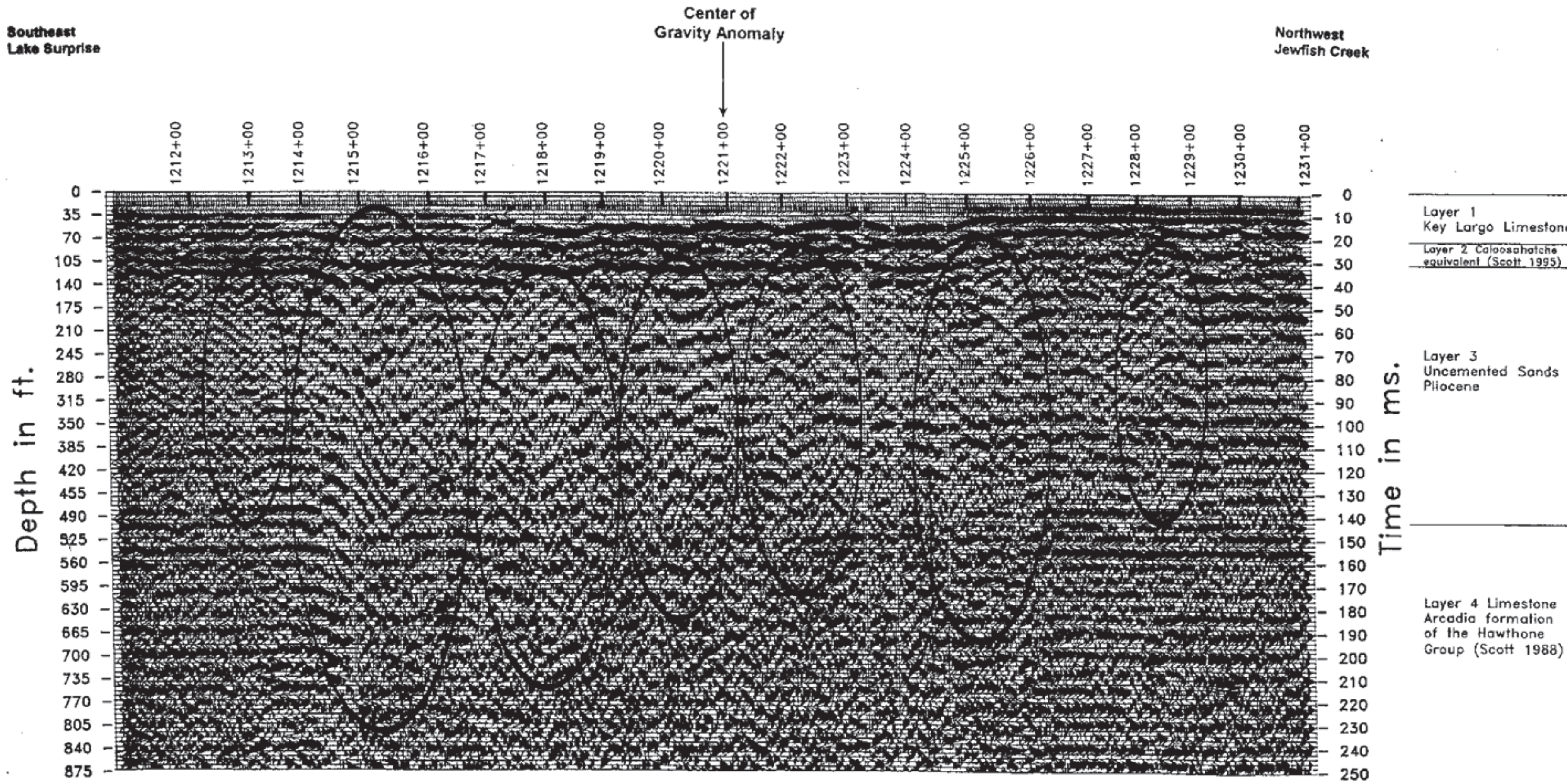
Albeit unanticipated, un-collapsed voids at depth are most likely to be localized, and small in scale. Specifically, cavities at the site are likely to be limited to less than 3 m (10 ft) in diameter, based on existing information from already collapsed features in the wider site vicinity (e.g., Reference 5). Collapse of a void with these dimensions in the Arcadia Formation (or lower layers) would result in a neglible settlement impact on the nuclear island foundation.

Figure 1 Jewfish Creek/Lake Surprise Feature Location and Anomalies



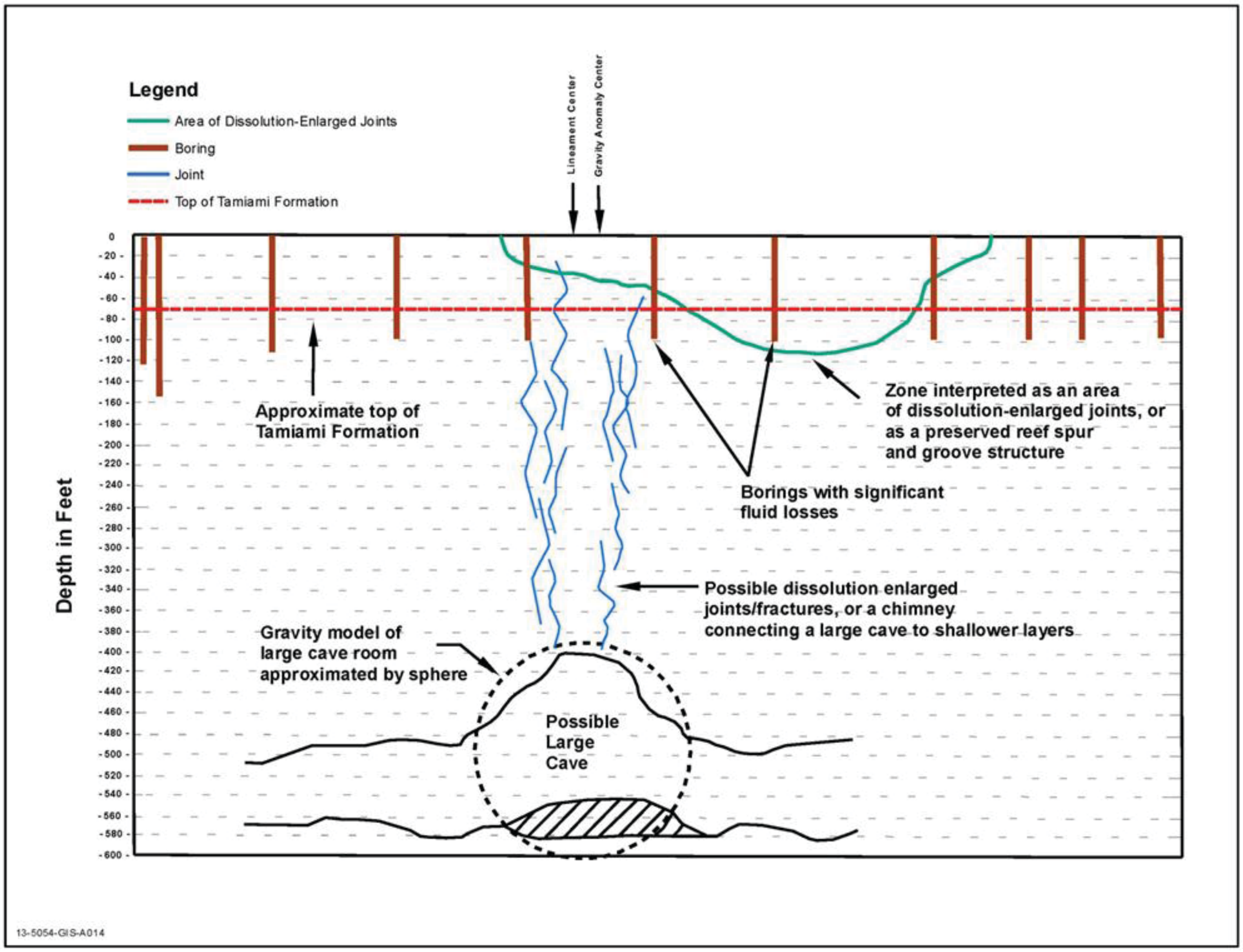
Source: References 1, 2, 3, and 4

Figure 2 Seismic-Reflection Profile from Jewfish Creek/Lake Surprise Showing Interpreted Collapse Features



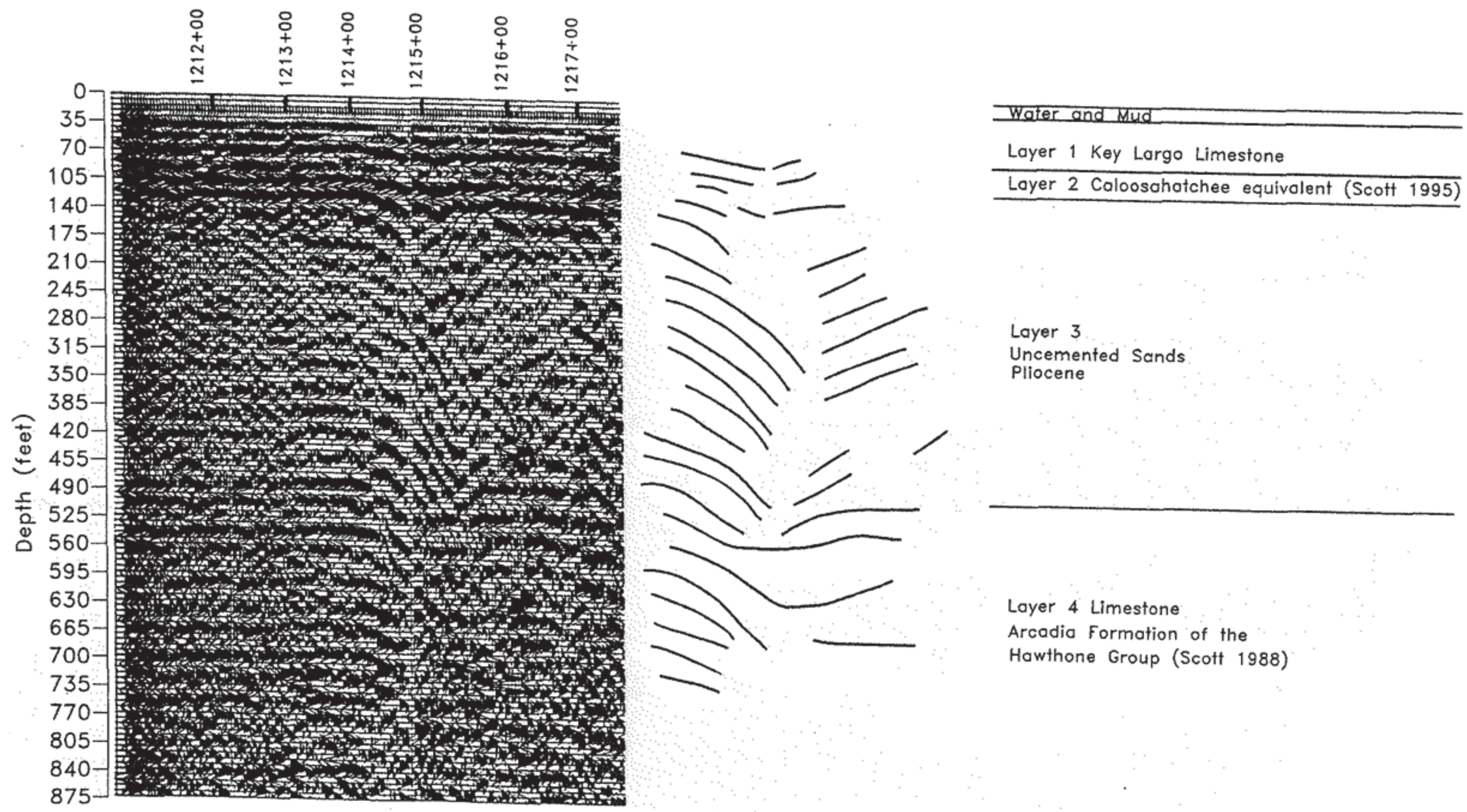
Source: Reference 4

Figure 3 Conceptual Model Showing Maximum Depth and Size of the Jewfish Creek/Lake Surprise Feature



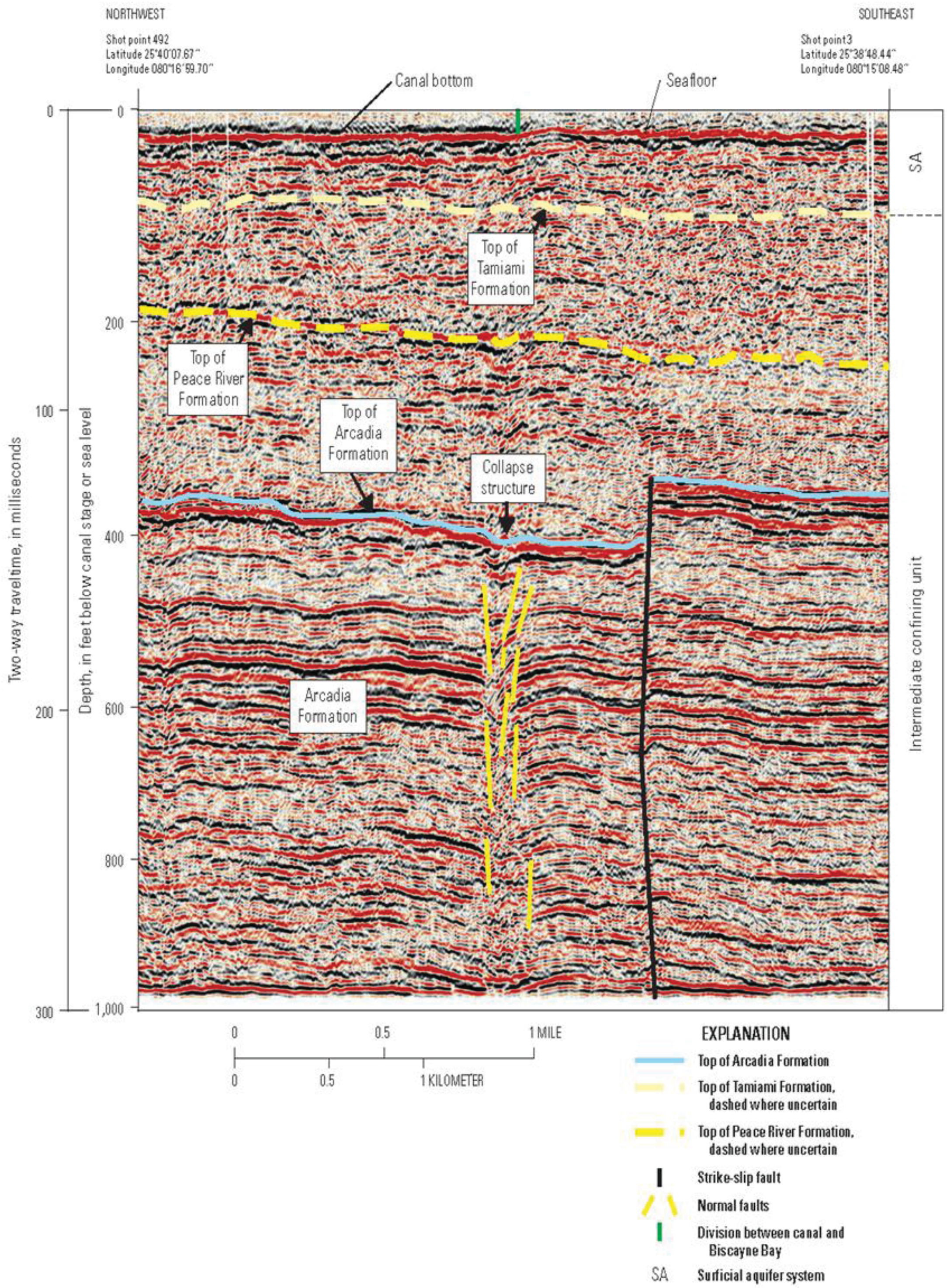
Source: Reference 2

Figure 4 Interpreted Seismic Data from the Largest Collapse Structure at Jewfish Creek



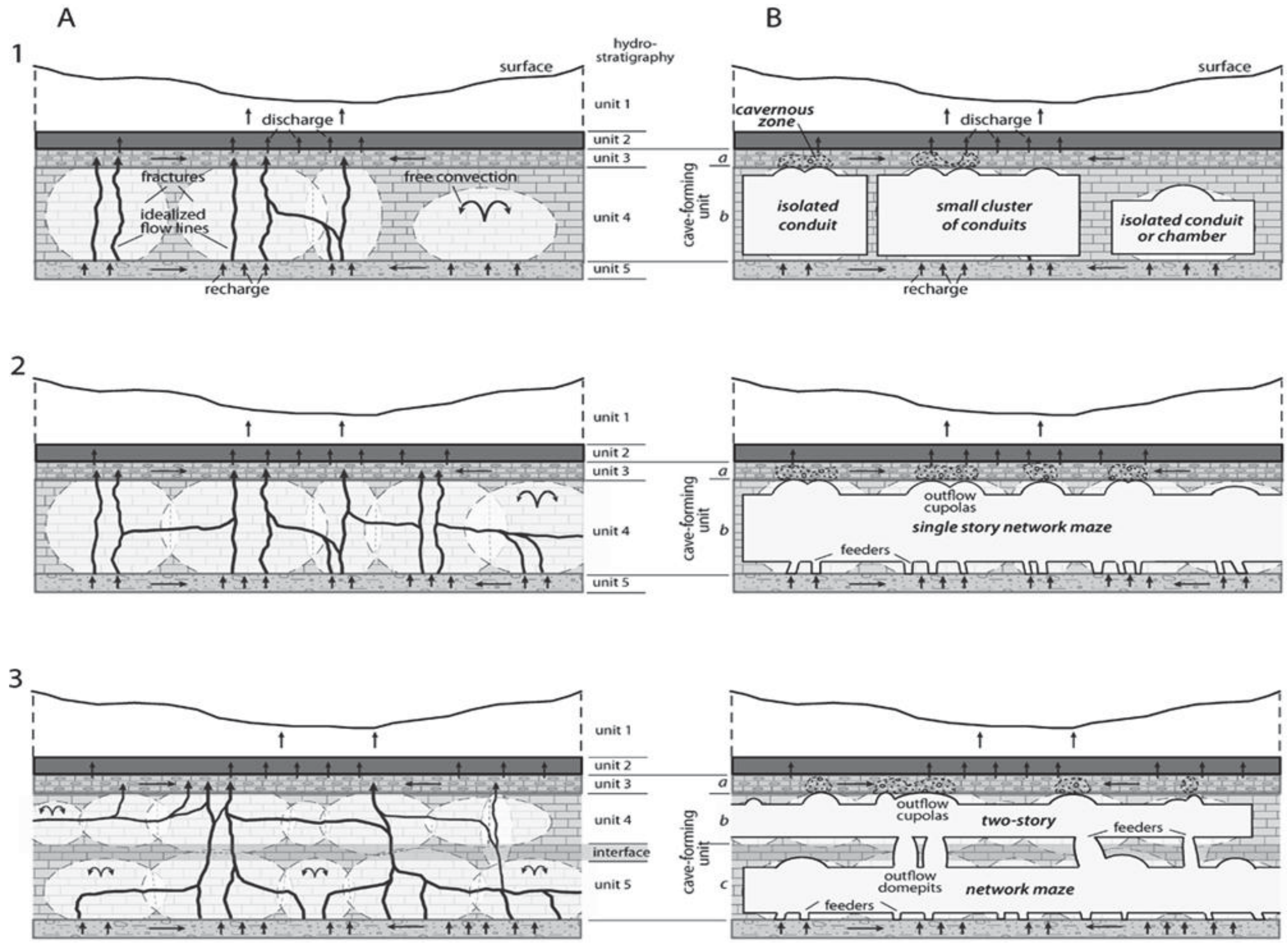
Source: Reference 4

Figure 5 Seismic Reflection Profile Showing Interpreted Sag



Source: Reference 8

Figure 6 Hydrogeologic Variants for Hypogene Cave Formation



Source: Reference 10

Figure 7 Surface and Subsurface Karst Features in Southeastern Florida

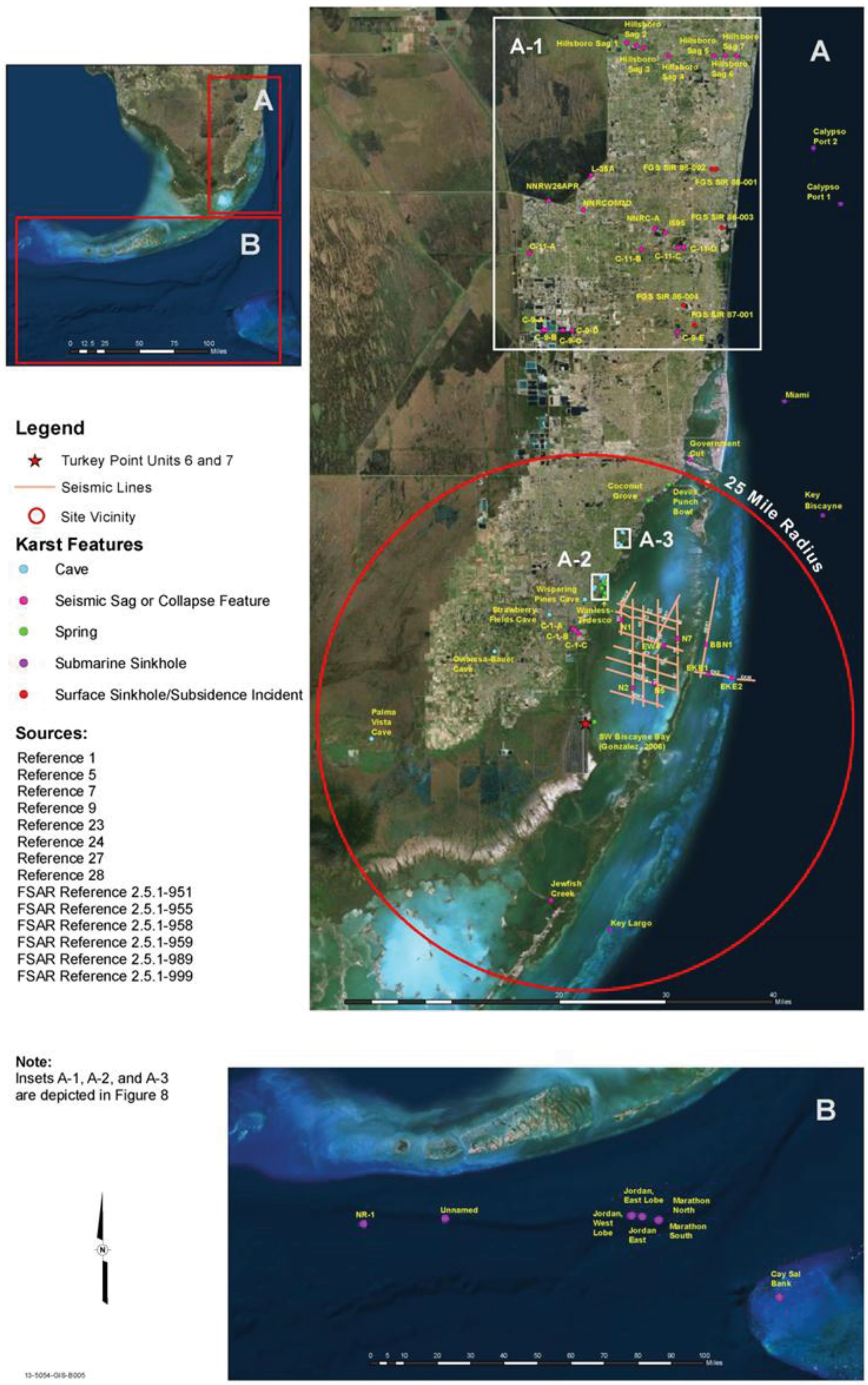
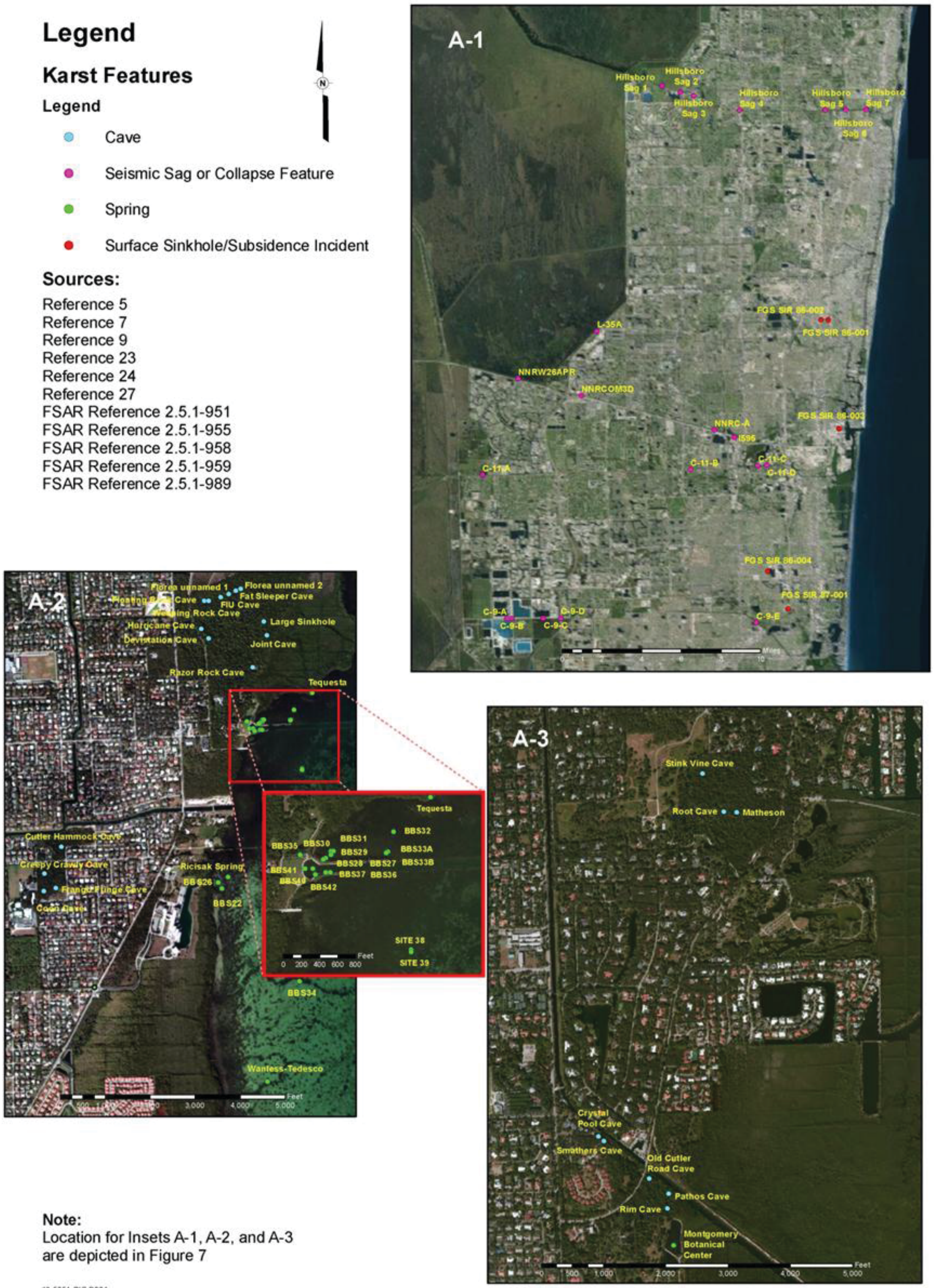


Figure 8 Karst Features Near the Turkey Point Units 6 & 7 Site



This response is PLANT SPECIFIC.

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ASSOCIATED COLA REVISIONS:

FSAR Subsection 2.5.1 will be revised in a future COLA revision as follows:

The 2nd paragraph of FSAR Subsection 2.5.1.1.1.1.1 will be revised in a future COLA revision as follows:

The Units 6 & 7 site is situated in the southern tip of the Florida Peninsula. The site region encompasses not only part of the Florida Peninsula, but also the southern half of the Florida Platform. **A detailed discussion related to karst feature development in the Florida Peninsula physiographic province, and in the southern Florida Platform is included in Subsection 2.5.1.1.1.1.1.1. Individual primary and**

secondary~~The~~ Florida Peninsula physiographic subprovinces that fall within that 200-mile radius site region are **also** described ~~below~~in **detail in** Subsection 2.5.1.1.1.1.1.1. The entire Florida Platform, including the Florida Escarpment (Figure 2.5.1-214), is discussed in Subsection 2.5.1.1.1.1.1.2. The unusually broad and shallow Atlantic Continental Shelf and Slope of Florida, including the Blake Plateau, while outside of the 200-mile site radius, are discussed in Subsection 2.5.1.1.1.1.1.3 because of their importance in protecting peninsular Florida from the effects of strong waves from the Atlantic Ocean.

A new subheading will be added before the first paragraph of FSAR Subsection 2.5.1.1.1.1.1.1 as follows:

2.5.1.1.1.1.1.1 Florida Peninsula Physiographic Subprovinces

General Geography and Geology of the Florida Peninsula

A new subheading will be added after the 10th paragraph of FSAR Subsection 2.5.1.1.1.1.1.1 as follows:

Karst Processes and Features on the Florida Peninsula

Karstification is the process created by chemical dissolution when weakly acidic groundwater circulates through soluble rock (Figure 2.5.1-221). Carbon dioxide from the atmosphere is fixed or converted in the soil horizon to an aqueous state, where it combines with rainwater to form carbonic acid, which readily dissolves carbonate rock. Root and microbial respiration in the soil further elevates carbon dioxide partial pressure, increasing acidity (lowering pH). In tropical and subtropical regions such as Florida, abundant vegetation, high rainfall, and high atmospheric CO_2 values favor the rapid dissolution of the preexisting limestone.

FSAR Subsection 2.5.1.1.1.1.1.1 subheading titled Freshwater Springs along Biscayne Bay will be revised in a future COLA revision as follows:

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**, and 1000**). 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) **(Figure 2.5.1-390)** 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.~~

Currently, karst spring catalogues maintained by FGS (Reference 1001) do not include entries for the Turkey Point Units 6 & 7 site vicinity or Broward or Miami-Dade counties. Evidence for spring flows (and inferred karst conduits) in the site vicinity (for example, at Coconut Grove and Devils Punch Bowl) is nonetheless provided by historical accounts (References 1002 and 1003). Anecdotal information suggests that submarine groundwater discharges into Biscayne Bay were particularly significant in the area between the Coral Gables Canal (near Coconut Grove) and the Mowry Canal, located approximately 5.1 kilometers (3.2 miles) north from the site, at least prior to canal construction (Reference 949).

Aerial imagery for the shoreline near Turkey Point Units 6 & 7 from 1938 clearly captures an offshore spring and groundwater seepage only 1500 meters (4921 feet) from the approximate site center-point (Figure 2.5.1-390). Gonzalez (Reference 1000) relocated the seepage/discharge point in 2004, but did not observe flow. Generally though, the approximately relocated spring site was characterized by sediment-filled, seagrass-covered karst holes.

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

Gonzalez (Reference 1000) reported that the spring waters were slightly acidic, and ranged in salinity from approximately 8 to 31 grams per liter (g/L) (equivalent to 8 parts per thousand [ppt] to 31 ppt). Foraminiferal assemblages associated with the springs were thus reported to include both brackish and fresh water species. Significantly, Gonzalez (Reference 1000) indicated that foraminifera tests recovered from the springs exhibited extensive pitting, and thus suggests that some carbonate dissolution occurs at the discharge sites.

Because offshore spring flow (shallow submarine groundwater discharge) in the immediate site vicinity is relatively low, it is likely that associated dissolution is limited.

~~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).

FSAR Subsection 2.5.1.1.1.1.1.1 subheading titled Cave Development along the Atlantic Coastal Ridge will be revised in a future COLA revision as follows:

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).~~ **Caves are not particularly common in the Turkey Point Units 6 & 7 site vicinity or in the wider southeastern Florida region (Figure 2.5.1-354). Cressler (Reference 955) described only 19 air-filled caves and one water-filled cave in southeastern Florida, although an additional seven caves have since been mapped by Florea (Reference 1004). Typically, these caves are located along the Atlantic Coastal Ridge or transverse glades (low relief, relict tidal channels) that cut across the Atlantic Coastal Ridge (Figures 2.5.1-390 and 2.5.1-391).**

~~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) **and Florea's (Reference 1004)** field observations and descriptions, the caves within the Pleistocene limestones fall into four categories: (1) ~~at least one is~~**some are** 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. **Entrances to the caves are either along the glade wall or occur as pits subjacent to the glade wall.** 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.~~**Of the caves identified by Cressler (Reference 955) and Florea (Reference 1004), 11 are located in the Deering Estate Preserve.**

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)-~~**95.4 meters (313 feet)-**long Fat Sleeper Cave **(Reference 1004)**. 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).

The 3rd paragraph of FSAR Subsection 2.5.1.1.1.1.1.1 subheading titled Submarine Paleokarst Sinkhole in the Key Largo National Marine Sanctuary will be revised in a future COLA revision as follows:

Submarine Paleokarst Sinkhole in the Key Largo National Marine Sanctuary

In summary, **it is postulated that** 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.

FSAR Subsection 2.5.1.1.1.1.1.1 subheading titled Deep Pore Water Upwelling will be replaced in a future COLA revision as follows:

~~**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)~~

Hypogene Dissolution

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

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

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

Meyer (Reference 1009) noted that groundwater ages and ^{14}C and uranium isotope concentration data within the Floridan aquifer substantiate Kohout convection, and suggested that lateral inland flows associated with the circulation pattern were as high as 52 meters (172 feet) per year in the early Holocene, at least in the so-named boulder zone in the Oldsmar Formation. Meyer (Reference 1009) estimated modern Kohout circulation inland flows (lateral) to be only about 1.5 meters (5 feet) per year. Morrissey et al. (Reference 1010) argued that this decreased flow was associated with increased coastal groundwater levels (i.e., hydraulic head) from long-term Holocene sea level rise, and subsequent reduced hydraulic gradients (and thereby flow velocities) across the Florida platform.

Morrissey et al. (Reference 1010) also suggested that the density difference between sea water and discharging freshwater (alone) could induce convection in the Floridan aquifer system, as similarly asserted by Sanford et al. (Reference 1011) and Hughes et al. (Reference 1012).

Possible Hypogene Dissolution on the Florida Peninsula

It is important to note that hypogene karst features do not necessarily manifest at the surface (or should not be expected to manifest at the surface) owing to the aforementioned characteristic separation from meteoric recharge. Surface exposure is typically only provided via surface denudation (e.g., uplift and erosion). Accordingly, direct evidence for hypogene dissolution (from cave morphology) is not readily available for southeastern Florida, as only epigenetic caves are known and accessible.

Very few studies from southeastern Florida explicitly address (or invoke) hypogene dissolution processes as a cave or cavity/void forming mechanism. Most notably, Cunningham and Walker (Reference 2.5.1-958) proposed two hypogene mechanisms to possibly explain structural sags in Biscayne Bay and the Atlantic Ocean: (1) upward groundwater flow via Kohout convection and subsequent carbonate dissolution by mixed fresh and saline waters, and (2) dissolution associated with upward ascending hydrogen-sulfide-rich groundwater, sourced from calcium sulfates in deeper Eocene (or Paleocene) age rocks. These features are described in more detail below.

The title and 5th paragraph of FSAR Subsection 2.5.1.1.1.1.1.1.1 subheading titled Submarine Paleokarst Sinkholes Beneath Biscane Bay will be revised and amended in a future COLA revision as follows:

Submarine ~~Paleokarst Sinkholes~~Sag Structures Beneath Biscayne Bay

Cunningham and Walker (Reference 958) suggested ~~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.~~

As noted above, the broad sag structures in Biscayne Bay are multi-storied (vertically stacked) features that can be interpreted as evidence for coalesced, collapsed, multi-story maze paleocave systems and associated deformation (fractures, faults, sagging, etc.). Narrower stacked sag structures, in turn, can be interpreted as evidence for more isolated (i.e., individual) subsurface void collapses. Generally, the hypogene dissolution process (speleogenesis) is associated with such multi-story maze caves and isolated sub-surface cavities/voids. Although Cunningham and Walker (Reference 958) did not explicitly attribute the aforementioned sags to hypogene dissolution processes, the vertical stacking is consistent with collapse in a multi-story hypogene cave system, as described by Klimchouk (Reference 1005). Nevertheless, Cunningham (Reference 999) cites evidence (unspecified) for hypogenic karst collapse in just one southeast Florida location, a borehole (well) in the Miami-Dade Water and Sewer Department (MDWASD) northern wastewater injection field, at depths attributed to the much deeper and older Avon Park and Oldsmar formations. Critically, though, it should be noted that Cunningham and Walker (Reference 958) present no tangible evidence to support a hypogene origin for these features, either via Kohout circulation and fresh/salt water mixing or dissolution by hydrogen-sulfide-rich waters. Moreover, Cunningham (Reference 999) has suggested that a different sag feature within the MDWASD's southern wastewater injection field could reflect subaerial exposure and sinkhole development (i.e., epigenetic dissolution) along a major sedimentation and subsidence stratigraphic/sequence boundary.

Regardless of the mechanism of formation **of the submarine sags beneath Biscayne Bay**, the geophysical data indicate the absence of deformation in rocks younger than **Pliocene**~~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 **Pliocene**~~middle Miocene~~ would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, **and Upper** 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.~~

The following subheading "sections" will be added to FSAR Subsection 2.5.1.1.1.1.1.1 after the section titled Submarine Paleokarst Sinkholes Beneath Biscayne Bay and before the section titled Crescent Beach Spring and Red Snapper Sink, off the Coast of Northeast Florida in a future COLA revision as follows:

Onshore Sag Structures in Broward and Miami-Dade Counties

In addition to the 12 sag structures imaged in Biscayne Bay, Cunningham and others (References 999, 1013, 1014, and 1015) have identified 24 onshore sag structures in northeastern Miami-Dade and eastern Broward counties (Figure 2.5.1-391). These features are also interpreted as paleokarst sinkholes or faults and fractures and have the same formation history as the broad and narrow seismic sag structural systems in Biscayne Bay (Reference 958).

Cunningham (Reference 999) noted that some onshore sag structures show deformation related features affecting younger units than those imaged beneath Biscayne Bay, where offset reflectors attributed to paleokarst related faults and fractures were observed to have their upper extents in the Mid-Miocene aged units (Reference 958). Whereas most paleokarst faults and fractures in the onshore canals were observed to truncate at the upper surface of the Middle Miocene Arcadia formation or lower, some in northern Broward County are observed to affect reflectors in the upper Miocene Peace River Formation as well as the overlying Ochopee Member of the Pliocene Tamiami Formation (References 1013 and 1015) (Figure 2.5.1-392). However, there is no deformation reported to affect units younger than the lower Pliocene, suggesting that the timing of karst formation and/or collapse into paleocave systems includes the Miocene and Pliocene Epochs. Furthermore, the onshore seismic sags closest to the site are not observed to affect any units above the top of the Arcadia Formation.

It is possible that the sags and recognized faults that cut through the upper surface of the Arcadia Formation form conduits for groundwater flow between the permeable zones of the Floridan aquifer system (Reference 999). This is indicated by detection of treated effluent in the uppermost major permeable zone of the Lower Floridan aquifer that was injected into the deeper Boulder Zone (References 1013 and 999). The detection of the treated effluent implies density-related, upward migration of fluids being the result of the lack of confinement between the two permeable zones, presumably enhanced by paleokarst features associated with the karst-collapse structure imaged on the onshore profiles (References 1013 and 999).

The imaging of twenty four seismic-sag features along 145 linear kilometers (90 miles) of seismic reflection acquisition would seem to imply that there are many more paleokarst collapse features that exist below Broward and Miami-Dade Counties, and south Florida in general, that have yet to be discovered. Since none of these filled paleokarst collapse features have been observed to affect units younger than Early Pliocene and there is no known surface expression, it is unlikely that they pose any hazard to the stability of the South Florida ground surface. Likewise, if any such features would happen to exist below the site vicinity or site, there is no reason to believe that they would pose a threat to the surface collapse at the site due to the thickness of the overlying strata.

Other Paleo-Karst Collapse Structures in Southern Florida

Several other paleo-karst collapse structures have been identified on the southern Florida Peninsula and Florida Platform. These features are discussed below.

Jewfish Creek Paleo-Karst Feature

A paleokarst feature of possible similar origin to the imaged sag structures in Biscayne Bay and Miami-Dade and Broward counties was identified during design work for a new bridge across Jewfish Creek and adjacent Lake Surprise on northern Key Largo (Figure 2.5.1-390) (Reference 1016).

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

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

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

A clear formation mechanism for the Jewfish Creek/Lake Surprise feature has not been indicated, but it has been intimated to be epigenetic (rather than hypogene) origin (Reference 1016). It should be noted that the collapse structures at Jewfish

Creek/Lake Surprise are interpreted to be centered in the late Oligocene to early Miocene age Arcadia Formation (Reference 1016). It is possible, then, that the collapsed cavities (or collapsed joints) were formed (or enlarged) via subaerial exposure and downward meteoric dissolution (i.e., epigenic or hypergenic dissolution) during middle to late Miocene sea level lowstands, estimated to be 300 meters (985 feet) below modern sea level, with considerations/corrections for subsidence (Reference 951). Alternatively, void formation may be linked to eogenetic (or syngenetic) dissolution processes, namely submarine groundwater discharge during sea level highstands and consequent enhanced carbonate dissolution at a former freshwater/saltwater interface, as described previously.

Because the collapse structures (as inferred from dipping strata) at Jewfish Creek/Lake Surprise extend upward into the Key Largo Formation, void development and joint enlargement could also be attributed, in part, to epigenic dissolution by meteoric waters (at least in more near-surface layers) during Pleistocene sea level lowstands. It is important to note, however, that the deep collapse origination point (at least 152 meters [500-feet deep]) precludes subaerial exposure during the maximum estimated late Pleistocene sea level lowstand (125 meters [410 feet]). Void collapse (and subsidence) at Jewfish Creek/Lake Surprise may instead represent cave or joint enlargement via phreatic dissolution, and subsequent (later) cave or joint collapse in the Pleistocene due to sea level lowering induced buoyancy losses (but not exposure) and corresponding load changes within overlying layers. Phreatic dissolution, in this case, would (again) likely have been associated with freshwater/saltwater mixing.

As noted above, the collapse structures at Jewfish Creek/Lake Surprise are also not entirely inconsistent with the narrow structural sag features described by Cunningham and Walker (Reference 958) and subsequently by Reese and Cunningham (Reference 1013) and Cunningham (Reference 999, 1014, and 1015) in Biscayne Bay and northeastern Miami-Dade and eastern Broward counties. However, these sag features are generally vertically stacked (multi-storied) and are not closely spaced or distributed horizontally as is the case at Jewfish Creek/Lake Surprise.

Government Cut Collapse Structure

Another possible onshore paleo-collapse feature was identified during geophysical and geotechnical investigations for a tunneling project in Miami Harbor, under the Government Cut shipping channel (Figure 2.5.1-390) (Reference 1017). Located approximately 42 kilometers (26 miles) northeast from the Turkey Point Units 6 & 7 site and 25 kilometers (15 miles) north from the sag features in Biscayne Bay, this feature was described as exhibiting “soft zones” and cavities exceeding 3 meters (10 feet) diameter, at depths (below sea level) between 20 meters and 30 meters (65 feet and 100 feet). Because this structure occurs at relatively shallow depths, it is likely associated with subaerial exposure and epigenic dissolution during sea level lowstands.

Submarine Sinkholes

Land et al. (Reference 1018) and, later, Land and Paull (Reference 951) mapped nine submarine sinkholes in the Florida Straits, on the Pourtalès and Miami terraces (Figure 2.5.1-390) at depths between 244 meters and 575 meters (800 feet and 1886 feet). Long and short axes and depths in the sinkholes average about 630 meters (2065 feet) and 440 meters (1444 feet) and 100 meters (328 feet) respectively. Land et al. (Reference 1018) (and Land and Paull [Reference 951]) interpreted the features as having formed underwater, and as rooted in Eocene and Oligocene limestones. Land and Paull (Reference 951) also suggested that some were possibly still active, given incomplete infilling.

Cunningham and Walker (Reference 958) suggested that the Pourtalès and Miami terrace sinkholes were evidence for fresh/salt water mixing resulting from upward flow driven by Kohout circulation, as described above. Kohout (References 1007 and 1008) predicted mixing and upward flow in these areas, but did not explicitly recognize the sinkholes as direct evidence for discharges. Land et al. (Reference 1018) and Land and Paull (Reference 951) only intimated that upward convective circulation could be responsible for the sinkholes, noting that the Pourtalès and Miami terrace sinkholes were laterally continuous with the Floridan aquifer and thus could simply represent past (or even present) freshwater discharge and dissolution associated with freshwater/saltwater mixing in the immediate discharge zone (i.e., non-hypogene mixing zone dissolution).

Generally, the Pourtalès and Miami terrace sinkhole locations are consistent with groundwater discharge loci (and inferred enhanced dissolution zones) generally predicted by numerical groundwater circulation models for the southern Florida Platform (Reference 1019). Under sea level highstand boundary conditions, these models predict increased saltwater encroachment (rather than discharge) and dissolution at depths exceeding 500 meters (1640 feet) (i.e., near the Florida Platform base). Contrastingly, lowstand model conditions predict increased groundwater discharge, and suggest that mixing will occur along the upper platform margin, at shallower depths.

Land et al. (Reference 1018) and Land and Paull (Reference 951) mapped only one sinkhole on the Pourtalès Terrace at depths greater than the aforementioned 500 meters (1640 feet) sea level highstand model dissolution limit. Land et al. (Reference 1018) noted that this karst feature, located near the base of the Pourtalès Terrace at a 575 meters (1886 feet) water depth, is positioned in a Quaternary sediment drape, suggesting recent formation, and thus is consistent with highstand model predictions for persistent submergence). Land and Paull (Reference 951) mapped the remaining Pourtalès sinkholes at depths between approximately 350 meters and 460 meters (1148 feet and 1509 feet). Generally, then, these additional sinkholes are consistent with groundwater discharge during an earlier sea level lowstand (probably in the Miocene).

It should be noted that two other potential collapse features, described as sinkholes, have also been identified offshore from Broward County, approximately 90 kilometers (56 miles) north-northeast from the site. Specifically, two large, depression features were identified by ENTRIX, Inc. during geophysical surveys conducted to support a now withdrawn application for the proposed Calypso liquefied natural gas (LNG) deep water port facility (Reference 1020). Centered roughly 10 kilometers and 16 kilometersm (6 miles and 10 miles) from the shore, as depicted on Figure 2.5.1-390, these features were estimated as 670 meters (2200 feet) and 365 meters (1200 feet) in diameter, respectively.

ENTRIX, Inc. (Reference 1020) specified that the southernmost Calypso feature (Calypso Port 1 on Figure 2.5.1-390) exhibited surface expression and thus indicates possible continued subsidence. In contrast, the northern sinkhole feature (Calypso Port 2) was evident only in the sub-surface. Given location and size, it is likely that the Calypso Port 1 and 2 features likely formed coincident with other submarine sinkholes in the Florida Straits described by Land and Paull (Reference 951) and Land et al. (Reference 1018).

The following paragraph is to be added to FSAR Subsection 2.5.1.1.1.1.1.1 subheading titled Sea Level Changes and Migration of Freshwater/Saltwater Interface and Conclusion after the second set of bullet points in a future COLA revision as follows:

Sea Level Changes and Migration of Freshwater/Saltwater Interface and Conclusion

It should be noted that the FGS have catalogued only five sinkhole openings (surface collapses) in Miami-Dade and Broward counties (Figure 2.5.1-390) (Reference 1021). FGS subsidence incident reports indicate that these features are not directly related to active rock dissolution and subsequent collapse, but instead to infrastructure issues, namely sediment piping associated with broken hydrants and water mains, or leaky storm drain boxes (i.e., urban development).

A new subheading will be added after the 5th paragraph at the end of the second set of bullet points in the section titled Sea Level Changes and Migration of Freshwater/Saltwater Interface and Conclusion of FSAR Subsection 2.5.1.1.1.1.1.1 as follows:

Primary and Secondary Physiographic Provinces of the Florida Peninsula

Recent work by the Florida Department of Environmental Protection and the FGS now favors an organization by primary and secondary physiographic provinces. This subsection reflects the new organization and does not refer to the three former physiographic zones of Florida. The hierarchy of primary and secondary physiographic zones pertinent to the site region is outlined in the table below.

The 6th paragraph of FSAR Subsection 2.5.1.2.4 will be revised in a future COLA revision as follows:

2.5.1.2.4 Site Geologic Hazards

Dissolution Features

According to Renken et al. (Reference 721), sinkholes and caves have been found in Miami-Dade County only along the Atlantic Coastal Ridge, where limestone is present at a relatively high elevation, extending southward from south Miami toward Everglades National Park (Figure 2.5.1-217). The Atlantic Coastal Ridge is up to ~~50 feet (15 meters) high and~~ **15 feet (4.5 meters) high as it** trends north-northeast to south-southwest into the site vicinity (Reference 265). Further discussion of the Atlantic coastal ridge is found in Subsection 2.5.1.1.1.1. Parker et al. (Reference 722) state that the Miami Limestone and Fort Thompson Formation have significant permeability and solution features that have created turbulent flow conditions in some wells. According to Cunningham et al. (Reference 723), topographic relief related to karst dissolution is well documented in the Lake Belt area of north-central Miami-Dade County approximately 17 miles (27 kilometers) northwest of Units 6 & 7. **No major sinkholes have been reported within the site vicinity with the closest reported sinkhole, near Ives Estates on the very northern edge of Miami-Dade County, is about 40 miles (63 kilometers) to the northeast of the site (Reference 1021). These features are discussed in greater detail in Subsection 2.5.1.1.1.1.1.1.** ~~These studies contain no suggestion of the presence of buried sinkholes, caverns, or other large-scale underground karst features in the vicinity of the site.~~

New paragraphs will be added before the very last paragraph of the section titled Dissolution Features of FSAR Subsection 2.5.1.2.4 in a future revision of the COLA as follows:

It should also be noted that the information related to submarine sinkholes, paleo-karst collapses, and sag structures in the site vicinity described in Section 2.5.1.1.1.1.1.1 suggests that while dissolution features are present, most are not currently active. Active dissolution is thus likely to be limited at Turkey Point Units 6 & 7, as is the potential for deformation due to collapses within existing (i.e., "paleo") dissolution features.

For example, the observed collapse structures at Jewfish Creek/Lake Surprise (Reference 1016) and Key Largo (Reference 959) appear to have occurred in the Pleistocene, coincident with sea level lowstands, and thus are not particularly relevant analogs for active (or future) surface collapse at (or near) the Turkey Point Units 6 & 7 site. Although substantial in scale and extent, the numerous sag features described in Cunningham and Walker (Reference 958) and various others (References 7, 8, and 9) similarly provide no evidence for post-Pliocene deformation. It seems likely then that comparable collapses within similar features, if present below Turkey Point Units 6 & 7, have already occurred (and are now stabilized).

Importantly, it should be noted that isopach and structure contour maps for the Pleistocene Key Largo Limestone and Fort Thompson Formation at Turkey Point Units 6 & 7 provide no evidence for co-located or similarly oriented closed-contour depressions that would indicate surface subsidence (Figures 2.5.1-342, 2.5.1-343, 2.5.1-344, and 2.5.1-349). Moreover, the few closed-contour depressions that have been mapped generally are not deeper than 0.3 meters to 0.6 meters (1 foot to 2 feet). Consequently, these data also suggest that large collapse structures do not underlie the site, or have stabilized (if present).

The following references will be added to FSAR Subsection 2.5.1 in a future revision of the COLA:

999. Cunningham, K.J., *Seismic-Sequence Stratigraphy and Geologic Structure of the Floridan Aquifer System Near "Boulder Zone" Deep Wells in Miami-Dade County, Florida*, U.S. Geological Survey Scientific Investigations Report 2015–5013, 28 p., 2015.

1000. Gonzalez, C.J., *Detection, Mapping, and Analysis of Freshwater Springs in Western Biscayne Bay, Florida*: M.A. Thesis, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, FL, 34 p., 6 appendices. 2006.

1001. Scott, T.M., G.H. Means, R. P. Meegan, R.C. Means, S.B. Upchurch, R.E. Copeland, J. Jones, T. Roberts, A. Willet, *Springs of Florida*, Florida Geological Survey Bulletin No. 66, Florida Department of Environmental Protection, 658 p., 2004.

1002. Ferguson, G.E., C.W. Lingham, S.K. Love, R.O. Vernon, *Springs of Florida*, Florida Geological Survey Bulletin No. 31, Florida Department Of Environmental Protection, 196 p., 1947.

1003. Parks, A., *The Forgotten Frontier: Florida Through the Lens of Ralph Middleton Munroe*, Second Edition, Centennial Press, p. 188, 2012.

1004. Florea, L.J., *Caves and Karst of the Atlantic Coastal Ridge – Miami-Dade County, Florida*, Paper No. 6-1, Geological Society of America – Southeastern Section – 58th Annual Meeting, 12–13 March, 2009.

1005. Klimchouk, A.B., *Principal Features of Hypogene Speleogenesis*, In A. Klimchouk and D. Ford (eds.), Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins, Ukrainian Institute of Speleology and Karstology Special Paper No. 1, pp. 7-15. 2009.

1006. Klimchouk, A.B., *Hypogene Speleogenesis: Hydrogeological and Morphogenetic Perspective*, Special Paper No. 1, National Cave and Karst Research Institute, Carlsbad, New Mexico, 106 p., 2007.

1007. Kahout, F.A., *A Hypothesis Concerning Cyclic Flow of Salt Water Related to Geothermal Heating in the Floridan Aquifer*, New York Academy of Sciences Transactions, Vol. 28, pp. 249-271, 1965.

1008. Kahout, F.A., *Ground-Water Flow and the Geothermal Regime of the Floridian Plateau*, Transactions of the Gulf Coast Association of Geological Societies, Volume XVII, pp. 339-354, 1967.

1009. Meyer, M.W., *Hydrogeology, Ground-Water Movement, and Subsurface Storage in the Floridan Aquifer System in Southern Florida*, United States Geological Survey Professional Paper 1403-G, 64 p., 1989.

1010. Morrissey, SK., J.F. Clark, M. Bennett, E. Richardson, M. Stute, *Groundwater Reorganization in the Floridan Aquifer Following Holocene Sea-Level Rise*, Nature Geoscience, Vol. 3, pp. 683-687, 2010.

1011. Sanford, W.E., F.F. Whitaker, P.L. Smart, G.D. Jones, *Numerical Analysis of Seawater Circulation in Carbonate Platforms: I. Geothermal Convection*, American Journal of Science, Vol. 298, pp. 801-828, 1998.

1012. Hughes, J.D., H.L. Vacher, W.E. Sanford, *Three-Dimensional Flow in the Florida Platform: Theoretical Analysis of Kohout Convection at its Type Locality*, Geology, Vol. 35, pp. 663-666, 2007.

1013. Reese, R.S., K.J. Cunningham, *Hydrogeologic Framework and Salinity Distribution of the Floridan Aquifer System of Broward County, Florida*, USGS Scientific Investigations Report 2014–5029, 60 p., 2014.

1014. Cunningham, K.J., *Integrating Seismic-Reflection and Sequence Stratigraphic Methods to Characterize the Hydrogeology of the Floridan Aquifer System in Southeastern Florida*, United States Geological Survey Open-File Report 2013–1181, 8 p., August 2013.

1015. Cunningham, K.J., *Integration of Seismic-Reflection and Well Data to Assess the Potential Impact of Stratigraphic and Structural Features on Sustainable Water Supply from the Floridan Aquifer System, Broward County, Florida*, United States Geological Survey Open-File Report 2014-1136, August 2014.

1016. Technos, Inc., *Subsurface Investigation of Possible Karst Conditions at Jewfish Creek Bridge Replacement, Monroe County, Florida*, Final Report Submitted to Steinman, Boynton, Gronquist, and Birdsall, June 10, 1996.

1017. Technos, Inc., *Geophysical Survey for Karst Characterization at Proposed Units 6 and 7 Turkey Point Nuclear Plant, Miami-Dade County, Florida*, Prepared For MACTEC Engineering and Consulting, Inc., Project No. 08-148, March 27, 2009

1018. Land, L.A., C.K. Paull, B. Hobson, *Genesis of a Submarine Sinkhole without Subaerial Exposure, Straits of Florida*, Geology, Vol. 23, pp. 949-951, 1995.

1019. Land, L.A., *Process and Manifestation of Fluid Exchange within Passive Continental Margins*, A Dissertation Submitted to the Faculty of the University of North Carolina at Chapel Hill in Partial Fulfillment of the Requirements for the degree of Doctor of Philosophy in the Department of Geological Sciences, UMI Number 9954666, 197 p., 1999.

1020. ENTRIX, Inc., *Draft Environmental Impact Statement for the Calypso LNG Deep Water Port License Application*, United States Coast Guard (USCG) Ports Standards Division Docket No. USCG-2006-26009, November 2, 2007.

1021. Florida Geological Survey, Florida Geological Survey Subsidence Incident Reports, Downloaded from http://www.dep.state.fl.us/geology/gisdatamaps/, Accessed April 2015.

The following figures will be provided in a future revision of the COLA:

Figure 2.5.1-390 Surface and Subsurface Karst Features in Southeastern Florida

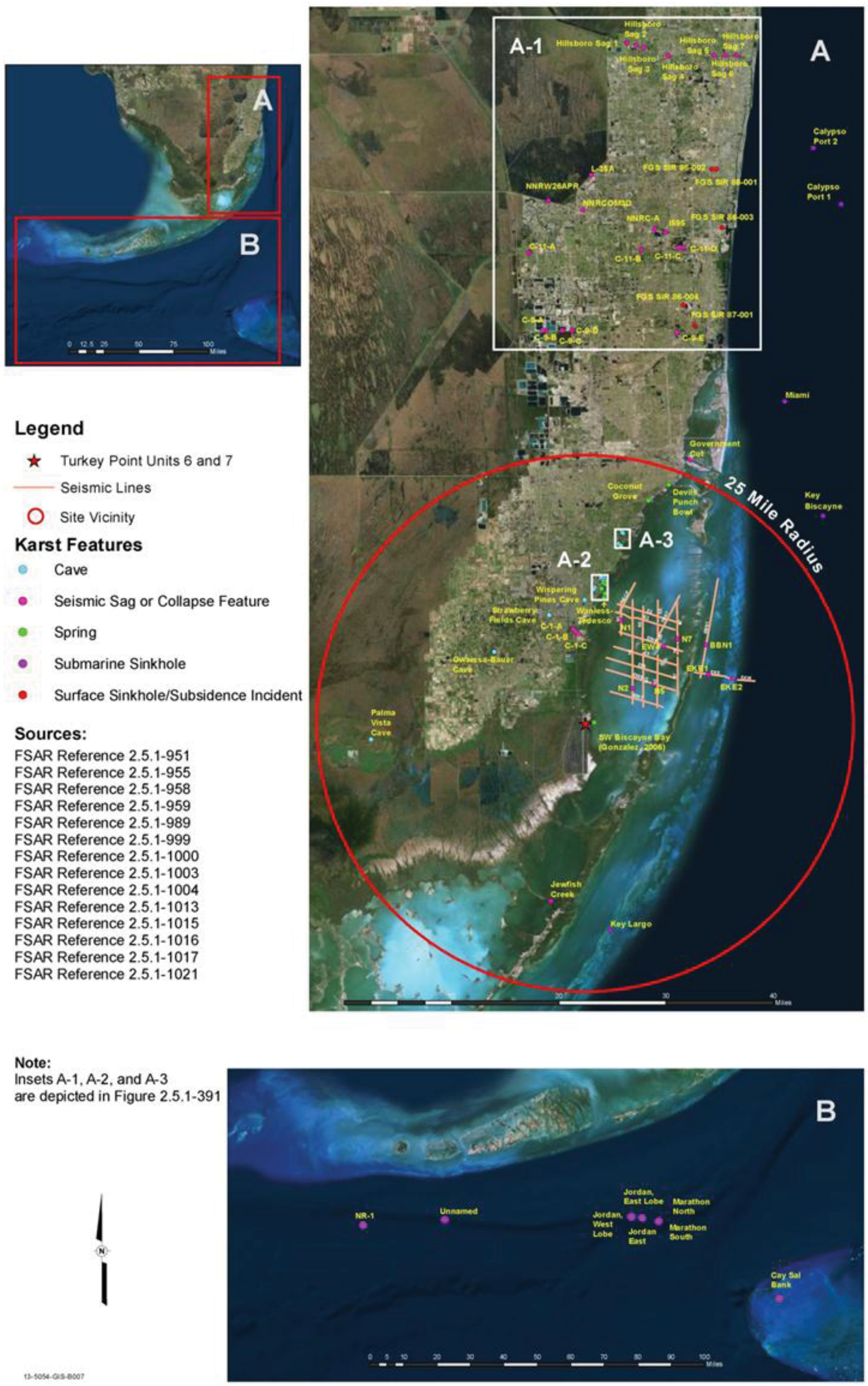


Figure 2.5.1-391 Karst Features Near the Turkey Point Units 6 & 7 Site

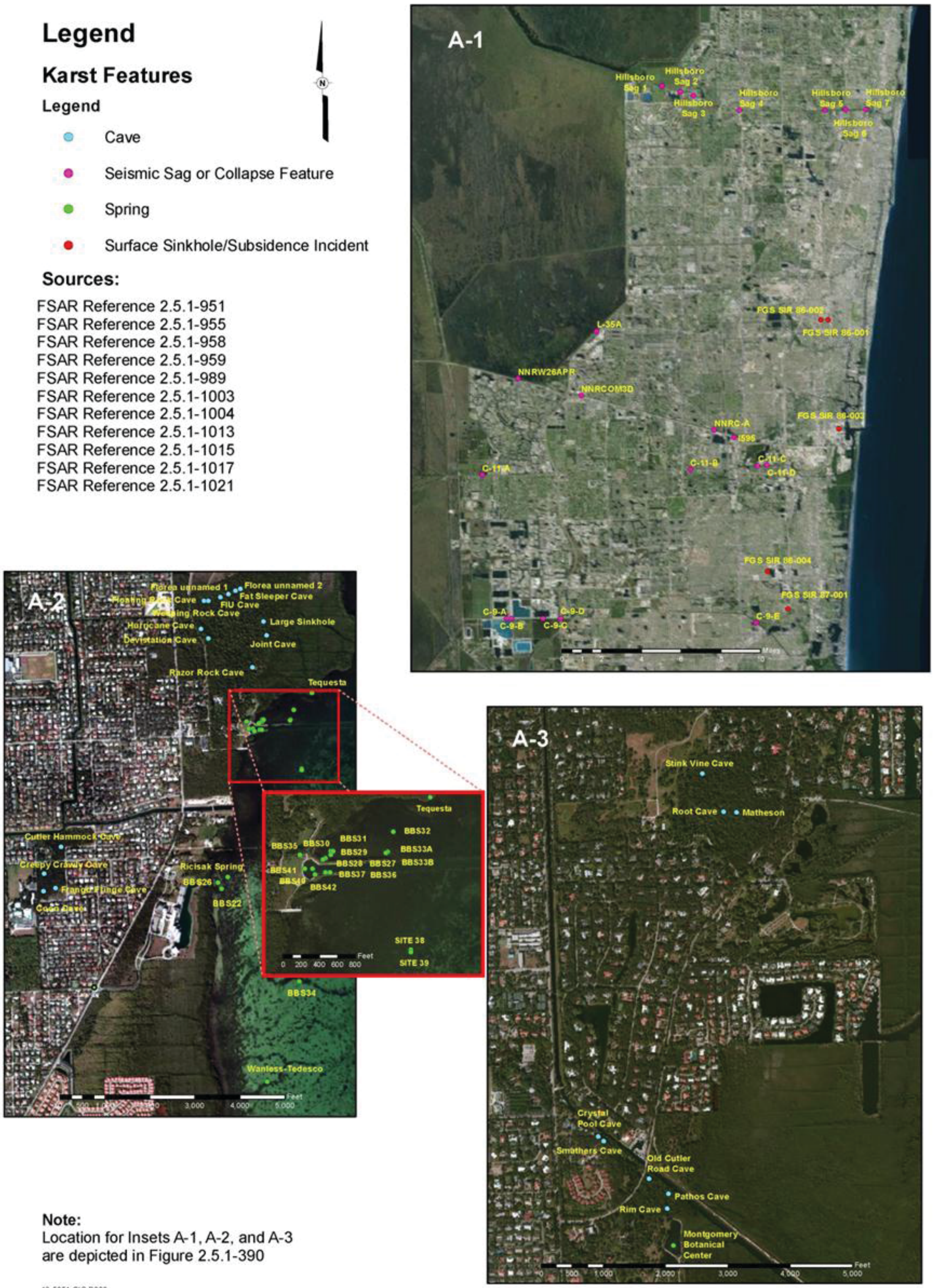
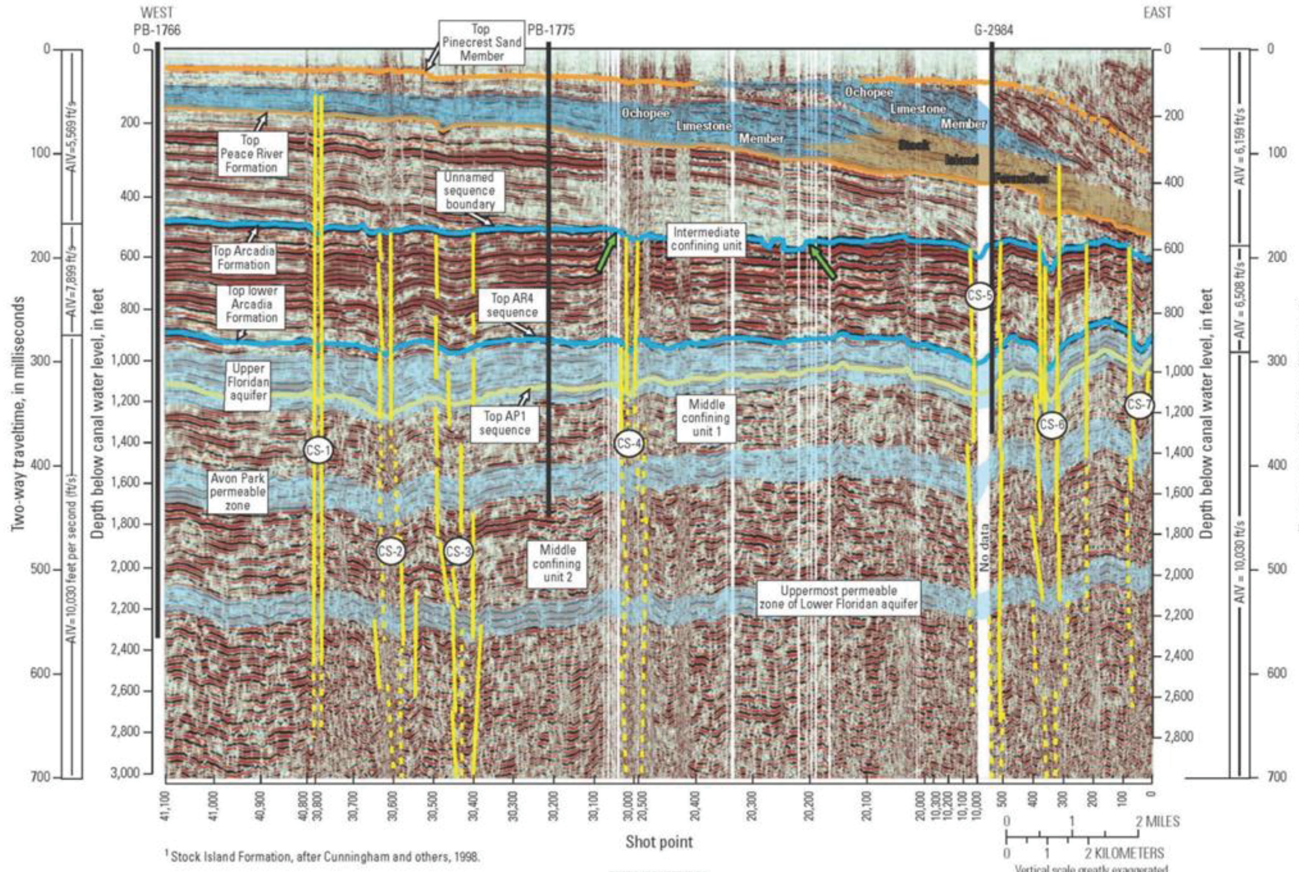


Figure 2.5.1-392 Seismic Sag Features in Hillsboro Canal, Broward and Palm Beach Counties



[1] Stock Island Formation, after Cunningham and others, 1998.

EXPLANATION

AIV **Average vertical-interval velocities shown on right and left sides**

(CS-1) **Seismic-sag structure and numeration**

Truncation of reflections—At the upper surface of the Arcadia Formation

Semi-vertical faults—Common within the limits of the structural sags. Dashed where most uncertain

Source: FSAR Reference 2.5.1-1013

13-5054-GIS-A012

FSAR Subsection Appendix 2.5AA will be revised in a future COLA revision as follows:

The 8th paragraph in the Executive Summary will be revised in a future COLA revision as follows:

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

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

The 5th paragraph of Section 2.2 will be revised in a future COLA revision as follows:

The larger average subaerial patch size relative to the average submarine patch size is consistent with their inferred origin (Subsection 2.5.3.2). The patches on the floor of Biscayne Bay likely formed during the Wisconsinan glacial advance, when sea level was approximately 100 meters (328ft) lower than the modern ocean. At that time, the floor of the bay and the area of the Turkey Point Units 6 &7 site both were subject to subaerial weathering and surficial dissolution. At the beginning of the Holocene, sea level rose, flooded the area that is now Biscayne Bay, and prevented further subaerial weathering and surficial dissolution in the bay. However, because it is at a higher elevation, the area of the site has remained subaerial since the Wisconsinan and has been subject to subaerial weathering and surficial dissolution for several thousand years longer than the floor of the bay. **Some of the vegetated patches on the floor of Biscayne Bay have been identified as the locations of historic and current submarine springs within the Biscayne Aquifer (Reference 2.5.1-1000). While most springs have been documented about 20 km or more north of the site, one has been documented just off shore of the site (Figure 2.5.1-291).**

The 7th paragraph of Section 2.2 will be revised in a future COLA revision as follows:

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

The 10th paragraph of Section 2.2 will be revised in a future COLA revision as follows:

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

The 11th paragraph of Section 2.2 will be revised in a future COLA revision as follows:

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

The 15th paragraph of Section 2.2 will be revised in a future COLA revision as follows:

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

The following paragraph will be added between paragraphs 4 and 5 of Section 2.3 in a future COLA revision as follows:

The Jewfish Creek paleosinkholes are subsurface features known from multiple independent sets of microgravity, seismic reflection, borehole, photo analysis and historical data that indicate anomalous subsurface conditions located between Lake Surprise and Jewfish Creek on Key Largo (Figure 2.5.1-390) (Reference 2.5.1-1016). Because seismic reflection surveys and borehole data indicate that dipping reflectors do not reach the surface of the overlying shallow rock and that it is not overdeepened, it is concluded the gravity anomaly is not related to shallow geologic conditions but something deep-seated (Reference 2.5.1-1016). Due to the fact that these features are rooted at great depth (213 m [700 ft]) and lack of surface expression, the Jewfish creek paleosinkholes probably have no similarlity in origin to the semicircular vegetated patches on the seafloor of Biscayne Bay. The Jewfish Creek karst features are more likely similar

in origin to the seismic-sag structures described by Cunningham and Walker (Reference 2.5.1-958) below Biscayne Bay, as well as those onshore in Broward and Miami-Dade Counties (References 2.5.1-999, 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015).

Section 4.1.2.1 will be revised in a future COLA revision as follows:

Freshwater Springs Near the Shore of Biscayne Bay

As further discussed in Subsection 2.5.1.1.1.1.1.1, fresh groundwater had formerly discharged along the shoreline east of the Atlantic Coastal Ridge and offshore as submarine freshwater springs in Biscayne Bay before lowering of surface water and groundwater levels in southeast Florida related to construction of drainage canals and withdrawals of groundwater to support urban development. Saline **to brackish** shoreline springs still exist in the bay **(Reference 2.5.1-1000)**. Their flow paths were likely formed originally by freshwater dissolution **(Figure 2.5.1-391) (Reference 2.5.1-1000)**. ~~However, their salinity levels of 8 to 31 g/L (8 to 32 parts per thousand) indicate that the springs no longer discharge freshwater (Reference 2.5.1-954).~~

Aerial imagery for the shoreline near Turkey Point Units 6 & 7 from 1938 clearly captures an offshore spring and groundwater seepage only 1,500 m (4,921ft) from the approximate site center-point (Figure 2.5.1-391). Gonzalez (Reference 2.5.1-1000) relocated the seepage/discharge point in 2004, but did not observe flow. Generally though, the approximately relocated spring site was characterized by sediment-filled, seagrass-covered karst holes.

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

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

Cave Development Along the Atlantic Coastal Ridge

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

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

FSAR Subsection 4.1.2.2 will be revised in a future COLA revision as follows:

~~4.1.2.2 Deep Pore Water Upwelling~~**Hypogene Dissolution**

~~Deep pore water upwelling is the flow of fresh groundwater through deep confined permeable sediments and rocks on the offshore continental shelf, driven by buoyancy as well as hydraulic pressure and thermal gradients. Evidence of current or former deep pore water upwelling is provided by the following.~~**Klimchouk (References 2.5.1-1005 and 2.5.1-1006) has generally described hypogene speleogenesis as dissolution-enlarged permeability (flow) structure development via ascending waters, driven by regional and/or more localized hydraulic potentials (i.e., hydrostatic pressures) or other convective circulation mechanisms. Given the vertical heterogeneity**

inherent in most sedimentary sequences, this upward groundwater flow implies some hydrological confinement (artesian conditions) rather than surface recharge. In southeastern Florida, confinement is largely provided by the Peace River and middle and upper (non-carbonate) Arcadia formations. Potential for ascending flow (and, by inference, hypogene speleogenesis) thus exists in the lowermost Arcadia Formation and the underlying Suwannee and Ocala limestones, and the Avon Park, Oldsmar, and upper Cedar Keys formations (i.e., the Floridan aquifer system).

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

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

Meyer (Reference 2.5.1-1009) noted that groundwater ages and radiocarbon (C-14) and uranium isotope concentration data within the Floridan aquifer substantiate Kohout convection, and suggested that inland flows associated with the circulation pattern were as high as 52 m (172ft) per year in the early Holocene, at least in the so-named boulder zone in the Oldsmar Formation. Meyer (Reference 2.5.1-1009) estimated modern Kohout circulation inland flows to be only about 1.5 m (5ft) per year. It is thus assumed that Kohout circulation (and, by inference, hypogene dissolution) has slowed over the Holocene, as sea levels stabilized. Morrissey et al. (Reference 2.5.1-1010) argued that this decreased inland flow was associated with increased coastal groundwater levels (i.e., hydraulic head) from long-term Holocene sea level rise, and subsequent reduced hydraulic gradients (and thereby flow velocities) across the Florida platform.

Very few studies from southeastern Florida explicitly address (or invoke) hypogene dissolution processes as a cave or cavity/void forming mechanism. Most notably, Cunningham and Walker (Reference 2.5.1-958) proposed two hypogene mechanisms to possibly explain structural sags in Biscayne Bay and the Atlantic Ocean: (1) upward groundwater flow via Kohout convection and

subsequent carbonate dissolution by mixed fresh and saline waters, and (2) dissolution associated with upward ascending hydrogen-sulfide-rich groundwater, sourced from calcium sulfates in deeper Eocene (or Paleocene) age rocks.

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

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

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

Submarine Paleokarst ~~Sinkholes~~Sag Structures Beneath Biscayne Bay

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

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

The following paragraph will be added after the subheading “section” titled Submarine Paleokarst Sinkholes Beneath Biscayne Bay and before the “section” titled Crescent Beach Spring and Red Snapper Sink as a new “section” in a future COLA revision as follows:

Onshore Sag Structures in Broward and Miami-Dade Counties

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

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

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

Importantly, in the Turkey Point Units 6 & 7 site vicinity, deformation associated with the aforementioned structural sags does not seem to extend beyond (above) the Oligocene to Miocene age Arcadia Formation. Nevertheless, sag features with deformation extending upward into the Peace River and Tamiami formations have

been imaged below the North New River and Hillsboro canals, located approximately 77 km and 101 km (48 mi and 63 mi) from the site, in Broward and Palm Beach counties (References 2.5.1-1013, 2.5.1-1014 and 2.5.1-1015). It is possible then that cave formation and/or collapse occurred as late as the Pliocene.

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

Jewfish Creek Paleo-Karst Feature

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

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

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

Technos (Reference 2.5.1-1016) interpreted the largest subsidence structure at Jewfish Creek/Lake Surprise as a cavity collapse in a soluble limestone layer, the

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

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

ASSOCIATED ENCLOSURES:

None