

Proposed Turkey Point Units 6 and 7

Docket Nos. 52-040 and 52-041

FPL Response to NRC RAI No. 02.05.01-17 (eRAI 6024)

L-2013-236 Attachment 15 Page 51 of 112

The following new figures will be included in FSAR Subsection 2.5.1 in a future COLA revision:

Figure 2.5.1-351 The two zones of secondary porosity on B-604 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (3 pages)

Figure 2.5.1-352 The two zones of secondary porosity on B-608 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (5 pages)

Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (5 pages)

Figure 2.5.1-385 Relation between Touching-Vug Porosity and Conduit Porosity for the Fort Thompson Formation and Miami Limestone of the Biscayne Aquifer in Cunningham et al. Study Area

Figure 2.5.1-386 Cross-Section A-A' (Vertical Exaggeration = 4:1)

Figure 2.5.1-387 Cross-Section B-B' (Vertical Exaggeration = 4:1)

Figure 2.5.1-388 Cross-Section C-C' (Vertical Exaggeration = 4:1)

Figure 2.5.1-389 Cross-Section D-D' (Vertical Exaggeration = 4:1)

Figure 2.5.1-351 The two zones of secondary porosity on B-604 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (1 of 3)

Log ID: **B-604 (DH)**
Total Depth: **165 ft**
Northing: **396,916 (NAD83/90)**
Easting: **876,592 (NAD83/90)**
Hole Diameter: **5" from 0.0 to 29.0 ft; 4" from 29.0 to 165.0 ft.**
Elevation (Ground Surface): **-1.5 ft**
Drilling Date: **Started 3/19/08 Completed 3/23/08**
Drilled By: **P. Pitts / R. Landeros**
Lithology Logged By: **S. Woodham**
Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 20.05 to 105 feet bgs.
Caliper (lower section) from 39.05 to 157 feet bgs.
Natural Gamma (lower and upper sections) from 20.05 to 157 feet bgs.
Receiver to receiver Vs and Vp from 26.3 to 150.9 feet bgs.
Acoustic Televiewer from 22.78 to 120.65 feet bgs.

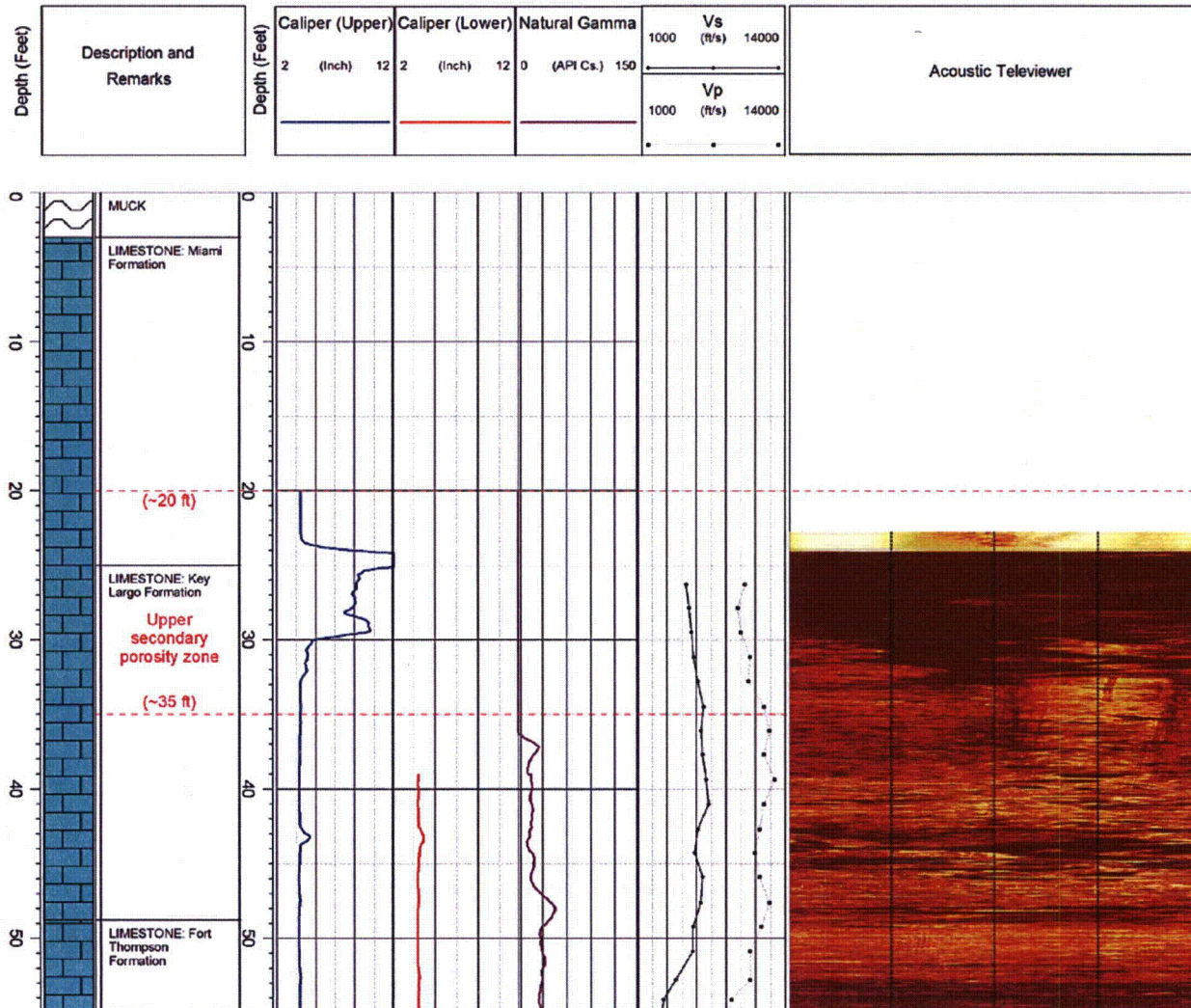


Figure 2.5.1-351 The two zones of secondary porosity on B-604 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (2 of 3)

Log ID: **B-604 (DH)**
Total Depth: **165 ft**
Northing: **396,916 (NAD83/90)**
Easting: **876,592 (NAD83/90)**
Hole Diameter: **5" from 0.0 to 29.0 ft; 4" from 29.0 to 165.0 ft.**
Elevation (Ground Surface): **-1.5 ft**
Drilling Date: **Started 3/19/08 Completed 3/23/08**
Drilled By: **P. Pitts / R. Landeros**
Lithology Logged By: **S. Woodham**
Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 20.05 to 105 feet bgs.
Caliper (lower section) from 39.05 to 157 feet bgs.
Natural Gamma (lower and upper sections) from 20.05 to 157 feet bgs.
Receiver to receiver Vs and Vp from 26.3 to 150.9 feet bgs.
Acoustic Televiewer from 22.78 to 120.65 feet bgs.

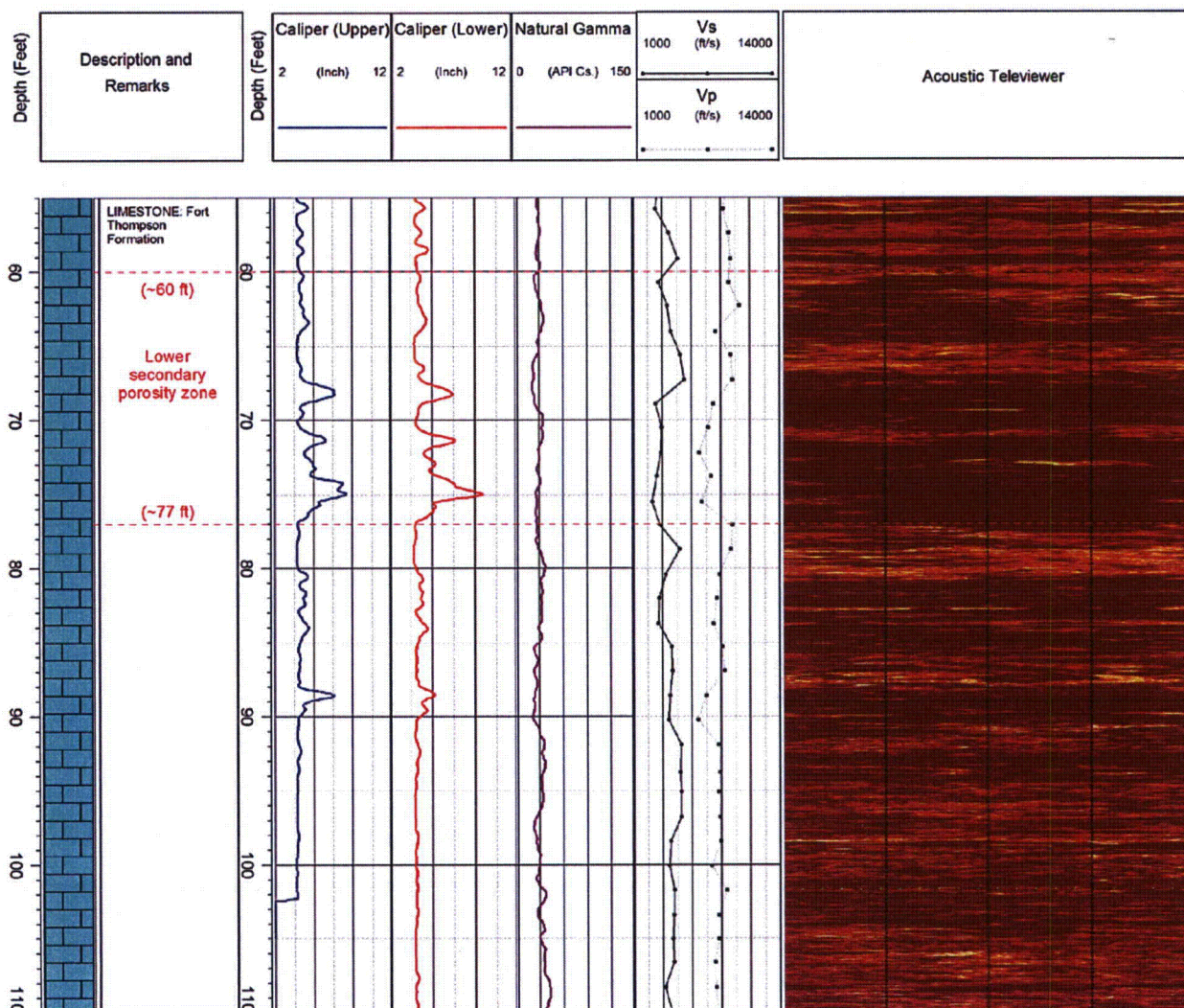


Figure 2.5.1-351 The two zones of secondary porosity on B-604 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (3 of 3)

Log ID: **B-604 (DH)**

Total Depth: **165 ft**

Northing: **396,916 (NAD83/90)**

Easting: **876,592 (NAD83/90)**

Hole Diameter: **5" from 0.0 to 29.0 ft; 4" from 29.0 to 165.0 ft.**

Elevation (Ground Surface): **-1.5 ft**

Drilling Date: **Started 3/19/08 Completed 3/23/08**

Drilled By: **P. Pitts / R. Landeros**

Lithology Logged By: **S. Woodham**

Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

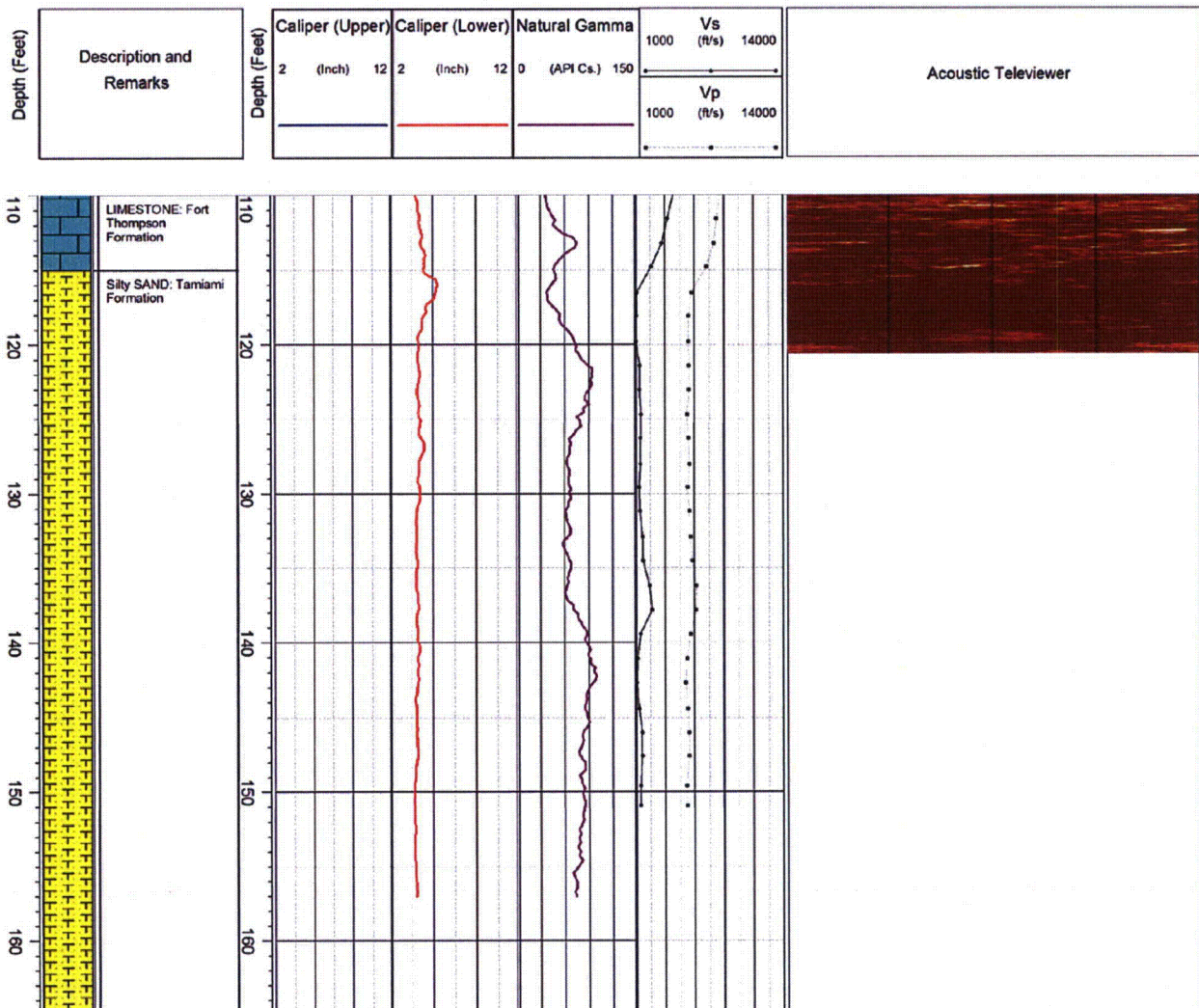
Caliper (upper section) from 20.05 to 105 feet bgs.

Caliper (lower section) from 39.05 to 157 feet bgs.

Natural Gamma (lower and upper sections) from 20.05 to 157 feet bgs.

Receiver to receiver Vs and Vp from 26.3 to 150.9 feet bgs.

Acoustic Televiewer from 22.78 to 120.65 feet bgs.



Source: Subsection 2.5.1 Reference 708

Figure 2.5.1-352 The two zones of secondary porosity on B-608 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (1 of 5)

Log ID: **B-608 (DH)**

Total Depth: **265.4 ft**

Northing: **396,830 (NAD83/90)**

Easting: **876,736 (NAD83/90)**

Hole Diameter: **5" from 0.0 to 34.0 ft; 4" from 34.0 to 265.4 ft.**

Elevation (Ground Surface): **-1.5 ft**

Drilling Date: **Started 3/25/08 Completed 4/2/08**

Drilled By: **R. Landeros/N. Rodriguez (MACTEC)**

Lithology Logged By: **S. Woodman/B. Taylor (MACTEC)**

Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 12.05 to 115 feet bgs.

Caliper (lower section) from 107.05 to 255 feet bgs.

Natural Gamma (lower and upper sections) from 12.05 to 255 feet bgs

Receiver to receiver Vs and Vp from 23 to 249.3 feet bgs.

Acoustic televiewer from 20 to 120.2 feet bgs.

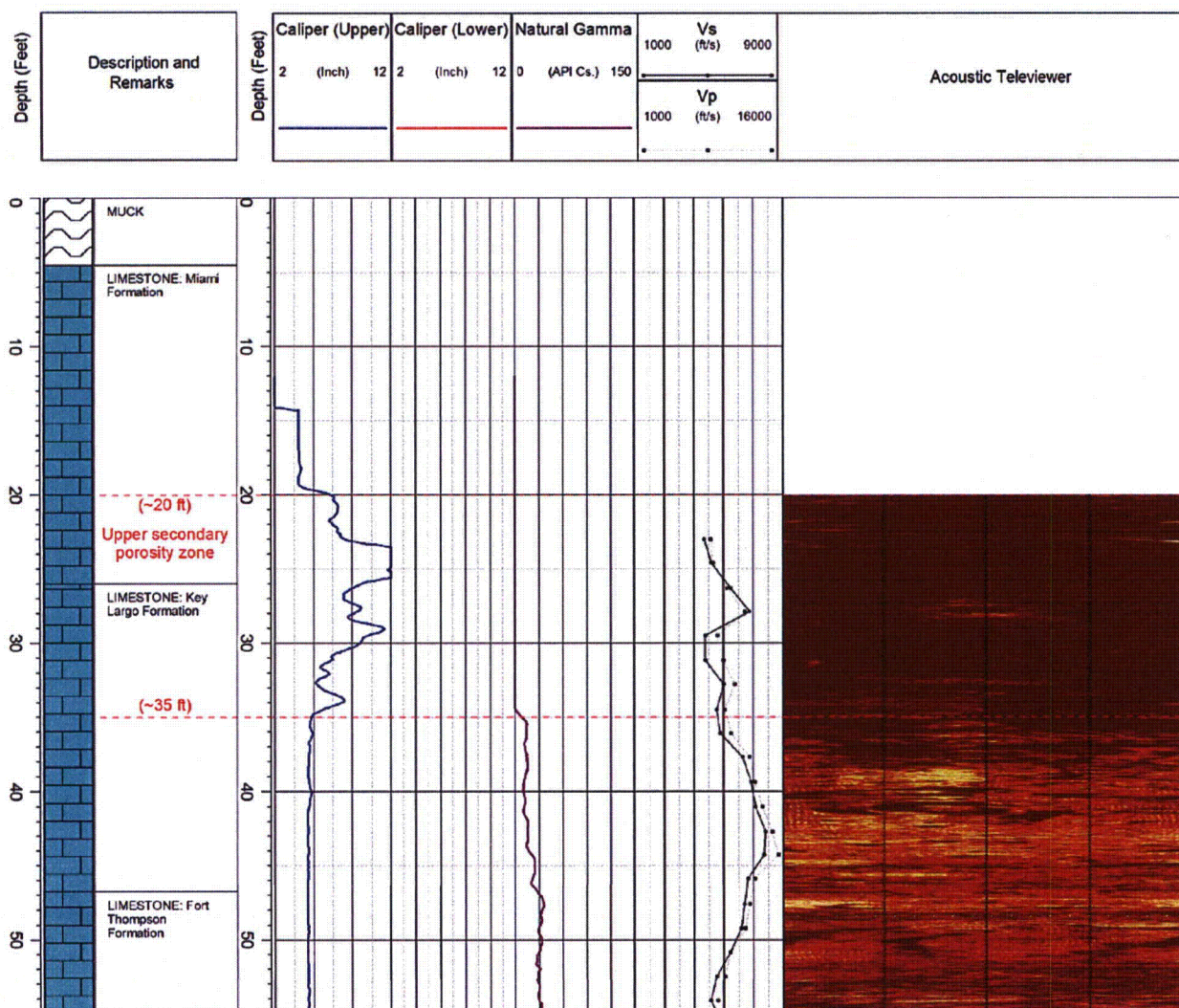


Figure 2.5.1-352 The two zones of secondary porosity on B-608 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (3 of 5)

Log ID: B-608 (DH)

Total Depth: 265.4 ft

Northing: 396,830 (NAD83/90)

Easting: 876,736 (NAD83/90)

Hole Diameter: 5" from 0.0 to 34.0 ft; 4" from 34.0 to 265.4 ft.

Elevation (Ground Surface): -1.5 ft

Drilling Date: Started 3/25/08 Completed 4/2/08

Drilled By: R. Landeros/N. Rodriguez (MACTEC)

Lithology Logged By: S. Woodman/B. Taylor (MACTEC)

Geophysical Log Operator: GEOVision Geophysical Services

Note:

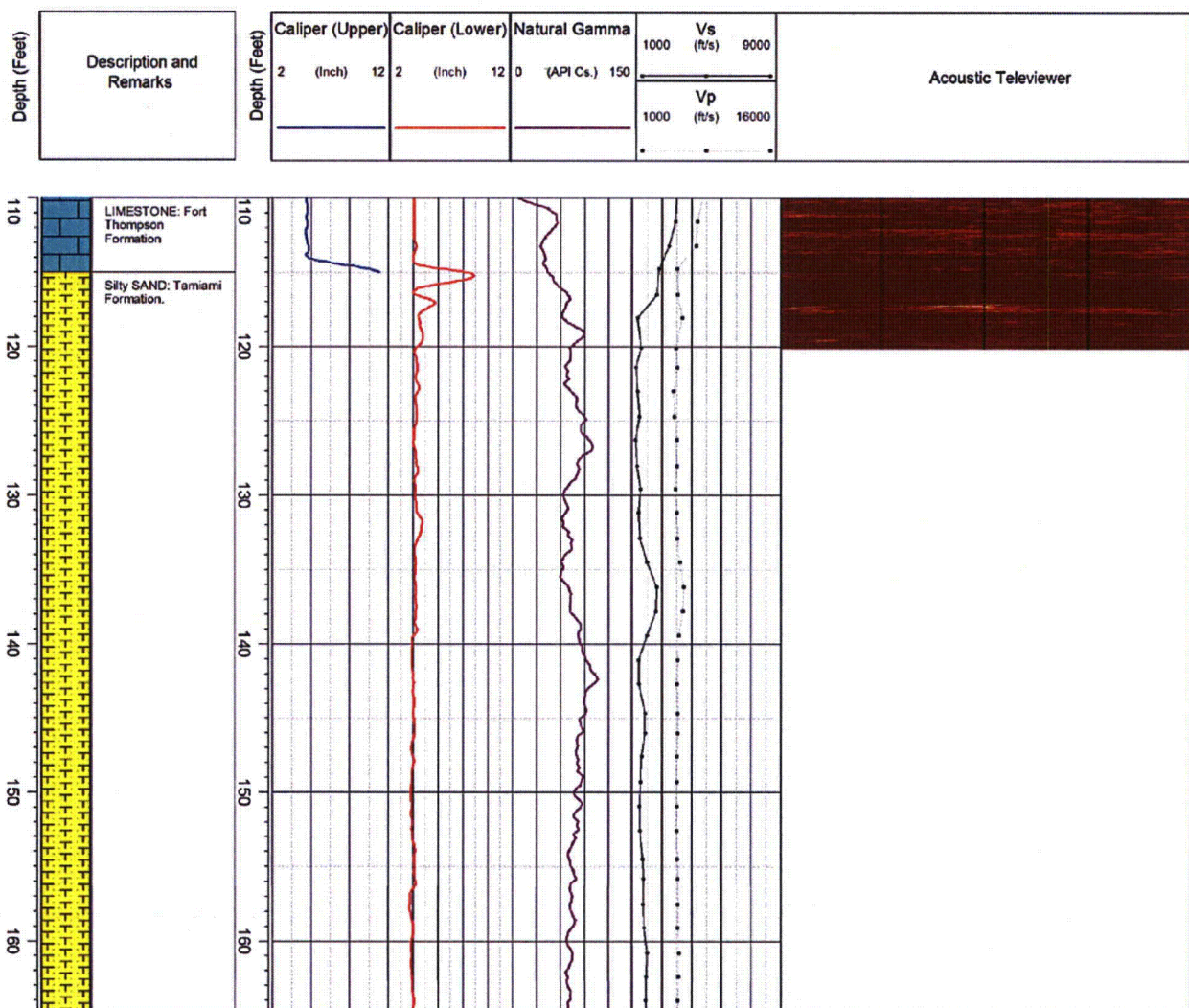
Caliper (upper section) from 12.05 to 115 feet bgs.

Caliper (lower section) from 107.05 to 255 feet bgs.

Natural Gamma (lower and upper sections) from 12.05 to 255 feet bgs

Receiver to receiver Vs and Vp from 23 to 249.3 feet bgs.

Acoustic televiewer from 20 to 120.2 feet bgs.



Proposed Turkey Point Units 6 and 7
Docket Nos. 52-040 and 52-041
FPL Response to NRC RAI No. 02.05.01-17 (eRAI 6024)
L-2013-236 Attachment 15 Page 58 of 112

Figure 2.5.1-352 The two zones of secondary porosity on B-608 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (4 of 5)

Log ID: B-608 (DH)

Total Depth: **265.4 ft**

Northings: 396,830 (NAD83/90)

Easting: 876,736 (NAD83/90)

Hole Diameter: 5" from 0.0 to 34.0 ft; 4" from 34.0 to 265.4 ft.

Elevation (Ground Surface): -1.5 ft

Drilling Date: Started 3/25/08 Completed 4/2/08

Drilled By: **R. Landeros/N. Rodriguez (MACTEC)**

Lithology Logged By: S. Woodman/B. Taylor (MACTEC)

Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 12.05 to 115 feet bgs.

Caliper (lower section) from 107.05 to 255 feet bgs.

Natural Gamma (lower and upper sections) from 12.05 to 255 feet bgs

Receiver to receiver Vs and Vp from 23 to 249.3 feet bgs.

Acoustic televiewer from 20 to 120.2 feet bgs.

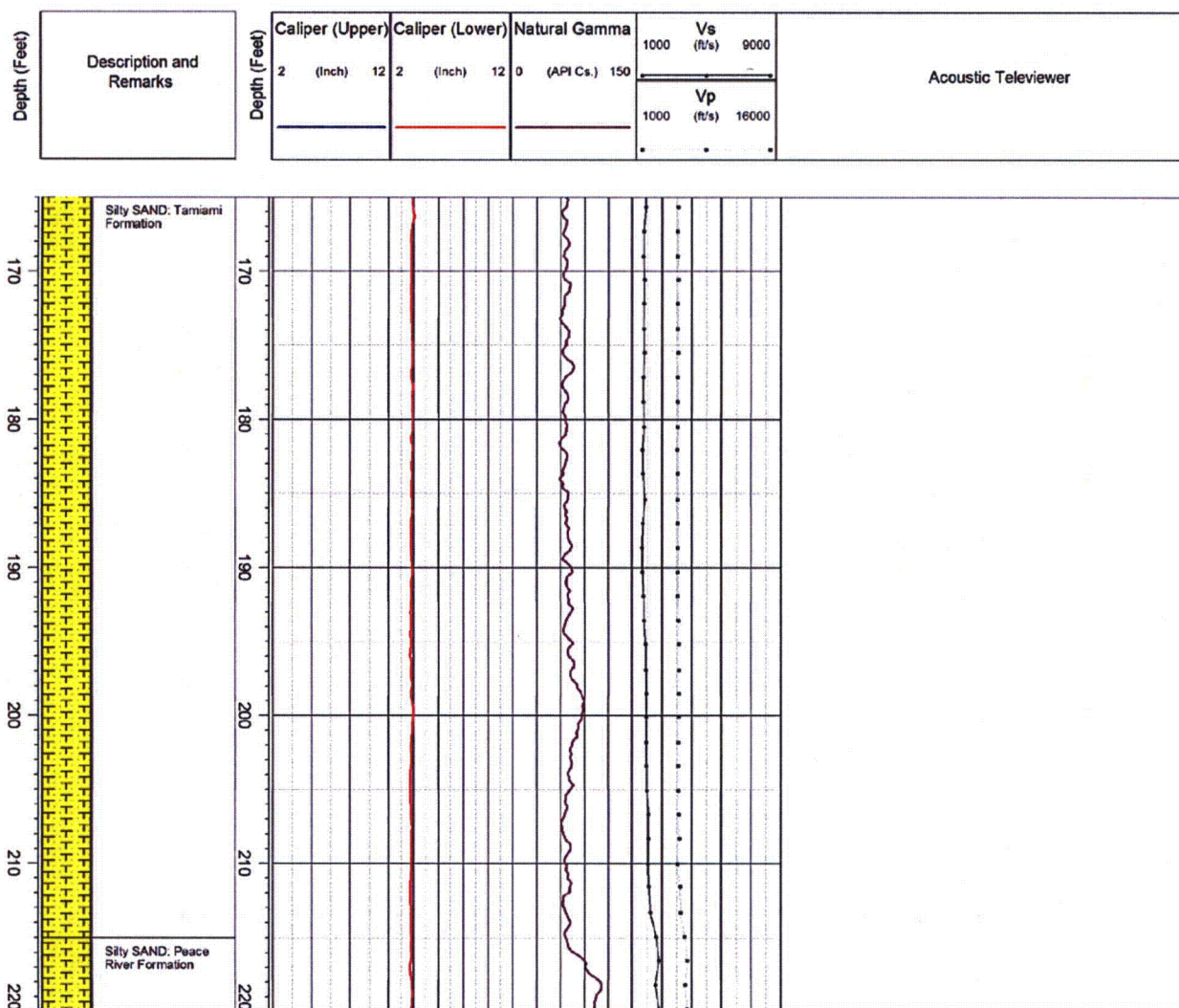


Figure 2.5.1-352 The two zones of secondary porosity on B-608 (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (5 of 5)

Log ID: B-608 (DH)

Total Depth: 265.4 ft

Northing: 396,830 (NAD83/90)

Easting: 876,736 (NAD83/90)

Hole Diameter: 5" from 0.0 to 34.0 ft; 4" from 34.0 to 265.4 ft.

Elevation (Ground Surface): -1.5 ft

Drilling Date: Started 3/25/08 Completed 4/2/08

Drilled By: R. Landeros/N. Rodriguez (MACTEC)

Lithology Logged By: S. Woodman/B. Taylor (MACTEC)

Geophysical Log Operator: GEOVision Geophysical Services

Note:

Caliper (upper section) from 12.05 to 115 feet bgs.

Caliper (lower section) from 107.05 to 255 feet bgs.

Natural Gamma (lower and upper sections) from 12.05 to 255 feet bgs

Receiver to receiver Vs and Vp from 23 to 249.3 feet bgs.

Acoustic televiewer from 20 to 120.2 feet bgs.

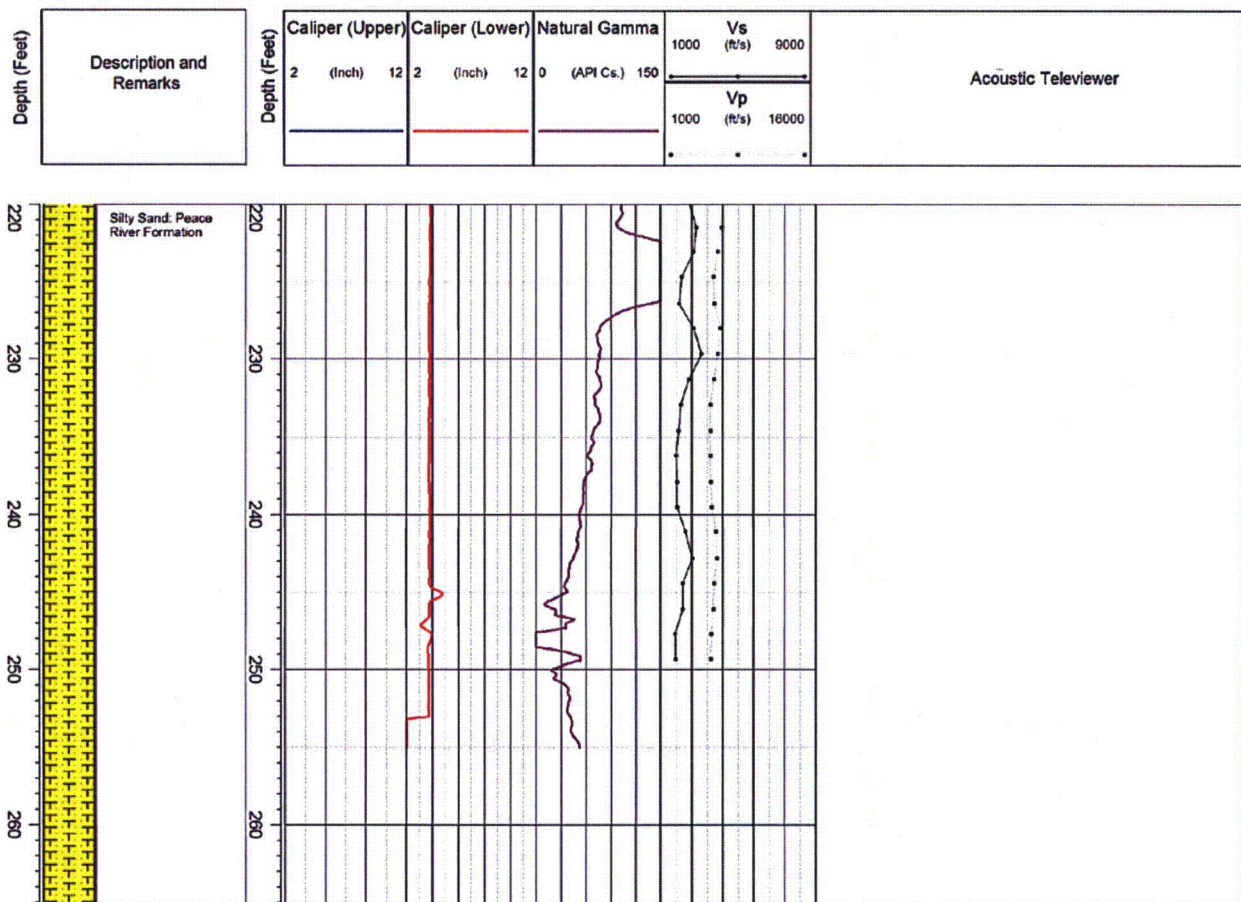


Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (1 of 5)

Log ID: **B-710G(DH)**

Total Depth: **273.5 ft**

Northing: **397,075 (NAD83/90)**

Easting: **875,792 (NAD83/90)**

Hole Diameter: **4" from 0.0 to 273.5 ft**

Elevation (Ground Surface): **-1.4 ft**

Drilling Date: **Started 3/10/08 Completed 3/13/08**

Drilled By: **R. Landeros / N. Rodriguez**

Lithology Logged By: **S. Woodham**

Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 10.4 to 130 feet bgs.

Caliper (lower section) from 90.4 to 264 feet bgs.

Natural Gamma (lower and upper sections) from 10.4 to 264 feet bgs.

Receiver to receiver Vs and Vp from 26.2 to 257.5 feet bgs.

Acoustic Televiewer from 19 to 120.4 feet bgs.

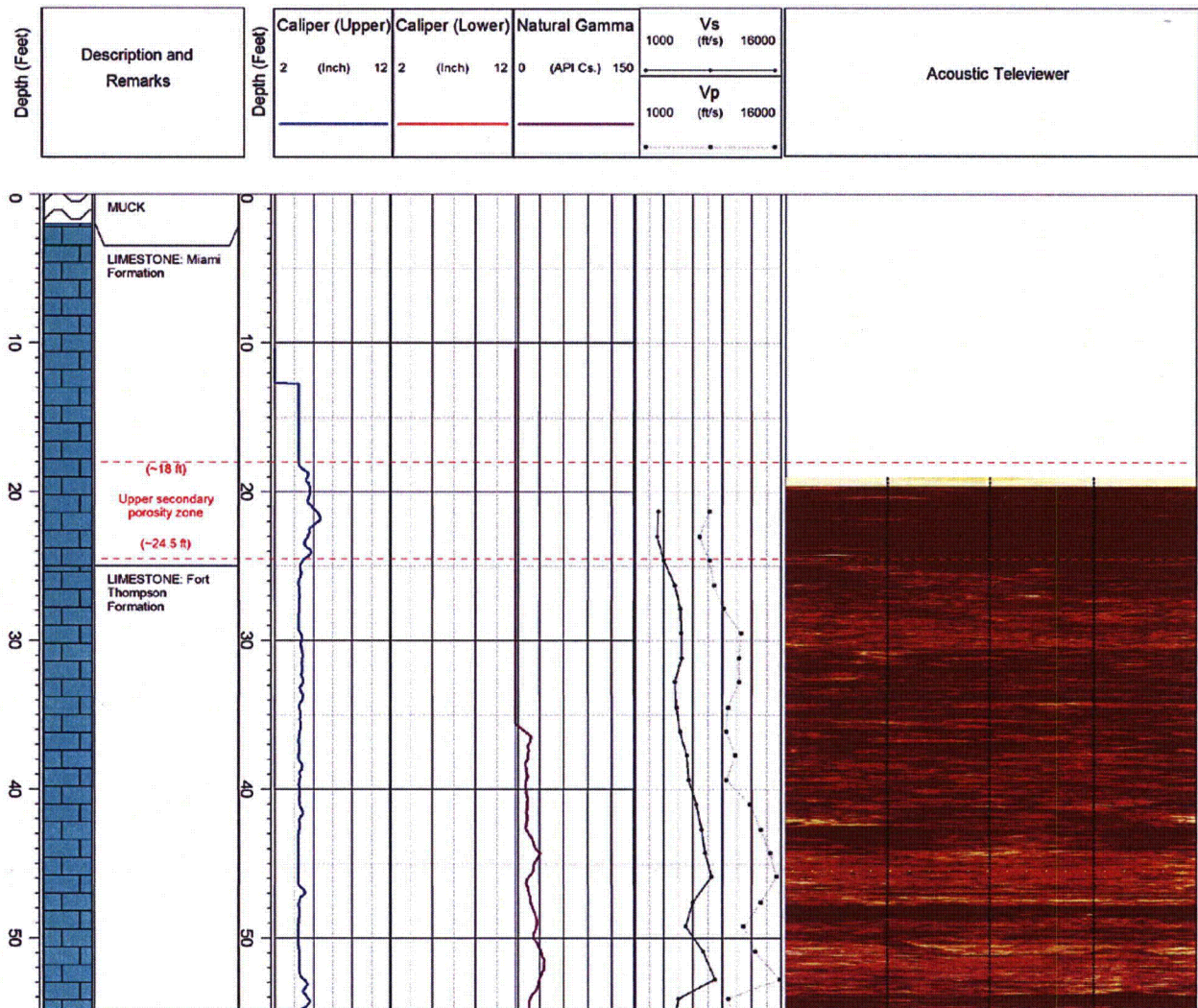


Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (2 of 5)

Log ID: **B-710G(DH)**
Total Depth: **273.5 ft**
Northing: **397,075 (NAD83/90)**
Easting: **875,792 (NAD83/90)**
Hole Diameter: **4" from 0.0 to 273.5 ft**
Elevation (Ground Surface): **-1.4 ft**
Drilling Date: **Started 3/10/08 Completed 3/13/08**
Drilled By: **R. Landeros / N. Rodriguez**
Lithology Logged By: **S. Woodham**
Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 10.4 to 130 feet bgs.
Caliper (lower section) from 90.4 to 264 feet bgs.
Natural Gamma (lower and upper sections) from 10.4 to 264 feet bgs.
Receiver to receiver Vs and Vp from 26.2 to 257.5 feet bgs.
Acoustic Televiewer from 19 to 120.4 feet bgs.

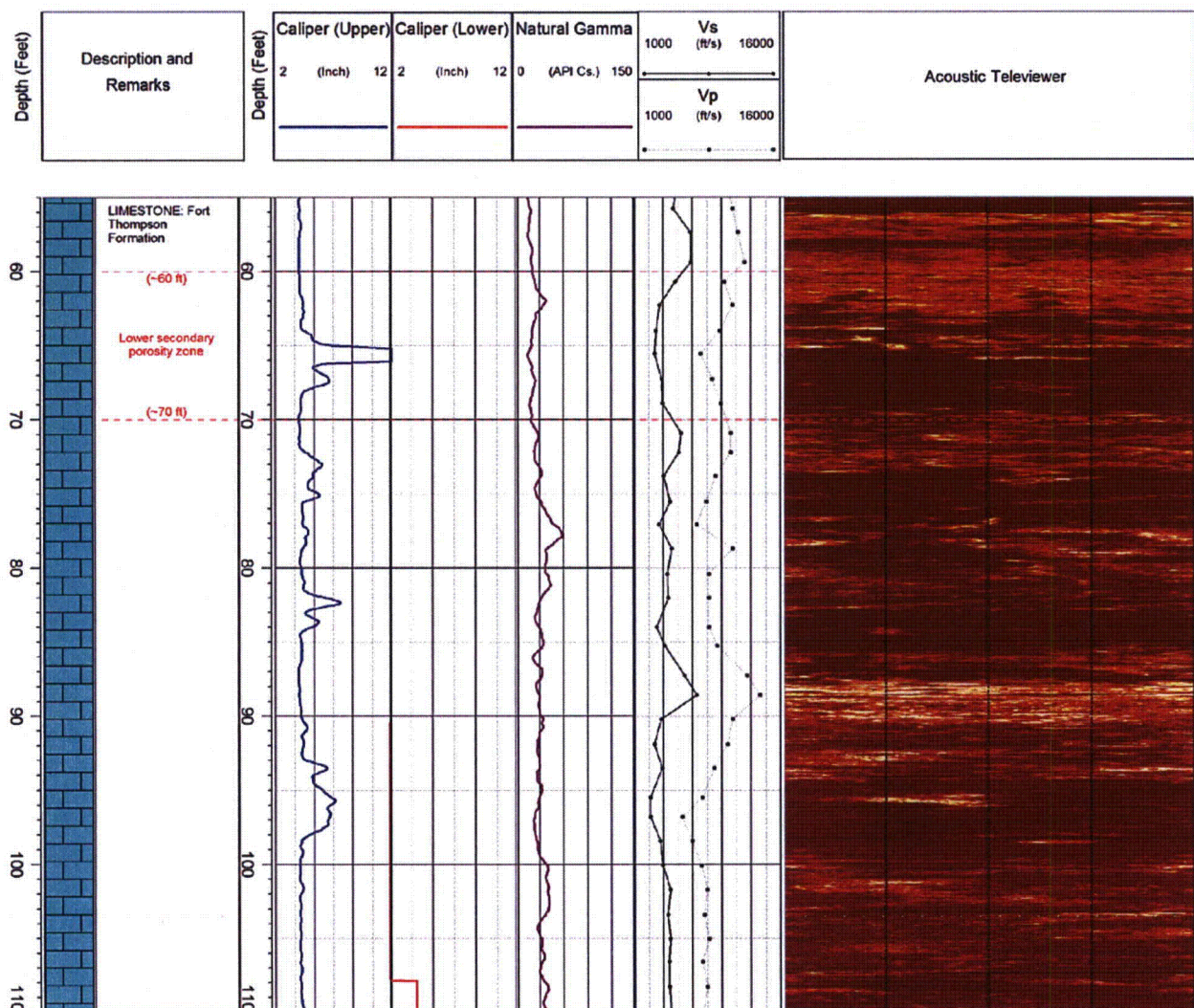


Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (3 of 5)

Log ID: **B-710G(DH)**
Total Depth: **273.5 ft**
Northing: **397,075 (NAD83/90)**
Easting: **875,792 (NAD83/90)**
Hole Diameter: **4" from 0.0 to 273.5 ft**
Elevation (Ground Surface): **-1.4 ft**
Drilling Date: **Started 3/10/08 Completed 3/13/08**
Drilled By: **R. Landeros / N. Rodriguez**
Lithology Logged By: **S. Woodham**
Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 10.4 to 130 feet bgs.
Caliper (lower section) from 90.4 to 264 feet bgs.
Natural Gamma (lower and upper sections) from 10.4 to 264 feet bgs.
Receiver to receiver Vs and Vp from 26.2 to 257.5 feet bgs.
Acoustic Televiewer from 19 to 120.4 feet bgs.

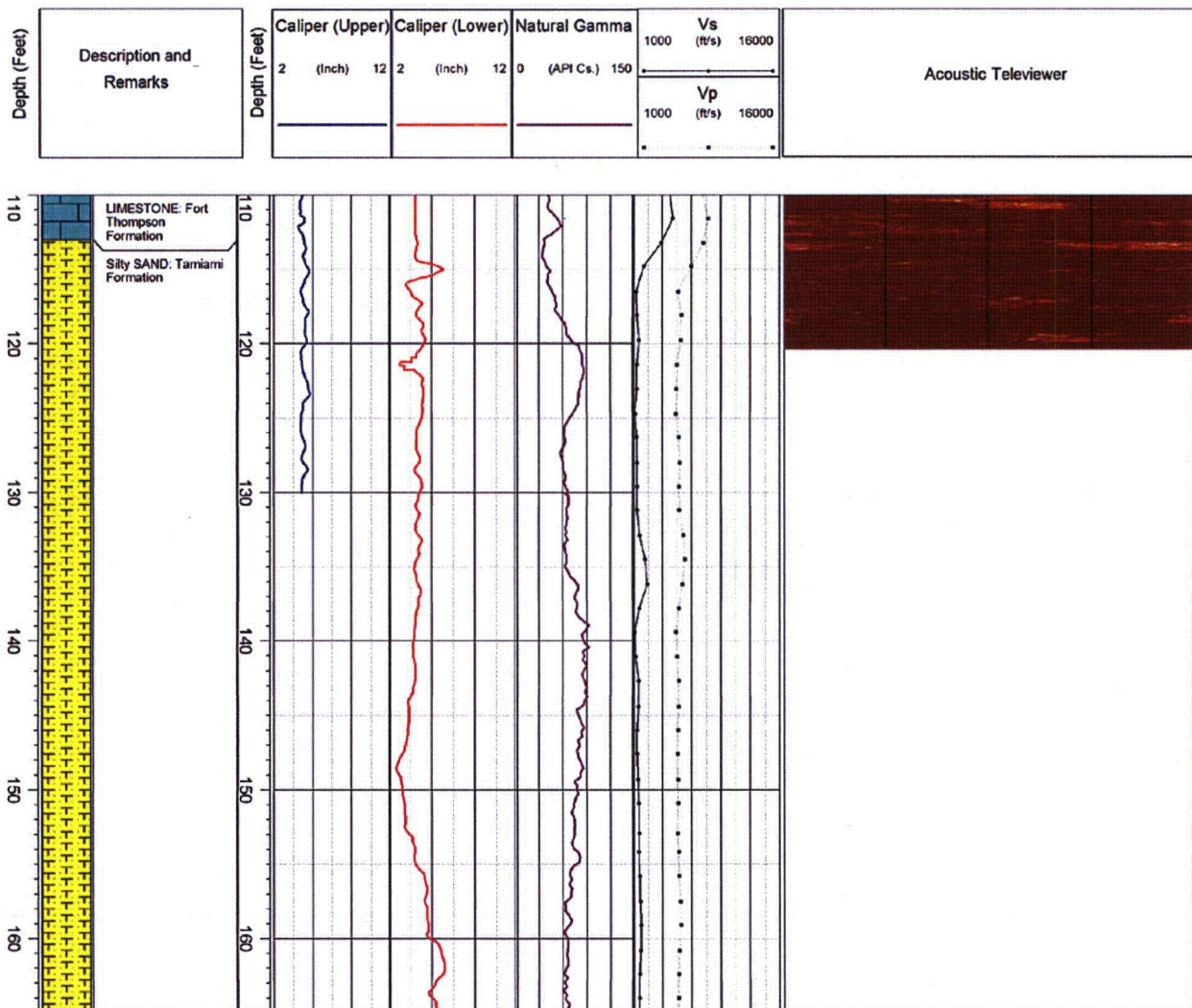


Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (4 of 5)

Log ID: **B-710G(DH)**

Total Depth: **273.5 ft**

Northing: **397,075 (NAD83/90)**

Easting: **875,792 (NAD83/90)**

Hole Diameter: **4" from 0.0 to 273.5 ft**

Elevation (Ground Surface): **-1.4 ft**

Drilling Date: **Started 3/10/08 Completed 3/13/08**

Drilled By: **R. Landeros / N. Rodriguez**

Lithology Logged By: **S. Woodham**

Geophysical Log Operator: **GEOVision Geophysical Services**

Note:

Caliper (upper section) from 10.4 to 130 feet bgs.

Caliper (lower section) from 90.4 to 264 feet bgs.

Natural Gamma (lower and upper sections) from 10.4 to 264 feet bgs.

Receiver to receiver Vs and Vp from 26.2 to 257.5 feet bgs.

Acoustic Televiewer from 19 to 120.4 feet bgs.

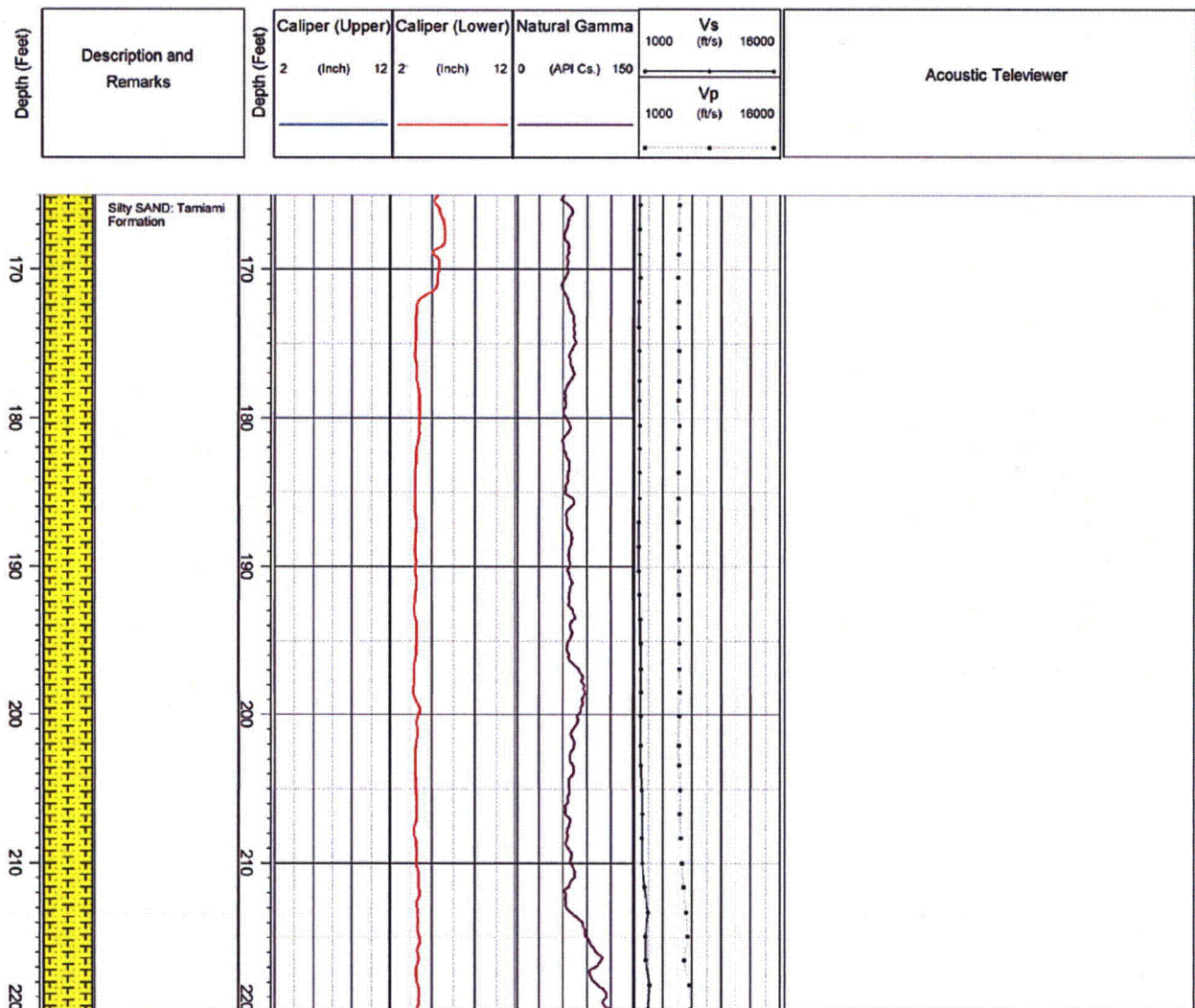


Figure 2.5.1-353 The two zones of secondary porosity on B-710 G (DH) showing the lithology, caliper, natural gamma, velocity (Vs and Vp) and acoustic televiewer logs (5 of 5)

Log ID: B-710G(DH)

Total Depth: 273.5 ft

Northing: 397,075 (NAD83/90)

Easting: 875,792 (NAD83/90)

Hole Diameter: 4" from 0.0 to 273.5 ft

Elevation (Ground Surface): -1.4 ft

Drilling Date: Started 3/10/08 Completed 3/13/08

Drilled By: R. Landeros / N. Rodriguez

Lithology Logged By: S. Woodham

Geophysical Log Operator: GEOVision Geophysical Services

Note:

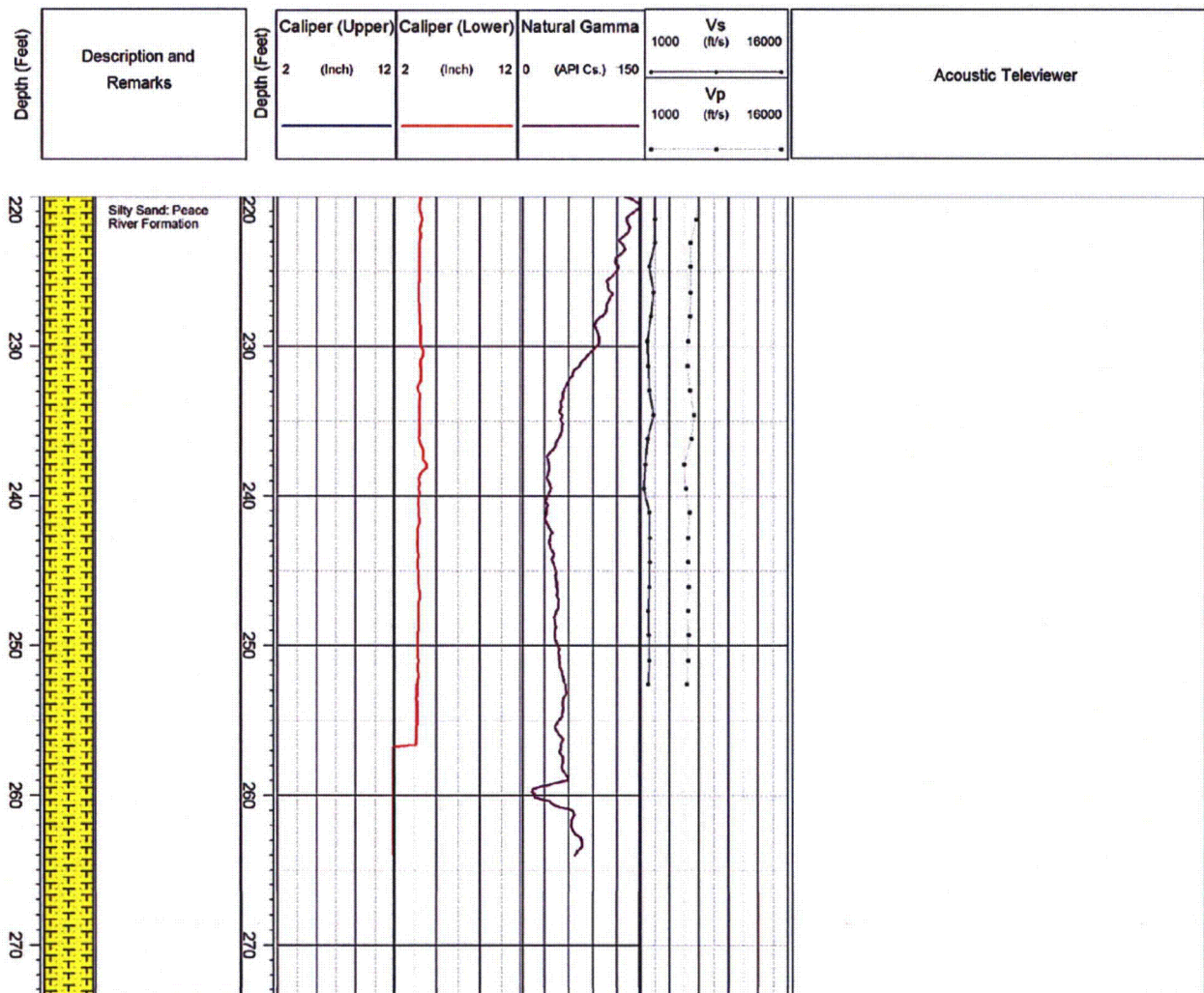
Caliper (upper section) from 10.4 to 130 feet bgs.

Caliper (lower section) from 90.4 to 264 feet bgs.

Natural Gamma (lower and upper sections) from 10.4 to 264 feet bgs.

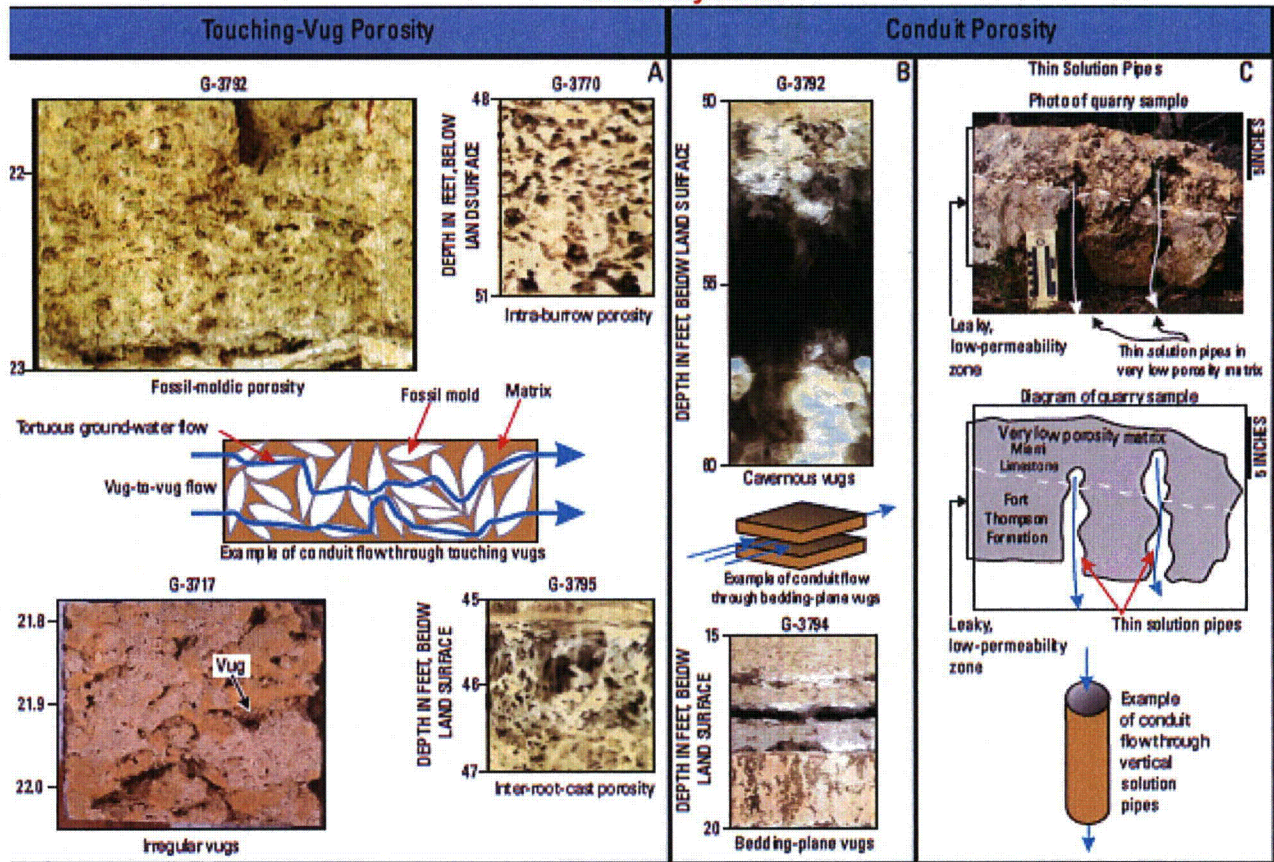
Receiver to receiver Vs and Vp from 26.2 to 257.5 feet bgs.

Acoustic Televiewer from 19 to 120.4 feet bgs.



Source: Subsection 2.5.1 Reference 708

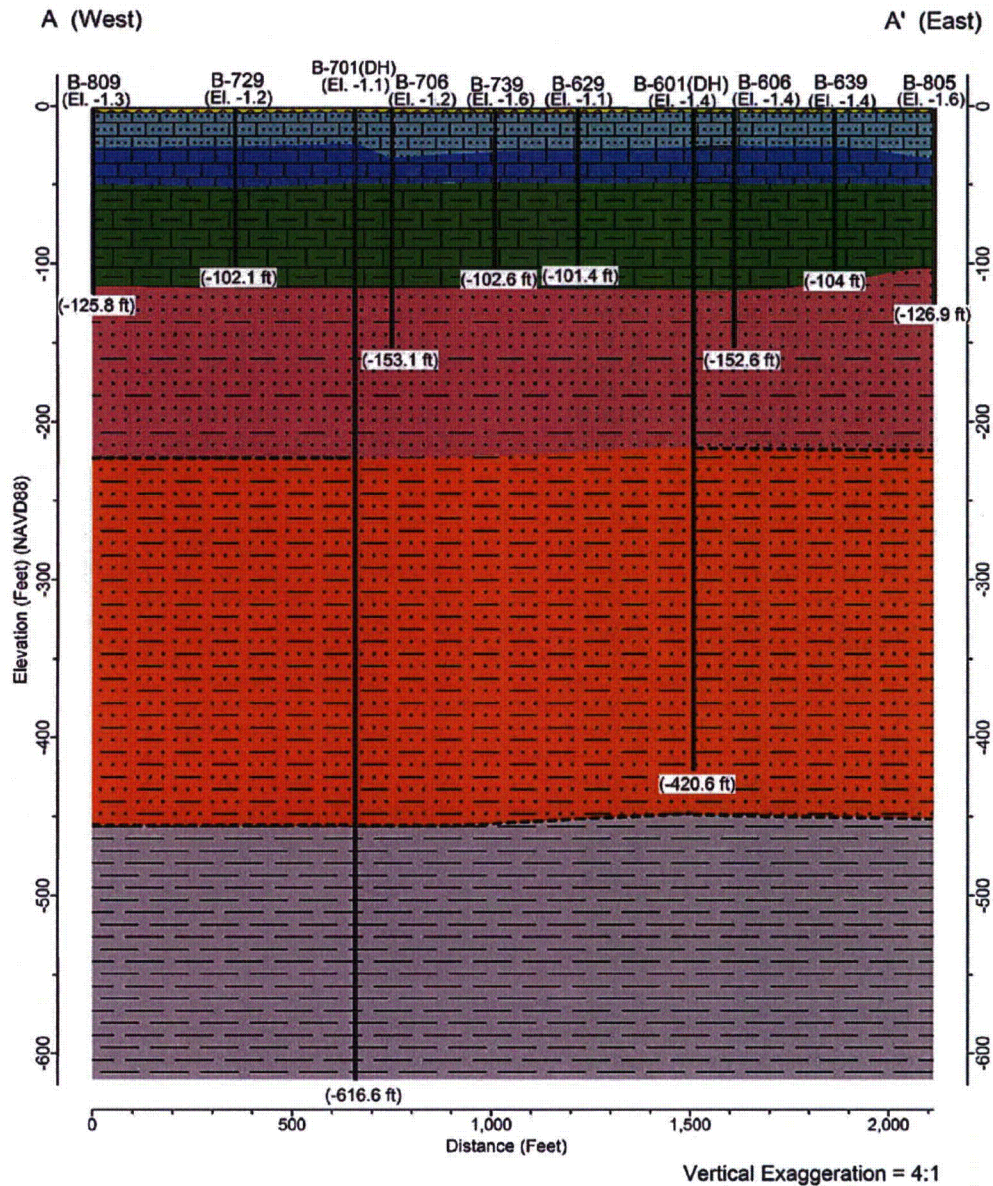
Figure 2.5.1-385 Relation between Touching-Vug Porosity and Conduit Porosity for the Fort Thompson Formation and Miami Limestone of the Biscayne Aquifer in Cunningham et al. Study Area



Source: modified from Subsection 2.5.1 Reference 404

Figure 2.5.1-386 Cross-Section A-A' (Vertical Exaggeration = 4:1)

This figure appears in Appendix 2.5AA as Figure 2.5AA-215



Stratigraphy	
	Muck/Peat
	Miami Limestone
	Key Largo Limestone
	Fort Thompson Fm.
	Tamiami Fm.
	Peace River Fm.
	Arcadia Fm.

Notes.

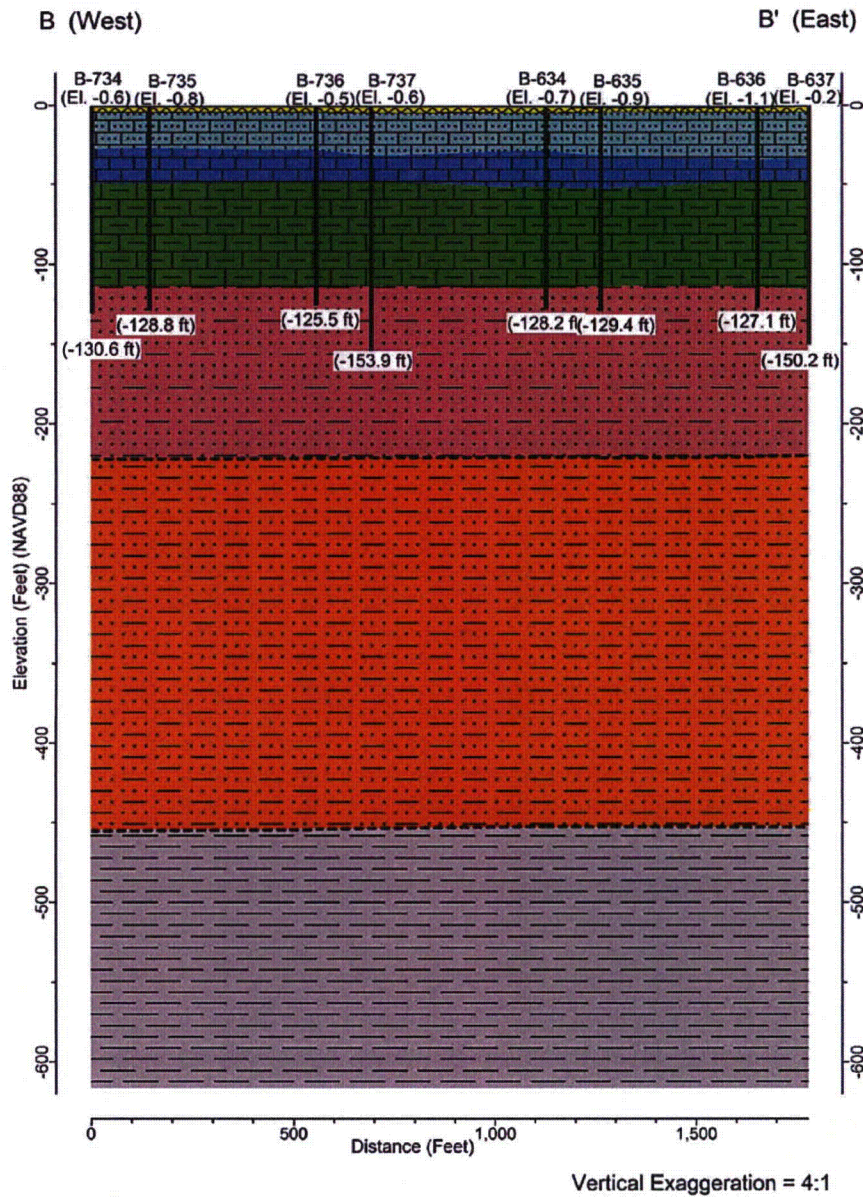
----- Stratigraphic contacts are approximate and interpolated from the borings. The dashed line is an extrapolated stratigraphic contact.

Subsurface data have been obtained only at the actual boring locations.

Actual stratification between the borings may differ.

Elevations (ft) are noted at the base of each boring.

Figure 2.5.1-387 Cross-Section B-B' (Vertical Exaggeration = 4:1)
This figure appears in Appendix 2.5AA as Figure 2.5AA-216



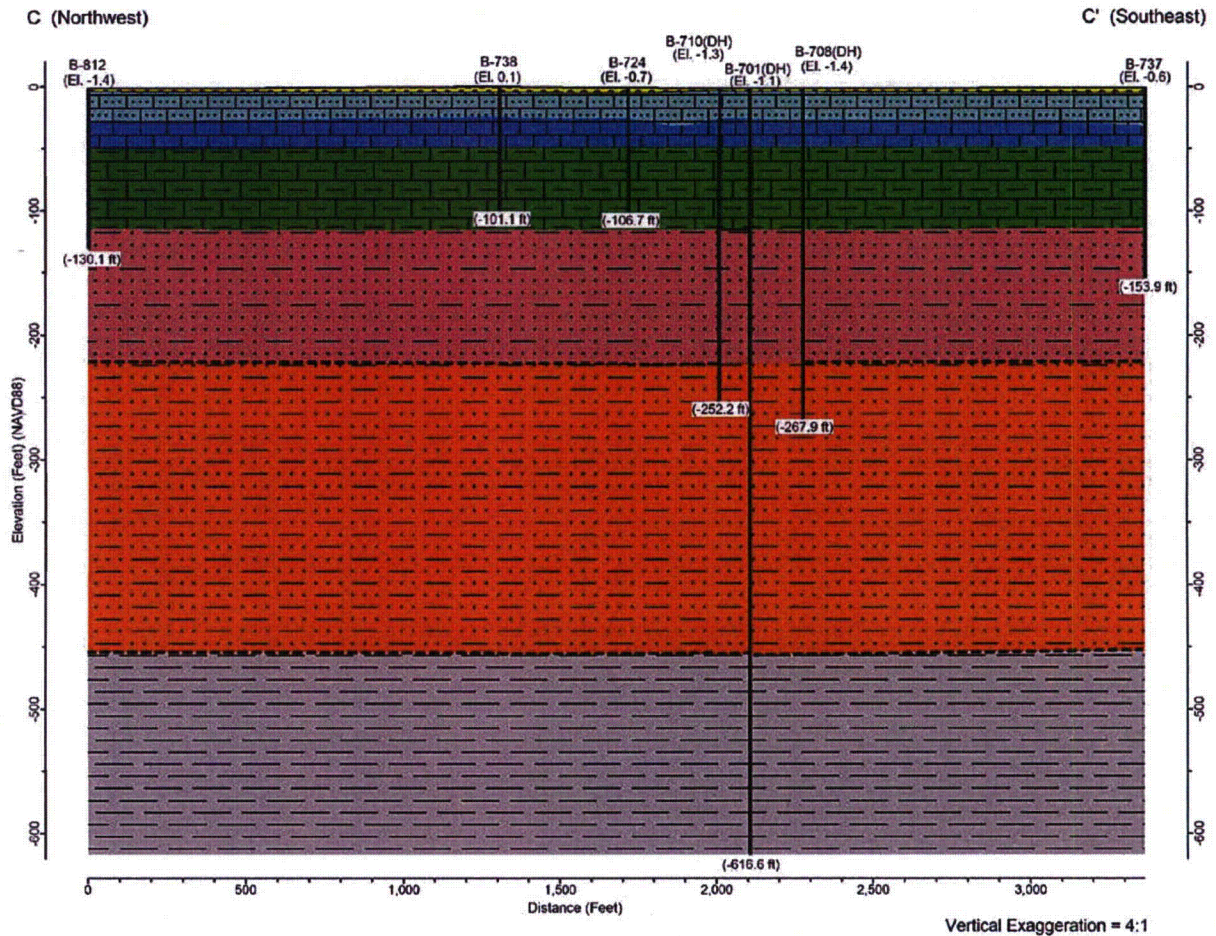
Stratigraphy	
	Muck/Peat
	Miami Limestone
	Key Largo Limestone
	Fort Thompson Fm.
	Tamiami Fm.
	Peace River Fm.
	Arcadia Fm.

Notes.

----- Stratigraphic contacts are approximate and interpolated from the borings. The dashed line is an extrapolated stratigraphic contact.

Subsurface data have been obtained only at the actual boring locations. Actual stratification between the borings may differ. Elevations (ft) are noted at the base of each boring.

Figure 2.5.1-388 Cross-Section C-C' (Vertical Exaggeration = 4:1)
This figure appears in Appendix 2.5AA as Figure 2.5AA-217

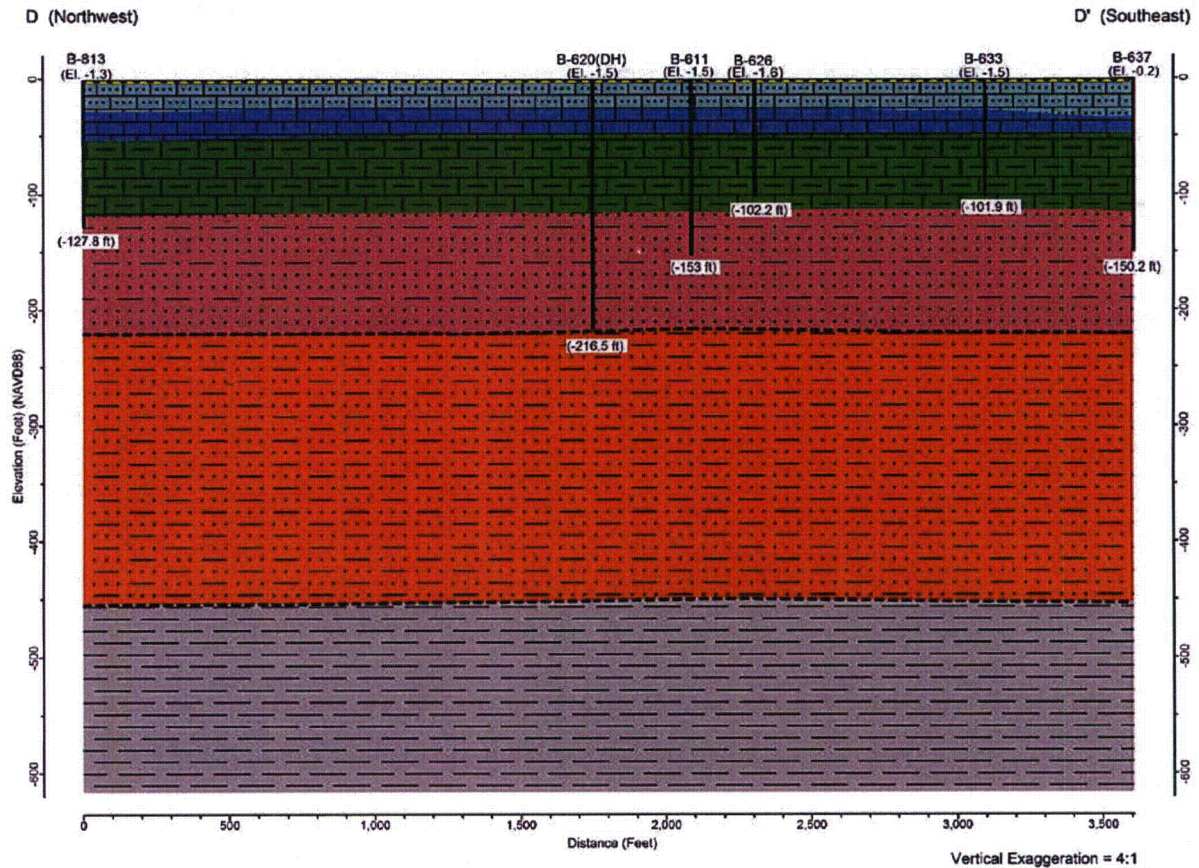


Stratigraphy	
	Muck/Peat
	Miami Limestone
	Key Largo Limestone
	Fort Thompson Fm.
	Tamiami Fm.
	Peace River Fm.
	Arcadia Fm.

Notes.

- Stratigraphic contacts are approximate and interpreted from the borings. The dashed line is extrapolated from select borings.
- Subsurface data have been obtained only at the actual boring locations.
- Actual stratification between the borings may differ.
- Elevations (ft) are noted at the base of the borings.

Figure 2.5.1-389 Cross-Section D-D' (Vertical Exaggeration = 4:1)
This figure appears in Appendix 2.5AA as Figure 2.5AA-201



Stratigraphy	
	Muck/Peat
	Miami Limestone
	Key Largo Limestone
	Fort Thompson Fm.
	Tamiami Fm.
	Peace River Fm.
	Arcadia Fm.

Notes.

--- Stratigraphic contacts are approximate and interpreted from the borings. The dashed line is extrapolated from select borings.

Subsurface data have been obtained only at the actual boring locations.

Actual stratification between the borings may differ.

Elevations (ft) are noted at the base of the borings.

Proposed Turkey Point Units 6 and 7

Docket Nos. 52-040 and 52-041

FPL Response to NRC RAI No. 02.05.01-17 (eRAI 6024)

L-2013-236 Attachment 15 Page 70 of 112

The following Appendix 2.5AA, Potential for Carbonate Dissolution and Karst Development at the Turkey Point Units 6 & 7 Site, will be included in a future revision of the COLA.

Proposed Turkey Point Units 6 and 7
Docket Nos. 52-040 and 52-041
FPL Response to NRC RAI No. 02.05.01-17 (eRAI 6024)
L-2013-236 Attachment 15 Page 71 of 112

Appendix 2.5AA

**POTENTIAL FOR CARBONATE DISSOLUTION AND KARST DEVELOPMENT AT THE
TURKEY POINT UNITS 6 & 7 SITE**

TABLE OF CONTENTS

<u>Executive Summary</u>	2.5AA-4
<u>1. Introduction</u>	2.5AA-5
<u>2. Surficial Dissolution Features (FSAR Subsections 2.5.1.2.4 and 2.5.3.8.2.1)</u>	2.5AA-6
<u>2.1. Vegetated Depressions at the Site</u>	2.5AA-7
<u>2.2. Vegetated Patterns on the Floor of Biscayne Bay</u>	2.5AA-8
<u>2.3. Comparison of Vegetated Depressions in the Site Vicinity to Other Paleokarst Features</u>	2.5AA-10
<u>3. Subsurface Dissolution Features at the Turkey Point Units 6 & 7 Site (FSAR Subsection 2.5.1.1.1.1.1 and 2.5.1.2.4)</u>	2.5AA-12
<u>3.1. Touching-Vug Porosity</u>	2.5AA-12
<u>3.2. Moldic Porosity</u>	2.5AA-12
<u>4. Potential for Formation of Other Types of Carbonate Dissolution Features at the Turkey Point Units 6 & 7 Site (FSAR Subsections 2.5.1.1.1.1.1.1)</u>	2.5AA-13
<u>4.1. Carbonate Dissolution Mechanisms</u>	2.5AA-13
<u>4.1.1. Point Source Discharge</u>	2.5AA-13
<u>4.1.2. Submarine Groundwater Discharge</u>	2.5AA-13
<u>4.1.2.1 Shoreline Flow</u>	2.5AA-14
<u>4.1.2.2 Deep Pore Water Upwelling</u>	2.5AA-17
<u>4.2. Effect of Sea Level Fluctuation on Migration of the Fresh Water/Salt Water Interface (FSAR Subsection 2.5.1.1.1.1.1.1)</u>	2.5AA-18
<u>4.3. Potential for Sinkhole Development During Site Construction (FSAR Subsection 2.5.4.5.4 and 2.5.4.6.2)</u>	2.5AA-18
<u>5. Clarification of Issues Related to Interpretation of Data From the Subsurface Investigation at the Turkey Point Units 6 & 7 Site</u>	2.5AA-19
<u>5.1. Assumptions in the Interpretation of the Microgravity Survey Data (FSAR Subsections 2.5.1.2.4 and 2.5.4.1.2.1)</u>	2.5AA-19
<u>5.2. Significance of Rod Drops as Indicators of Possible Subsurface Cavities (FSAR Subsections 2.5.1.2.4 and 2.5.4.1.2.1)</u>	2.5AA-20
<u>5.3. Significance of Closed Contours on the Key Largo Isopach Map (FSAR Subsection 2.5.1.2.2)</u>	2.5AA-21
<u>6. Conclusions</u>	2.5AA-22
<u>7. References</u>	2.5AA-23

LIST OF TABLES

<u>Table 2.5AA-201. Tabulated Data on Area and Distribution of Vegetated Patches</u>	<u>2.5AA-25</u>
--	-----------------

LIST OF FIGURES

<u>Figure 2.5AA-201. Cross-Section D-D' (Vertical Exaggeration = 4:1)</u>	<u>26</u>
<u>Figure 2.5AA-202. Google Earth Image of Biscayne Bay Adjacent to the Turkey Point Units 6 & 7 Site Showing Possible Alignments of Vegetated Patches</u>	<u>27</u>
<u>Figure 2.5AA-203. Areas Evaluated for Size and Density of Vegetated Patches.....</u>	<u>28</u>
<u>Figure 2.5AA-204. Close-Up View of Potential Semicircular Arrangement of Vegetated Patches</u>	<u>29</u>
<u>Figure 2.5AA-205. Google Earth Image of the Sinkhole Reported by Shinn et al.</u>	<u>30</u>
<u>Figure 2.5AA-206. Aerial Photo (1994) of Biscayne Bay Adjacent to the Turkey Point Units 6 & 7 Site</u>	<u>31</u>
<u>Figure 2.5AA-207. Isopach Map of the Key Largo Limestone.....</u>	<u>32</u>
<u>Figure 2.5AA-209. Structure Contour Map of the Top of the Key Largo Limestone</u>	<u>34</u>
<u>Figure 2.5AA-210. Isopach Map of the Fort Thompson Formation</u>	<u>35</u>
<u>Figure 2.5AA-211. Cross-Section A-A' Truncated (Vertical Exaggeration = 12:1).....</u>	<u>36</u>
<u>Figure 2.5AA-212. Cross-Section B-B' Truncated (Vertical Exaggeration = 12:1).....</u>	<u>37</u>
<u>Figure 2.5AA-213. Cross-Section C-C' Truncated (Vertical Exaggeration = 12:1)</u>	<u>38</u>
<u>Figure 2.5AA-214. Cross-Section D-D' Truncated' (Vertical Exaggeration = 12:1)</u>	<u>39</u>
<u>Figure 2.5AA-215. Cross-Section A-A' (Vertical Exaggeration = 4:1)</u>	<u>40</u>
<u>Figure 2.5AA-216. Cross-Section B-B' (Vertical Exaggeration = 4:1)</u>	<u>41</u>
<u>Figure 2.5AA-217. Cross-Section C-C' (Vertical Exaggeration = 4:1)</u>	<u>42</u>

Executive Summary

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

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

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

The zones of secondary porosity have developed by solution enlargement of two types of sedimentary structures: "touching-vug porosity" and "moldic porosity" (FSAR Subsection 2.5.1.2.4). Touching-vug porosity forms the "Upper Zone" of secondary porosity on the site that occurs near the contact of the Miami Limestone and the underlying Key Largo Limestone, within the approximate depth interval of 20 to 35 feet (6.1 to 10.7 meters) below the current land surface (FSAR Figures 2.5.1-351, -352, and -353). Because the current land surface elevation at the site is approximately 0 feet (0 meters) NAVD88, this depth interval is also the approximate elevation interval of -20 to -35 feet (-6.1 to -10.7 meters) NAVD88. This zone will be removed completely during excavation of the nuclear island foundations.

Moldic porosity forms the "Lower Zone" of secondary porosity on the site and occurs in pockets within the approximate depth interval of 60 to 75 feet (-60 to -75 feet, or -18.3 to -22.9 meters NAVD88) in the Fort Thompson Formation. While both the Upper and Lower zones of secondary porosity formed in paleo-mixing zones of fresh groundwater and seawater, groundwater in these zones now is saline (FSAR Tables 2.4.12-210 and 2.4.12-211) and not conducive to further dissolution of the limestone host rock.

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

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

Evidence of deep pore water upwelling in or near the site region is also discussed in FSAR Subsection 2.5.1.1.1.1.1.1.1. This process occurs within the sea bed on the off-shore 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 500 feet (152 meters) of low-permeability rocks and sediments that overlie and confine the Floridan Aquifer (FSAR Figures 2.4.12-202 and 2.4.12-204). Deep pore water upwelling generally occurs well off shore, where the slope of the shelf is steeper and erosion of this thickness of confining sediments more likely. For this reason, carbonate dissolution associated with deep pore water upwelling is not likely to pose a threat of surface collapse or sinkhole hazard at the site.

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

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

1. Introduction

This appendix summarizes information previously provided in the FSAR and in the responses to various requests for additional information by the NRC and provides additional information pertaining to the potential for carbonate dissolution and karst development at the Turkey Point Units 6 & 7 site. This summary outlines the extent to which karst features have developed on and adjacent to the site,

the processes by which they were formed, and the improbability of contemporary carbonate dissolution resulting in the formation of large subsurface voids with the potential for collapse. Based upon investigations completed to date, including review of published reports pertaining to karst development in south Florida and a detailed site subsurface geotechnical investigation, two types of features related to carbonate dissolution have been identified on the site: vegetated depressions at and near the ground surface and zones of secondary porosity within the underlying limestone. The vegetated depressions have formed by a surficial dissolution mechanism, as discussed further in Section 2. The zones of secondary porosity have formed by a subsurface mechanism of solution enlargement of sedimentary structures in the carbonate rock, as discussed further in Section 3. Neither of these features is believed to pose a hazard of sinkhole development or foundation instability at the site, as detailed in the discussions in Sections 2 and 3.

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

The fresh groundwater/saltwater interface within the surficial aquifer that underlies the site is currently located approximately 6 miles (9.6 kilometers) inland from the site (FSAR Figure 2.4.12-207). Groundwater in the aquifer is saline at the site (FSAR 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 0.78 foot (0.2 meter) per century (Reference 2.4.5-206). Therefore, a fresh groundwater/saltwater mixing zone that would promote carbonate dissolution does not exist, and there does not appear to be a potential for development of large underground caverns with the potential for collapse at the site.

2. Surficial Dissolution Features (FSAR Subsections 2.5.1.2.4 and 2.5.3.8.2.1)

Karstification resulting from dissolution of carbonate rock can lead to creation of sinkholes when the process occurs at or near the earth surface. As further discussed in FSAR Subsection 2.5.1.1.1.1.1, the U.S. Geological Survey has identified three main types of sinkholes in Florida (FSAR Reference 2.5.1-264), and the Florida Geological Survey has classified four type areas of sinkhole occurrences throughout the state (FSAR Figure 2.5.1-222). The Turkey Point Units 6 & 7 site is located within Area I where, if they occur, sinkholes are typically surface-solution sinkholes. In this type of sinkhole, limestone is exposed at the ground surface or under a thin mantle of overburden and subject to subaerial dissolution by slightly acidic surface water. Dissolution is concentrated at the surface and along fractures, joints and other openings in the rock.

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

2.1. Vegetated Depressions at the Site

Numerous circular or ellipsoidal vegetated and/or water filled depressions that are generally less than one foot lower than the surrounding area have been identified on the site (FSAR Subsection 2.5.3.8.2.1). Based on published literature (FSAR Reference 2.5.1-264), the FSAR for Turkey Point Units 3 and 4 (FSAR Reference 2.5.1-712, p. 2.9-3), geologic field reconnaissance and data from a detailed site subsurface investigation that included a multi-method surface geophysical survey (FSAR References 2.5.1-708 and 2.5.1-988), these features on the site and nearby on the floor of Biscayne Bay are thought to be the result of a subaerial, epigenic, gradual, top-down process of carbonate dissolution caused by downward seepage of slightly acidic meteoric water following fractures, joints and bedding planes. This process of carbonate dissolution is currently active on the site and was active beneath Biscayne Bay during the Wisconsin glacial stage when continental glaciation had lowered sea level approximately 100 meters and exposed the limestone on the floor of Biscayne Bay to subaerial weathering and dissolution. Formation of the vegetated patterns beneath the bay is discussed further in Section 2.2.

FSAR Subsection 2.5.4.4.5 discusses a multi-method surface geophysical survey designed to detect possible dissolution features beneath the footprint of the nuclear islands at the site. The locations of the vegetated depressions correlate well with data from the geophysical surveys (FSAR Figures 2.5.4-223 and -228). The surveys indicate that the features are characterized by up to 20 feet (6.1 meters) of muck accumulated within soft zones of the Miami Limestone and upper Key Largo Limestone. Outside of the vegetated depressions, a surficial layer of muck generally 2 to 6 feet (0.6 to 1.8 meters) thick is present throughout the site (FSAR Subsection 2.5.1.2.2). The areas of thicker muck likely represent zones of increased dissolution with possible small voids, dissolution-enlarged fractures and softer rock. Soft zones within the Miami Limestone indicated by relatively low Standard Penetration Test "N" values recorded in logs of soil borings drilled on the geophysical survey lines correlate well with low-gravity anomalies, suggesting that the gravity anomalies identify areas of soft rock rather than large subsurface voids. Within the limits of the geophysical survey imposed by diminishing resolution with depth, measured variations in shear and compressional seismic wave velocities integrated with microgravity data (FSAR Figures 2.5.4-226 and -227) indicate the vegetated depressions appear to be underlain by relatively un-karstified, un-deformed rock within the Key Largo Limestone rather than rock that has been undermined to the extent that it may be subject to collapse.

2.2. Vegetated Patterns on the Floor of Biscayne Bay

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

The locations of the vegetated depressions onsite correlate well with results of the geophysical surveys conducted to identify possible subsurface cavities, as part of the site subsurface investigation (FSAR Figures 2.5.4-223 and -228). The surveys indicate that the features are characterized by up to 20 feet of muck accumulated within soft zones of the Miami Limestone and upper Key Largo Limestone. Outside of the vegetated depressions, a surficial layer of muck generally 2 to 6 feet thick is present throughout the site (FSAR Subsection 2.5.1.2.2). The areas of thicker muck beneath the vegetated depressions likely represent zones of increased dissolution with possible small voids, dissolution-enlarged fractures and softer rock.

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

The average areas of the individual vegetated patches in the subaerial circles 1 and 2 are 780 and 540 square meters (8,396 and 5,812 square feet), respectively, and the average areas for the submarine patches in circles 3 and 4 are 180 and 320 square meters (1,938 and 3,444 square feet), respectively (Table 2.5AA-201). While the submarine patches have lower average areas, the average values for both locations (subaerial and submarine) are of the same order of magnitude. The size distribution of the patches in both the subaerial and submarine environments is variable, with high standard deviations for the patch areas, and a size range that varies from 20 square meters (215 square feet) to greater than 7,900 square meters (85,000 square feet). Very similar vegetated patch densities are calculated for subaerial and submarine areas (Table 2.5AA-201). The statistics for the subaerial circles are somewhat skewed by the presence of a few very large patches (especially in circle 1), reflected by the fact that the standard deviations of the patch areas in these circles are actually larger than the mean. These outliers may in fact consist of several smaller patches, which have been obscured by vegetation. Otherwise, the patches in all four circles display similar characteristics, with similar minimum patch sizes and population densities.

The larger average subaerial patch size relative to the average submarine patch size is consistent with their inferred origin (FSAR Subsection 2.5.3.2). The patches on the floor of Biscayne Bay likely formed during the Wisconsin glacial advance, when sea level was approximately 328 feet (100 meters) 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 Wisconsin and has been subject to subaerial weathering and surficial dissolution for several thousand years longer than the floor of the bay.

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

The imagery available through Google Earth 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 (1,575 feet) and 368 meters (1,207.5 feet), respectively (Figure 2.5AA-202 labels A and B, respectively). 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) (FSAR Reference 2.5.3-228) discussed in Section 4.1.2.1.

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

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

As discussed in Section 4.1.2.2, Cunningham and Walker (FSAR 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 (FSAR Figure 2.5.1-356). The data exhibit disturbances in parallel seismic reflections that correspond to the carbonate rocks of the Floridan Aquifer system and the lower part of the overlying intermediate confining unit (FSAR 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 (FSAR References 2.5.1-958 and 2.5.1-989).

Regardless of the mechanism of formation, the geophysical data indicate the absence of deformation in rocks younger than middle Miocene (FSAR Figures 2.5.1-357, -358, and -359). This finding suggests that if the same mechanism had been active at the Turkey Point Units 6 & 7 site during the Eocene, none of the strata younger than middle Miocene would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, Tamiami Formation and Peace River Formation. The total thickness of this section at the site is approximately 450 feet (137.2 meters) (FSAR Figure 2.5.1-332). Deformation of rocks below this depth is not likely to pose a threat of surface collapse at the site.

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

The apparent origin of the greater topographic relief and a much more developed karst regime within the cenotes terrain in the Yucatan Peninsula relative to the Turkey Point Units 6 & 7 site and its vicinity is the relatively high rate of fresh groundwater discharge from a large inland watershed in the

Yucatan that produces a more robust mixing zone and more carbonate dissolution (FSAR Reference 2.5.1-965). The fresh groundwater/saltwater interface at the site is located approximately 6 miles inland (FSAR Figure 2.4.12-207) and groundwater at the site is saline (FSAR Tables 2.4.12-210 and 2.4.12-211). Therefore, a fresh groundwater/saltwater mixing zone that would promote dissolution of the limestone underlying the vegetated features on the floor of Biscayne Bay does not now exist at the site. The absence of a more developed karst topography or an active mixing zone near the site suggests that the process of carbonate dissolution that is instrumental in forming the cenotes of the Yucatan is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site or beneath the vegetated patches on the floor of nearby Biscayne Bay.

Biscayne Bay has been modified and dredged and has an average water depth that ranges from 6 to 13 feet (1.8 to 4 meters) (FSAR Reference 2.5.1-991). Assuming the water level in the bay is at 0 feet NAVD88, the floor of Biscayne Bay ranges in elevation from approximately -6 to -13 feet NAVD88. According to Reich et al. (FSAR Reference 2.5.1-992), sediments overlying bedrock in the bay range in thickness from less than 6 inches to 30 feet. Using this information and the elevations of the bottom of the bay, it is concluded that the surface elevation of the bedrock over which the vegetated patches occur on the floor of the bay ranges from approximately -6.5 to -43 feet NAVD88. As discussed in FSAR Subsection 2.5.1.2.4 an upper zone of secondary porosity within the Biscayne Aquifer is located near the contact of the Miami Limestone and Key Largo Limestone at an approximate elevation of -28 feet NAVD88. A lower zone of secondary porosity is located within the Fort Thompson Formation at an approximate elevation of -65 feet NAVD88. Based on site stratigraphic data collected during the subsurface investigation (FSAR Reference 2.5.1-708), the units are relatively flat and, therefore, it appears that the upper zone of secondary porosity at the site occurs within the stratigraphic interval of the limestone surface over which the vegetated patches occur on the floor of Biscayne Bay. The results of the site subsurface investigation described in FSAR Subsections 2.5.1.2 and 2.5.4.1.2.1 as well as the results of a multi-method surface geophysical survey designed to detect subsurface cavities (within the limitations of the geophysical survey imposed by diminishing resolution with increasing depth, decreasing cavity size, and increasing offset from survey lines), demonstrate the absence of large solution features at this stratigraphic interval.

Although the upper zone of secondary porosity and the vegetated patches on the floor of Biscayne Bay may be in the same stratigraphic interval, the formation of these dissolution features is somewhat different. Dissolution features such as the vugs in the upper zone of secondary porosity are typically post-depositional and occur in a subsurface freshwater/saltwater mixing zone or in a freshwater phreatic system in which groundwater has filled open spaces and causes dissolution. The vegetated patches on the floor of the bay appear to be surficial paleo-dissolution features that formed during the Wisconsin glacial stage of the Pleistocene when sea level was approximately 328 feet (100 meters) lower than the modern ocean (FSAR Reference 2.5.1-262) and at an elevation favorable for surficial dissolution by rainwater of subaerial limestone in what is now the bay.

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

The imagery available through Google Earth was reviewed specifically to look for possible semicircular alignments in the on-site surficial depressions and vegetated patches in Biscayne Bay. Two possible semicircular arrangements of vegetated patches are observed just east of the site in images obtained on March 26, 2011 (Figures 2.5AA-202 and 2.5AA-204). These arcs of vegetation seem to have radii of roughly 480 meters (1,575 feet) and 368 meters (1,208 feet) (areas "A" and "B", respectively, in Figure 2.5AA-202). If these features were each a complete circle rather than a semicircle or arc, they would be similar in diameter to the approximately 600 meter (1,968 feet) diameter submarine paleokarst sinkhole investigated by Shinn et al. in the Key Largo National Marine

Sanctuary (FSAR Reference 2.5.3-228). This submarine paleokarst sinkhole is discussed in Section 4.1.2.1 and FSAR Subsection 2.5.1.1.1.1.1.1.

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

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

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

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

3. Subsurface Dissolution Features at the Turkey Point Units 6 & 7 Site (FSAR Subsection 2.5.1.1.1.1.1.1 and 2.5.1.2.4)

The second type of feature related to carbonate dissolution identified on the site is secondary porosity. Zones of secondary porosity have formed in limestone beneath the site where micro-karst features have developed (FSAR Subsections 2.4.12.3.1 and 2.5.1.2.4). These zones of secondary porosity provide pathways of preferential groundwater flow. The micro-karst features formed when fresh groundwater formerly flowed from inland areas, mixed with seawater, and facilitated dissolution

of sedimentary structures in the rock as it flowed through the zone of secondary porosity to the sea. However, the data from extensive site investigation for Turkey Point Units 6 & 7 (FSAR Reference 2.5.1-708) offer no evidence that karstification of the area has developed cavernous limestone with the potential for collapse. The zones of secondary porosity can be subdivided into two categories: touching-vug porosity and moldic porosity.

3.1. Touching-Vug Porosity

Touching-vug porosity occurs on the site within the approximate depth interval of 20 to 35 feet (6.1 to 10.7 meters) below the current land surface (-20 to -35 feet or -6.1 to -10.7 meters NAVD88) (FSAR Figures 2.5.1-351, -352, and -353) near the contact of the Key Largo Limestone and the Miami Limestone and forms the "Upper Zone" of secondary porosity. The origin of this porosity is solution enlargement of burrows, inter-burrow vugs, moldic fossils, root molds, and vugs between root casts (FSAR Reference 2.5.1-405). These structures are sufficiently numerous and closely spaced so as to form a laterally continuous zone of interconnected voids. Data from drilling and coring within the zone of touching-vug porosity during the site subsurface investigation have shown the zone to be laterally persistent, with voids generally of centimeter scale, and very few indications of larger voids (i.e., one relatively short rod drop in each of 2 in a total of 88 geotechnical borings). A description of rod drops and their significance is further discussed in Section 5.2.

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

3.2. Moldic Porosity

Moldic porosity occurs in pockets within the approximate depth interval of 60 to 75 feet (18.3 to 22.9 meters) below current land surface (-60 to -75 feet or -18.3 to -22.9 meters NAVD88) (FSAR Figures 2.5.1-351, -352, and -353) in the Fort Thompson Formation and forms the "Lower Zone" of secondary porosity at the site. The origin of this zone is preferential dissolution of fossil shells and other organic structures rather than the matrix rock within which they are contained, resulting in void spaces within molds of the structures. Data from drilling and coring within the zone of moldic porosity during the site subsurface investigation have shown the zone not to be laterally persistent but occurring in isolated pockets within sandy zones, with very few indications of larger voids (i.e., one relatively short rod drop in each of 3 in a total of 88 geotechnical borings).

Dissolution of the limestone in this zone of secondary porosity likely occurred during the mid-Pleistocene Epoch when sea level fluctuated to a level lower than when the Fort Thompson Limestone was formed and fresh groundwater from inland areas discharged through the formation toward the sea. As noted previously, the current position of the freshwater/saltwater interface is

approximately 6 miles (9.6 kilometers) inland from the site (FSAR Figure 2.4.12-207), groundwater within the zone of moldic porosity is saline (FSAR Tables 2.4.12-210 and 2.4.12-211), the long term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.78 foot (0.2 meter) per century (Reference 2.4.5-206), and there is no freshwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote further dissolution of the limestone within the zone of moldic porosity does not now exist and development of large underground caverns with the potential for collapse is not likely within this Lower Zone of secondary porosity.

4. Potential for Formation of Other Types of Carbonate Dissolution Features at the Turkey Point Units 6 & 7 Site (FSAR Subsections 2.5.1.1.1.1.1)

4.1. Carbonate Dissolution Mechanisms

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

4.1.1. Point Source Discharge

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

Outfalls closest to the site are the Model Land Canal (C107) outfall near the southeast corner of the Turkey Point cooling water canals, approximately 5.0 miles (8 kilometers) south of the site, and the Florida City Canal outfall, approximately 1.2 miles (1.9 kilometers) north of the site (FSAR Figure 2.4.1-203). Because of their distance from the site and the effects of variable discharge from the outfalls related to operation of their control structures, variable rainfall, tidal fluctuations, and hurricanes, neither outfall is likely to induce formation of cavernous limestone with the potential for collapse at the site.

4.1.2. Submarine Groundwater Discharge

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

4.1.2.1. Shoreline Flow

Shoreline flow is the movement of groundwater into the near-shore ocean driven by an inland hydraulic head through an aquifer to the near-shore mixing zone at the interface of the freshwater lens near the top of the aquifer and the saltwater wedge near the bottom of the aquifer. The resulting chemical disequilibrium with respect to calcium carbonate saturation (FSAR Reference 2.5.1-945) promotes dissolution of carbonate rock. The near-shore groundwater flow domain has been referred to as a subterranean estuary because of its similarity to the dynamic nature of a surface estuary with respect to tidal influence and mixing of waters with differing chemistry (FSAR Reference 2.5.1-946).

As further discussed in the following subsections, several features identified within the site region provide evidence of current or former shoreline flow.

Freshwater Springs Near the Shore of Biscayne Bay

As further discussed in FSAR 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 prior to 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 shoreline springs still exist in the bay. Their flow paths were likely formed originally by freshwater dissolution. However, their current salinity levels of 8 to 31 g/L (8 to 32 parts per thousand) indicate that the springs no longer discharge freshwater (FSAR Reference 2.5.1-954). The current 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. The diminished discharge and water quality in the shoreline springs suggests that the propensity for further development of dissolution features by shoreline flow in near-shore 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.

Cave Development Along the Atlantic Coastal Ridge

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

Most caves of southeastern Florida occur on or along the eastern flanks of the Atlantic Coastal Ridge or along the edges of transverse glades that cut through the Atlantic Coastal Ridge. This landform ranges in elevation from approximately 10 to 50 feet (3 to 15 meters) above sea level and averages about 5 miles (8 kilometers) in width. The Atlantic Coastal Ridge is composed of the Miami Limestone (FSAR 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 (FSAR References 2.5.1-405 and 2.5.1-928). As sea level decreased during the Wisconsin 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 currently approximately 6 miles (9.6 kilometers) inland from the coast (FSAR Figure 2.4.12-207), groundwater at the site is saline (FSAR 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 0.78 foot (0.2 meter) per century (Reference 2.4.5-206), resulting in shoreline flow at the Turkey Point Units 6 & 7 site that is brackish to saline. Therefore, the mixing-zone process that formed the caves along the flanks of the Atlantic Coastal Ridge is not likely to be currently active in formation of cavernous limestone with the potential for collapse in the area of the site.

Karst Development on Emergent Carbonate Islands in the Bahamas

As further discussed in FSAR Subsection 2.5.1.1.1.1.1, flank margin caves form on emergent carbonate islands in the Bahamas as large globular mixing chambers at the freshwater/saltwater interface near the shoreline. Banana Holes are another karst feature in the Bahamas. These features form inland from the flank margin caves and near the top of the fresh groundwater lens where the vadose and phreatic freshwaters mix. Both flank margin caves and banana holes are found in the Bahamas at elevations of 1 to 6 meters (3.3 to 20 feet) above the current sea level. The caves likely formed during the Sangamon interglacial stage (FSAR Reference 2.5.1-263), when sea level was higher than it is now. The process of shoreline flow that formed the flank margin caves may be active in the Bahamas today, but at an elevation closer to modern sea level. However, similar processes are not likely to be active currently at the Turkey Point Units 6 & 7 site because of the absence of fresh groundwater shoreline flow near the site. The current position of the freshwater/saltwater interface is approximately 6 miles (9.6 kilometers) inland from the site (FSAR Figure 2.4.12-207), groundwater at the site is saline (FSAR 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 0.78 foot (0.2 meter) per century (Reference 2.4.5-206). Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist.

Submarine Paleokarst Sinkhole in the Key Largo National Marine Sanctuary

As further discussed in FSAR Subsection 2.5.1.1.1.1.1, a large sediment-filled submarine paleokarst sinkhole with a diameter of approximately 600 meters (1,968 feet) and a depth likely to exceed 100 meters (328 feet) has been investigated by Shinn et al. in the Key Largo National Marine Sanctuary off Key Largo, Florida (FSAR Reference 2.5.3-228). Shinn et al. postulate that the Key Largo submarine paleokarst sinkhole is a cenote that developed during the Pleistocene. As sea level rose during recession of the last (Wisconsinan) glacial stage, a freshwater lake in the bottom of the sinkhole would have deepened as the groundwater level adjusted to the rising sea level. Infilling of the sinkhole most likely began with precipitated freshwater calcite muds (i.e. marl). The area of the sinkhole eventually became engulfed by the sea, marine sedimentation ensued and the area evolved to the current marine environment, at which point conditions conducive for continued limestone dissolution and sinkhole formation no longer existed.

As noted previously, because the current position of the freshwater/saltwater interface is approximately 6 miles (9.6 kilometers) inland from the site (FSAR Figure 2.4.12-207), groundwater at the site is saline (FSAR 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 0.78 foot (0.2 meter) per century (Reference 2.4.5-206), there is no fresh groundwater shoreline flow near the site. Therefore, a freshwater/saltwater mixing zone that would promote carbonate dissolution at the site does not now exist, and the process of shoreline flow that formed the Key Largo submarine paleokarst sinkhole is not a mechanism that is likely to produce cavernous limestone with the potential for collapse at the site.

Blue Holes in Eastern South Andros Island, Bahamas

As further discussed in FSAR Subsection 2.5.1.1.1.1.1, the blue holes beneath South Andros Island, Bahamas are surface openings leading to an extensive system of submarine caves developed along near-shore fracture systems. Formation of the blue holes, which reach depths exceeding 100 meters, began during a previous eustatic sea-level low stand associated with advance of continental glaciation during the Pleistocene. Circulation of fresh groundwater to the blue holes is facilitated by the fracture permeability that exists within the fracture systems in the carbonate rock. Mixing of fresh

groundwater and seawater in the fracture systems has facilitated dissolution of the rock and vertical development of the blue holes as sea level rose during one or more interglacial stage(s) of the Pleistocene.

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

Karst Development on the Yucatan Peninsula, Quintana Roo, Mexico

The Yucatan Peninsula is outside of the 200-mile radius "site region", but karst development there provides evidence of former shoreline flow and, therefore, is discussed here. As further discussed in FSAR Subsection 2.5.1.1.1.1.1, caves have formed in the Yucatan Peninsula along the margin of the discharging fresh groundwater lens as a result of freshwater/saltwater mixing near the coast.

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

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

4.1.2.2. Deep Pore Water Upwelling

Deep pore water upwelling is the flow of fresh groundwater through deep confined permeable sediments and rocks on the off-shore 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.

Submarine Paleokarst Sinkholes Beneath Biscayne Bay

Cunningham and Walker (FSAR 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. The data exhibit disturbances in parallel seismic reflections that correspond to the carbonate rocks of the Floridan aquifer system and the lower part of the overlying intermediate confining unit. The disturbances in the seismic reflections are indicative of structural deformation in carbonate rocks of Eocene to middle Miocene age. As discussed further in FSAR Subsection 2.5.1.1.1.1.1, 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 dissolution due to deep pore water upwelling.

Regardless of the formative process, the geophysical data indicate the absence of deformation in rocks younger than middle Miocene (FSAR Figures 2.5.1-357, -358, and -359). This finding suggests that, if the same mechanism had been active at the Turkey Point Units 6 & 7 site during the Eocene, none of the strata younger than middle Miocene would be deformed. These younger strata include the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, Tamiami Formation and Peace River Formation. The total thickness of this section at the site is approximately 450 feet (137.2 meters) (FSAR Figure 2.5.1-332). Deformation of rocks below this depth is not likely to pose a threat of surface collapse at the site.

Crescent Beach Spring and Red Snapper Sink

Crescent Beach is located on a barrier island near St Augustine, in northeast Florida. They are outside of the 200-mile radius "site region", but the spring and sink are evidence of deep pore water upwelling and warrant discussion here. As further discussed in FSAR Subsection 2.5.1.1.1.1.1, Crescent Beach Spring is a freshwater submarine spring located about 4 kilometers (2.5 miles) east of Crescent Beach and is considered a first-order spring with a flow rate of greater than 40 cubic meters per second (634,000 gallons per minute) (FSAR Reference 2.5.1-946). The spring is located at a depth of 18 meters (59 feet) in the Atlantic Ocean, and erosion of confining strata to a depth of 38 meters (125 feet) at the mouth of the vent has enabled direct hydrologic communication of confined groundwater in the Floridan Aquifer with coastal bottom waters.

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

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

the shelf is steeper and erosion of this thickness of confining sediments is more likely. For this reason, carbonate dissolution associated with deep pore water upwelling from the Floridan Aquifer is not likely to pose a threat of surface collapse or sinkhole hazard at the site.

4.2. Effect of Sea Level Fluctuation on Migration of the Freshwater/Saltwater Interface (FSAR Subsection 2.5.1.1.1.1.1)

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

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

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

4.3. Potential for Sinkhole Development During Site Construction (FSAR Subsection 2.5.4.5.4 and 2.5.4.6.2)

The deepest excavations during plant construction will be approximately 35 feet (10.7 meters) below the current grade level (FSAR Subsections 2.5.4.5.4 and 2.5.4.6.2). This depth is also approximately 35 feet (10.7 meters) below the water table (Appendix 2.4.12-2AA). The current plan to provide temporary ground support and control groundwater during site construction is discussed in Section 5.1 and in FSAR Subsection 2.5.4.6.2.

Construction of the proposed reinforced concrete diaphragm walls and grout plug is expected to provide a low-permeability barrier to groundwater flow that will minimize seepage into the foundation excavations and lowering of the hydrostatic head within the Biscayne Aquifer surrounding the excavations. Dewatering requirements during construction are expected to be greatly reduced by use of these construction techniques. Change in hydrostatic stress or reduction of buoyant support of the limestone due to lowering of groundwater levels within the Biscayne Aquifer related to construction

dewatering is expected to be negligible and not to induce carbonate dissolution, cavity formation, or sinkhole collapse.

5. Clarification of Issues Related to Interpretation of Data From the Subsurface Investigation at the Turkey Point Units 6 & 7 Site

5.1. Assumptions in the Interpretation of the Microgravity Survey Data (FSAR Subsections 2.5.1.2.4 and 2.5.4.1.2.1)

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

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

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

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

Based on review of the complete geophysical data set, there is no evidence for the presence of large paleokarst sinkholes or large open voids within the survey area. However, resolution of the geophysical data diminishes with increasing depth, decreasing cavity size, and increasing offset from

survey lines, introducing an element of uncertainty regarding the interpretation of these data at and below the approximate depth of the nuclear island foundations.

To reduce uncertainties in the resolution and interpretation of microgravity data with depth and offset from geophysical survey lines and boreholes, a second microgravity survey at the base of the excavations for the nuclear island foundations is proposed. As further discussed in FSAR Subsections 2.5.4.5.4 and 2.5.4.6.2, the current plan to provide temporary ground support and control groundwater while excavating is to install (prior to excavation) reinforced concrete diaphragm walls from the ground surface to approximately elevation -60 feet (-18.3 meters) NAVD88 on all four sides of the excavation and an approximately 25-foot (7.6 meter) thick grout plug throughout the entire area within the diaphragm walls in the elevation interval from approximately -35 to -60 feet (-10.7 to -18.3 meters) NAVD88 (immediately below the bottom of the foundations). The objective of the grout plug is to fill voids that may exist beneath the nuclear island excavations and reduce vertical groundwater seepage into the excavations.

It is anticipated that the density of the grout plug will be similar to that of the rock on which the nuclear islands will be founded (Key Largo Limestone). Therefore, the grout plug effectively will be transparent to the proposed microgravity survey and the survey should be capable of detecting an anomaly produced by a water-filled cavity that is 10 feet (3 meters) in diameter if it is roughly the shape of a horizontal cylinder, or 25 feet (7.6 meters) in diameter if it is roughly spherical, centered approximately 40 feet (12.2 meters) below the base of the excavation (and 15 feet [4.6 meters] below the bottom of the grout plug). Preliminary estimates indicate that a hypothetical solution cavity with an approximate diameter of 30 feet (9.1 meters) at a depth immediately below elevation -60 feet (-18.3 meters) NAVD88 would have a negligible effect on the stability of the nuclear island foundation.

5.2. Significance of Rod Drops as Indicators of Possible Subsurface Cavities (FSAR Subsections 2.5.1.2.4 and 2.5.4.1.2.1)

A "rod drop" occurs when, while drilling, the bit encounters a relatively soft zone or void and the drill head and rod string suddenly advances at a rate much faster than the rate when drilling the overlying more competent material. A rod drop can also occur during standard penetration testing (SPT) when the weight of the string of drill rods is sufficient to advance the SPT sampler at the bottom of the borehole without additional blows of the sampling hammer. The occurrence of a rod drop indicates the presence of very soft or very loose material, which can be interpreted as void or cavity infill or as inter-bedded materials with substantially different hardness or compactness. Alternatively, a rod drop could indicate that the drill or sampler might have penetrated a cavity that is only partially filled with soft or loose material. Rod drops are typically noted on a geotechnical borehole log as weight of rods ("WOR") or weight of hammer ("WOH") in reference to the number of hammer blows required to advance the sampler (for example, in geotechnical boring logs for borings B-637 and B-738 in FSAR Reference 2.5.1-708).

It can be noted that each of the 88 geotechnical borings drilled in support of the detailed site subsurface investigation was advanced to a minimum depth of 100 feet (30.5 meters), with many drilled to 150 feet (45.7 meters) or more, and none encountered large paleokarst sinkholes or large open voids. As further discussed in FSAR Subsection 2.5.1.2.4, throughout a total of approximately 9,000 feet (2,744 meters) of drilling, relatively small (0.5 to 4 feet) (0.15 to 1.2 meters) rod drops were encountered once in each of only 6 borings (FSAR Reference 2.5.1-708). The locations of the borings in which rod drops occurred are shown in FSAR Figure 2.5.1-378.

None of the recorded rod drops occurred in borings drilled in either nuclear island. Two of the rod drops occurred within the Miami Limestone (B-637 and B-805), which will be completely removed beneath the nuclear islands. One of the rod drops (B-714) occurred at the bottom of the Fort Thompson Formation, as the drill penetrated the sand at the top of the Tamiami Formation. The

remaining three rod drops (B-738, B-811, and B-814) occurred within sandy zones in the Fort Thompson Formation.

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

5.3. Significance of Closed Contours on the Key Largo Isopach Map (FSAR Subsection 2.5.1.2.2)

Isopach and structure contour maps for the Key Largo Limestone and Fort Thompson Formation illustrate the thickness and surface topography of these units, which may show evidence for subsurface voids in either unit. These maps are included here as Figures 2.5AA-207, -208, -209, and -210. Geologic cross-sections A-A', B-B', C-C' and D-D' have also been revised. The locations of their surface traces are shown on Figures 2.5AA-207, -208, -209, and -210. Two versions of each of the four cross-sections are provided. Cross-sections in the first set (Figures 2.5AA-211, -212, -213, and -214) are truncated at the elevation of -200 feet (-61 meters) NAVD88 and depict the subsurface stratigraphy with a vertical exaggeration of 12 to 1. Figures 2.5AA-215, -216, -217 and -201 depict a thicker section of the subsurface stratigraphy on the same cross-sections with a vertical exaggeration of only 4 to 1.

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

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

It can be noted that, with one exception, in the few instances where closed-contour depressions have been mapped on the structure contour and isopach maps, the topographic relief within the depressions is no more than one or two feet (0.3 to 0.6 meters). This observation suggests that the

topography of the top surface of both the Key Largo Limestone and Fort Thompson Formation is relatively flat. The one exception is on the top of the Key Largo Limestone (Figure 2.5AA-209) in the vicinity of boring B-706, where the topographic relief is approximately 6 feet (1.8 meters). Comparison with the isopach map of the Key Largo Limestone (Figure 2.5AA-207) reveals that boring B-706 is within a broad area of thinning of the unit that may be an expression of paleodrainage.

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

Similarly, the structure contour map of the top of the Key Largo Limestone (Figure 2.5AA-209) does not correlate strongly with data from the microgravity geophysical survey (FSAR Figure 2.5.4-228), which provides an interpretation of the depth to which dissolution has produced softer rock with possible small voids within the Miami Limestone and Key Largo Limestone (FSAR Figure 2.5.4-226 and -227). This finding suggests that the depressions on Figure 2.5AA-209 do not indicate areas of dissolution that fully penetrate the overlying Miami Limestone and extend down into the Key Largo Limestone. However, it should be noted that the elevations of the bottom of the depressions on Figure 2.5AA-209 (-32 to -35 feet [-9.8 to -10.7 meters] NAVD88) appear to be near the limit at which the microgravity survey can resolve structures of interest (FSAR Figure 2.5.4-227).

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

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

6. Conclusions

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

An Upper Zone of secondary porosity has formed in a zone of touching-vug porosity near the contact of the Miami Limestone and the Key Largo Limestone. A Lower Zone of secondary porosity has formed in a zone of moldic porosity in the underlying Fort Thompson Formation. The mixing zone in which the Upper Zone of secondary porosity formed was active at the site during the Wisconsinan

advance of continental glaciation when the eustatic sea level was approximately 100 meters lower than the modern ocean. The Lower Zone of secondary porosity formed in a mixing zone during an earlier sea level low-stand of the Pleistocene that followed a sea level high-stand during which the Fort Thompson Formation was deposited.

The process that formed the vegetated depressions at the site and its vicinity is ongoing. However, the depressions appear to be no more than approximately 20 feet (6.1 meters) deep and are not subject to collapse into an underground cavity. The stratigraphic interval in which they occur will be removed completely during excavation of the nuclear islands. Groundwater at the site is currently saline, the fresh groundwater/saltwater interface is approximately 6 miles (9.6 kilometers) inland from the site, and mean sea level near the site is rising. Therefore, a fresh groundwater/saltwater mixing zone that would promote further carbonate dissolution within the zones of secondary porosity does not now exist at the site. Consequently, development of large underground caverns at the site with the potential for collapse is not likely.

Structure contour and isopach maps for the Key Largo Limestone and Fort Thompson Formation and cross-sections prepared with data from the site geotechnical subsurface investigation do not suggest the existence of large underground caverns or sinkholes. This conclusion is supported by the data from a multi-method surface geophysical survey designed to detect large subsurface cavities that might produce foundation instability in the nuclear islands (within the limits of the survey imposed by decreasing resolution with increasing depth, decreasing cavity size, and increasing offset from survey lines).

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

7. References

- 201 NOAA, Biscayne Bay, FL (S200) Bathymetric Digital Elevation Model (30 meter resolution) Derived from Source Hydrographic Survey Soundings Collected by NOAA, 1998. Available at www.estuarinebathymetry.noaa.gov, accessed November 7, 2011.**
- 202 Google Earth, 25° 25' 40.45" N and 80° 19' 17.56" W. Europa Technologies, Imagery date: March 26, 2011, accessed on November 8, 2011.**
- 203 Google Earth, 25° 25' 17.07" N and 80° 18' 51.66" W. Europa Technologies, Imagery date: March 26, 2011, accessed on November 8, 2011.**
- 204 Google Earth, 25° 08' 37.11" N and 80° 17' 49.54" W. Imagery date: December 23, 2010, accessed on November 7, 2011.**
- 205 Google Earth, 25° 25' 40.45" N and 80° 19' 17.58" W. Europa Technologies, U.S. Geological Survey, Imagery date: January 14, 1994, accessed on November 7, 2011.**

Proposed Turkey Point Units 6 and 7
Docket Nos. 52-040 and 52-041
FPL Response to NRC RAI No. 02.05.01-17 (eRAI 6024)
L-2013-236 Attachment 15 Page 95 of 112

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

Circle Area	Surface Type	No. of patches	Density of patches (per mi²)	Mean patch area (m²)	St. dev. of patch area (m²)	Min area (m²)	Max area (m²)
1	Subaerial	67	237	780	1420	20	7910
2	Subaerial	55	195	540	640	40	2440
3	Primarily submarine	67	237	180	150	20	700
4 ¹	Submarine	51 ¹	180	320	290	30	1420

¹ Mapping does not cover the entire area of the circle because the area of the circle extends beyond the area of aerial photo coverage; therefore, count is absolute minimum.