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

SRP Section: 02.05.01 - Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 2 (RGS2)

NRC RAI Number: 02.05.01-18 (eRAI 6024)

FSAR Figures 2.5.1-274 through 278 and 280, 281, and 287 shows annotated seismic sections, however the staff notes that more information is needed in order to evaluate the relative ages of deformation shown in these seismic cross sections.

In order for the staff to fully understand the regional site geology area and in support of 10 CFR 100.23, please indicate the ages and formation names, if known, of the various sedimentary strata on these figures. Please clarify what is the interpreted depth to faulted strata.

FPL RESPONSE:

This response provides revised FSAR Figures 2.5.1-274 through -278, -280, -281, and -287. These figures are revised to show additional information, including seismic sequence designations and ages of faulted strata, where known. Formation names are discussed in the response text when identified by the original authors. All annotations added by FPL reflect the interpretations of the original authors, with the exception of the depth to faulted strata (in either meters or seconds). The authors typically do not describe depth to faulted strata in their papers, and therefore, FPL estimated depths from the published figures. Table 1 summarizes the information below using the best estimate of the depth from the original seismic sections. Depth is provided in meters if the original seismic section provided a depth conversion on the scale; otherwise, it is provided in seconds (two-way travel time). No attempt was made to convert two-way travel time to meters. It should be noted that these estimated depths are approximate, considering the vertical scale of the figures printed in the publications (in some cases on the order of 1:20,000).

Figure 2.5.1-274

The seismic line in FSAR Figure 2.5.1-274 is from FSAR 2.5.1 Reference 785, hereafter referred to as Austin et al. (1988). Austin et al. (1988) identify 10 prominent seismic sequence boundaries above a mid-Cretaceous (?) target horizon; however, these sequences are not correlated with individual geologic formations. They interpret this target horizon as a buried shallow-water carbonate platform, with an Albian-Cenomanian (mid-Cretaceous) age. Similarly, Sheridan et al. (1981) (FSAR 2.5.1 Reference 424) hypothesize that this platform is mid-Cretaceous in age.

The only age information provided by Austin et al. (1988) for the prominent seismic sequence boundaries above the target horizon is for the 8/9 boundary (upper reflector in Figure 2.5.1-274, Figure 14 from Austin et al. (1988)), which is the only well-sampled part of the section at Site 626. They correlate the debris flows and turbidites sampled there with the Great Abaco Member of the Blake Ridge Formation, which would mean sequence 9 is composed of middle Miocene deposits. Austin et al. (1988) note that consistent fault offset is only seen at the sequence 1/2 boundary. One of these faults is interpreted to almost reach the 2/3 boundary, which lies at a depth of 1.74 kilometers (1.08 miles) beneath sea level and roughly 940 meters (3080 feet) beneath the seafloor (assuming a mean water depth of 800 meters (2620 feet), see Table 5 and Figure 13 from Austin et al. 1988. This faulting occurred between the deposition of mid-Cretaceous and middle Miocene sequences.

The revised annotated figure is presented in the Associated COLA Revisions section.

Figure 2.5.1-275

FSAR Figure 2.5.1-275 shows a seismic section from FSAR 2.5.1 Reference 791, hereafter referred to as Van Buren and Mullins (1983), depicting the Walkers Cay fault and four seismic sequences NLBB-1 (youngest) through NLBB-4 (oldest). These seismic sequences are not correlated with individual geologic formations. RAI response 2.5.1-14 also discusses the Walkers Cay fault and Figures 2.5.1–275, -276, and -277.

Van Buren and Mullins (1983) interpret layer NLBB-4 as shallow-water platform interior carbonates ranging in age from Santonian to mid-Cenomanian, which they correlate to the 83.5 Ma boundary between Santonian and Campanian limestones. This is also the top of sequence BP-4 from Shipley et al. (1978), which contains Santonian to mid-Cenomanian strata.

Van Buren and Mullins (1983) correlate layer NLBB-3 with sequence BP-3 of Shipley et al. (1978), containing Campanian to Maestrictian sediments (approximately 83.5 Ma to 65.5 Ma, according to Van Buren and Mullins 1983, Figure 6). Shipley et al. (1978) describe sequence BP-3 as outer shelf slope to open marine fine-grained carbonates.

Van Buren and Mullins (1983) interpret layer NLBB-2 as fine-grained periplatform oozes and lower-slope submarine slide/sedimentary gravity deposits. Van Buren and Mullins (1983) correlate the unconformity at the top of Layer NLBB-2 with the late Oligocene drop in sea level (approximately 30 Ma), which would mean it corresponds to the Paleocene to late-Oligocene sequence BP-2 of Shipley et al. (1978).

Van Buren and Mullins (1983) interpret layer NLBB-1 as slope-front fill facies consisting of fine-grained periplatform oozes and lower slope proximal to distal sediment gravity flow deposits, which is consistent with core samples. Van Buren and Mullins (1983) date this layer as Late Oligocene to Recent, but they do not formally correlate to strata defined by Shipley et al. (1978) in the text of their paper. However, Figure 6 from Van Buren and Mullins (1983) shows NLBB-1 corresponding to BP-1 from Shipley et al. (1978).

Van Buren and Mullins (1983) do not provide specific constraints on the upward termination of faulting in their text or figures. The base of NLBB-1 is clearly offset in Figure 2.5.1-275, and the authors note evidence for recurrent faulting within this sequence. However, Van Buren and Mullins (1983) also depict two continuous, apparently unfaulted, reflectors immediately above the fault in a line drawing of the upper half of the thickness of the Late Oligocene to Recent sedimentary package (NLBB-1). The fault tip, as dashed by Van Buren and Mullins (1983), is located within the middle portion of layer NLBB-1, approximately 100 meters (330 feet) below the seafloor.

The revised annotated figure is presented in the Associated COLA Revisions section.

Figure 2.5.1-276

FSAR Figure 2.5.1-276 is also taken from Van Buren and Mullins (1983) and includes the same stratigraphy as Figure 2.5.1-275. Depth to faulted strata is difficult to discern as much of the faulting in this figure is speculative (drawn with dashed lines), and no reflectors are depicted in the uppermost portion of the line drawing by Van Buren and Mullins (1983). Given this, FPL can only state that these faults penetrate the lower portion of NLBB-1, but a precise upward termination cannot be estimated. Four faults are depicted by Van Buren and Mullins (1983) in Figure 2.5.1-276 as offsetting the base of layer NLBB-1 (uppermost reflector) and upward into the late Oligocene to Recent section. The westernmost fault intersects the base of layer NLBB-1 at an approximate depth of 110 meters (360 feet) beneath the seafloor; however, the authors extend the fault as a dashed line to within 25 meters (82 feet) of the seafloor.

The revised annotated figure is presented in the Associated COLA Revisions section.

Figure 2.5.1-277

Austin et al. (1988) identify seven seismic stratigraphic sequences that they label A through G (top to bottom). These seismic sequences are not correlated with individual geologic formations. Comparing to other studies, Austin et al. (1988, p. 394) indicate that their F/G boundary corresponds to the NLBB-3/4 boundary of Van Buren and Mullins (Table 1 of Van Buren and Mullins 1983), marking the top of the uppermost Albian shallow-water platform carbonates sampled at Site 627 (Austin et al. 1986a). Above this, Austin et al.'s (1988) seismic sequence boundary C/D is correlated with the boundary between latest early Miocene debris flows and Early Paleocene to Early Miocene limestone at Site 627 (Austin et al. 1986a). Based on depth and seismic velocity comparisons, the C/D boundary of Austin et al. (1988, Figure 5) corresponds to the NLBB-1/2 boundary from Van Buren and Mullins (1983). Austin et al. (1988, p. 395) note that "the distinct vertical facies succession" clearly observable in LBB 17 and LBB 18 is "more chaotic" at LBB 13. Thus, the C/D boundary (and to a lesser extent, the F/G boundary) highlighted in red in Figure 2.5.1-277 represents a best effort by FPL to separate seismic facies.

In Figure 2.5.1-277, the authors point out the location of three fault strands on the lower part of the profile, but no faults are drawn within the profile to help assess the authors' interpretation of the shallowest faulted strata. The top of Austin et al.'s (1988) Early Cretaceous seismic sequence G is clearly offset in three relatively narrow zones, with the majority of displacement occurring on the westernmost fault splay, which is closest to the mapped trace of the Walkers Cay fault. Moving upsection along this splay, FPL interprets displacements to become smaller and spread over a greater width. In latest early Miocene and younger beds (seismic sequences A-C), monoclinal folding has disappeared, and the reflectors appear parallel, consistent with a decrease in slip with time.

Therefore, the base of C appears to constrain the upward limit of faulted strata (i.e., sequence D is the uppermost faulted unit). The depth to the bottom of sequence C (meters below sea level) is contoured in Austin et al. (1988) as shallowing along LBB-13 from approximately 1300 meters (4270 feet) in the east to 1160 meters (3810 feet) in the west. Similarly, Austin et al. (1988) contours the thickness of sequences A-C; along LBB-13, these sequences range from 250-300 meters (820-980 feet) thick.

Evidence of faulting and folding in Figure 2.5.1-277 is most evident along the western two fault strands; the stratigraphic relationships on the easternmost splay are more difficult to interpret. In several places near the identified fault trace, down-to-the-west apparent offsets are visible, and a syncline is developed above this splay at a depth of 1.5 seconds or within the C-D seismic sequences (Miocene to Eocene age strata).

The revised annotated figure is presented in the Associated COLA Revisions section.

Figure 2.5.1-278

FSAR Figure 2.5.1-278 shows a portion of a seismic line crossing the Santaren anticline published in FSAR 2.5.1 Reference 479, hereafter referred to as Masaferro et al. (2002). The authors correlated strong reflectors in their data to reflectors identified by FSAR 2.5.1 Reference 385, hereafter referred to as Eberli et al. (1997), further to the northwest. Eberli et al. (1997) dated their reflectors using biostratigraphic indicators collected from ODP Leg 166 boreholes, and Masaferro et al. (2002) adopt these ages when dating the key layers from C-M (bottom to top). Intermediate layers (C1, G1, etc.) are undated.

The ages of layers C-M are identified in FSAR figure 2.5.1-278. The ages for these layers are: C (23.7 Ma), D (23.2 Ma), E (19.2 Ma), F (16.0 Ma), G (15.1 Ma), H (12.2 Ma), I (10.1 Ma), J (9.0 Ma), K (6.2 to 8.7 Ma), L (5.6 Ma), and M (3.6 Ma). Geologic formations are not identified; instead, Masaferro et al. (2002) rely on the general characterization provided by Ball et al. (1985) (FSAR 2.5.1 Reference 501) and Eberli et al. (1997), who identify the entire sequence as mixed pelagic/hemipelagic sediments intermittently interrupted by platform-derived carbonates with varying amounts of clay.

Layer E (19.2 Ma) is identified by Masaferro et al. (2002) as the oldest layer that overlaps, rather than onlaps, the Santaren anticline and represents a transition to much lower fold growth rates FSAR Reference 426 (Masaferro et al. 1999, Figure 11a, Figure 13a and 13b, and Figure 15; Masaferro et al. 2002, Figure 3a and 3b). After deposition of layer L (5.6 Ma), individual modeled fold uplift rates are essentially zero; the largest uplift rate of 0.08 millimeters per year (0.003 inches per year) occurs in layer L2 (Masaferro et al. 2002, Figure 4c). The youngest interval for which a non-zero uplift rate was calculated was the M2-M3 interval, which has a 0.05 millimeters per year (0.002 inches per year) fold uplift rate (Masaferro et al. 2002). RAI response 2.5.1-15 discusses the uncertainties associated with these observations.

The revised annotated figure is presented in the Associated COLA Revisions section.

Figures 2.5.1-280 and 281

Figures 2.5.1-280 and 281 are seismic lines from offshore Cuba shown in FSAR Reference 497, hereafter referred to as Echevarria-Rodriguez et al. (1991). In both figures, the authors use Roman numerals to designate seismic horizons of Tertiary, Upper Cretaceous, and Upper Jurassic age. These horizons are not correlated with individual geologic formations. They do not trace these horizons, but FPL has presented a best effort at doing so in the attached annotated figure. In figure 2.5.1-280, which depicts seismic line A-A', Echevarria-Rodriguez et al. (1991) indicate that both the northern and southern faults terminate upward just below the seismic horizon labeled Tertiary, at approximately 0.7 and 0.5 seconds (two-way travel time) beneath the seafloor, respectively.

In Figure 2.5.1-281, seismic line B-B' has several faults, the youngest of which is depicted by Echevarria-Rodriguez et al. (1991) to terminate upward at the Upper Cretaceous seismic horizon, at approximately 1.2 seconds (two-way travel time) beneath the seafloor. FPL highlights this fault depicted by the authors in black, along with their best effort at tracing the Upper Cretaceous seismic horizon. FPL also notes that deformation may be interpreted just above the upper termination of this fault; however, the uppermost 0.26 seconds (two-way travel time) of this seismic section appear undeformed. No other stratigraphic information for these seismic lines is presented in Echevarria-Rodriguez et al. (1991).

The revised annotated-figure is presented in the Associated COLA Revisions section.

Figure 2.5.1-287

FSAR 2.5.1 Reference 484, hereafter referred to as Moretti et al. (2003), identifies seismic reflectors A-M (bottom to top). These reflectors were correlated to the known lithostratigraphy of north-central and western Cuba using existing and newly acquired analysis of samples from western Cuba. The authors note that some of the ages they present are hypothetical, and correlation to seismic reflectors is open to debate.

Group C, the lowermost unit in Figure 2.5.1-287, is interpreted as Jurassic synrift clastic deposits. Moretti et al. (2003) assign an Oxfordian age and associate this unit with the San Cayetano Formation based on source-rock potential.

Moretti et al. (2003) interpret groups D-F as middle Oxfordian to Hauteverian postrift regional platform carbonates. Group D is divided into two sections. The lower section (D1) is correlated with the Jagua Formation, which is known to form the base of this carbonate platform in western Cuba. The suggested age is upper Oxfordian. Moretti et al. (2003) correlate the upper section (D2) with the Kimmeridgian San Vicente Formation. Group E is thought to comprise the Americano, Artemisa, and Cifuentes Formations, which span upper Kimmeridgian to Tithonian time (top Jurassic). The authors suggest Group F comprises the Tumbadero, Sumidero, and Ronda formations, spanning Berriasian to Hauteverian time.

Moretti et al. (2003) interpret groups G-J as middle Cretaceous Bahama Channel deposits. Group G is correlated with the Aptian-Albian-Early Cenomanian Pons and Carmita formations by comparing onshore and offshore drill core data. Group H is correlated with the Cenomanian/Turonian Angelica Formation based on new onshore drill core analysis. The authors propose that Group J is composed of Paleocene sediments.

Groups I-M are not discussed in the text, but Figure 2 from Moretti et al. (2003) associates these groups with relative ages. Group I is thought to be late Cretaceous, groups J, K, and L are respectively correlated with the Paleocene, Eocene, and Oligocene, and Group M is Neogene to Recent.

Numerous normal faults cut Upper Jurassic and older horizons, and three of these faults appear to reach the middle Cretaceous unconformity (MCU on revised Figure 2.5.1-287), which initiated after late Cenomanian time and continued to the Maastrichtian or later. One offshore normal fault terminates upward within Group M Miocene-Pleistocene strata, within approximately 0.12 seconds of the seafloor (two-way travel time). To the south, several faults associated with the Cuban fold and thrust belt are depicted. The seismic horizons are not traced near these structures, but the faults terminate upward between 0.3 and 0.7

seconds below the seafloor (two-way travel time). In the text, Moretti et al. (2003) describe this thrusting as Eocene in age.

The revised annotated figure is presented in the Associated COLA Revisions section.

Table 1: Summary of depth to uppermost faulted strata for seismic sections

Figure Number	Feature	Uppermost Faulted Stratigraphic Layer and Age	Approximate Depth Below Seafloor to Uppermost Faulted Strata
274	Basement faults in the eastern Straits of Florida	Seismic sequence 2, age not specified by authors	940 s (3080 feet), below 2/3 sequence boundary
275	Walkers Cay fault	NLBB-1, Late Oligocene to Recent	Fault tip dashed to within 100 meters (330 feet) of seafloor by authors
276	Walkers Cay fault	NLBB-1, Late Oligocene to Recent	Westernmost fault tip dashed to within 25 meters (82 feet) of seafloor by authors
277	Walkers Cay fault	Seismic sequence D, Early Miocene	250-300 meters (820-980 feet), although this is equivocal since the authors do not draw a fault
278	Santaren anticline	Discrete faulting is not interpreted by the authors	Layer E (19.6 Ma) is first to overlap fold, uplift rate above Layer L (5.6 Ma) is indistinguishable from 0
280	Offshore Cuban fold-and-thrust belt	Just below Tertiary horizon	0.5 seconds (two-way travel time)
281	Offshore Cuban fold-and-thrust belt	Just above Upper Cretaceous horizon	1.2 seconds (two-way travel time), potentially as shallow as 0.26 s
287	Offshore Cuban fold-and-thrust belt and normal faults	Cuban fold-and-thrust belt: Eocene Normal fault: Group M, Miocene to Pleistocene	Cuban fold-and-thrust belt: 0.3-0.7 seconds (two-way travel time) Normal fault: 0.12 seconds (two-way travel time)

This response is PLANT SPECIFIC.

References:

1. Austin, J. A., Schlager, W., Palmer, A. A., et al., 1986. *Proceedings Initial reports ODP Leg 101*, Chapter 6 Site 627: Southern Blake Plateau, pp. 111-212.
2. Shipley, T.H., Buffler, R.T., and Watkins, J.S., 1978. Seismic stratigraphic and geologic history of Blake Plateau and adjacent western Atlantic continental margin, *American Association of Petroleum Geologists Bulletin,* Vol. 62, pp. 792–812.

ASSOCIATED COLA REVISIONS:

FSAR Subsection 2.5.1.1.1.3.2.2 will be revised in several instances as indicated below and as indicated to the response to RAI 2.5.1-14, concerning the Walkers Cay fault.

Mesozoic Normal Faults of the Bahama Platform

As described above, the openings of the Gulf of Mexico and Atlantic Ocean led to the development of Mesozoic normal faults that extended the basement beneath the Florida and Bahama Platforms. No detailed maps of the entire subsurface Bahama Platform exist, but limited mapping of such faults has been done in conjunction with large-scale seismic surveys. For example, Austin et al. (Reference ~~432~~**785**) identify seven normal faults cutting a Cretaceous horizon in the Exuma Sound, and a seismic line in the Straits of Florida identified several minor normal faults cutting **strata above** a **mid-**Cretaceous **shallow-water carbonate platform at a depth of 940 meters below the seafloor** ~~horizon~~ (Figure 2.5.1-274). More commonly, the basement of the Bahama Platform is depicted as a series of fault blocks with syn-tectonic Triassic to Jurassic strata, draped by undeformed Cretaceous strata (Figures 2.5.1-264 and 2.5.1-243).

Santaren Anticline

The northwest-trending detachment fold that affects Cretaceous to Miocene strata and represents the northern limit of the Cuban fold-thrust belt (Reference 501) (Figure 2.5.1-229). Initial work indicated that folding initiated in the Late Cretaceous, reached maximum expression in the early Cenozoic, and experienced differential compaction in the late Cenozoic (Reference 501), a timeline consistent with the end of Cuban orogeny in the latest Eocene. Detailed analysis of the stratigraphy indicates that the syn-tectonic growth strata may range in age from Eocene to Late Pliocene. The analysis was also used to infer Pliocene or potential Quaternary activity on the structure (References 477 and 479). However, this detailed stratigraphic analysis indicates that the vast majority of uplift or shortening occurred before 20 Ma, with an average fold uplift rate of 0.03 millimeters/year characterizing the anticline after approximately 20 Ma (Reference 479). **Layer E (19.2 Ma) is the oldest layer that overlaps, rather than onlaps, the Santaren anticline, and represents a transition to much lower fold growth rates (Figure 2.5.1-278).** Most strata younger than 15 Ma drape across the fold crest maintaining constant bed thickness, but some beds do thin across the anticline (Reference 479) (Figure 2.5.1-278). **After deposition of layer L (5.6 Ma), individual modeled fold uplift rates are essentially zero; the largest uplift rate of 0.08 mm/yr occurs in layer L2 (Reference 479). The youngest interval for which a non-zero uplift rate was calculated was the M2-M3**

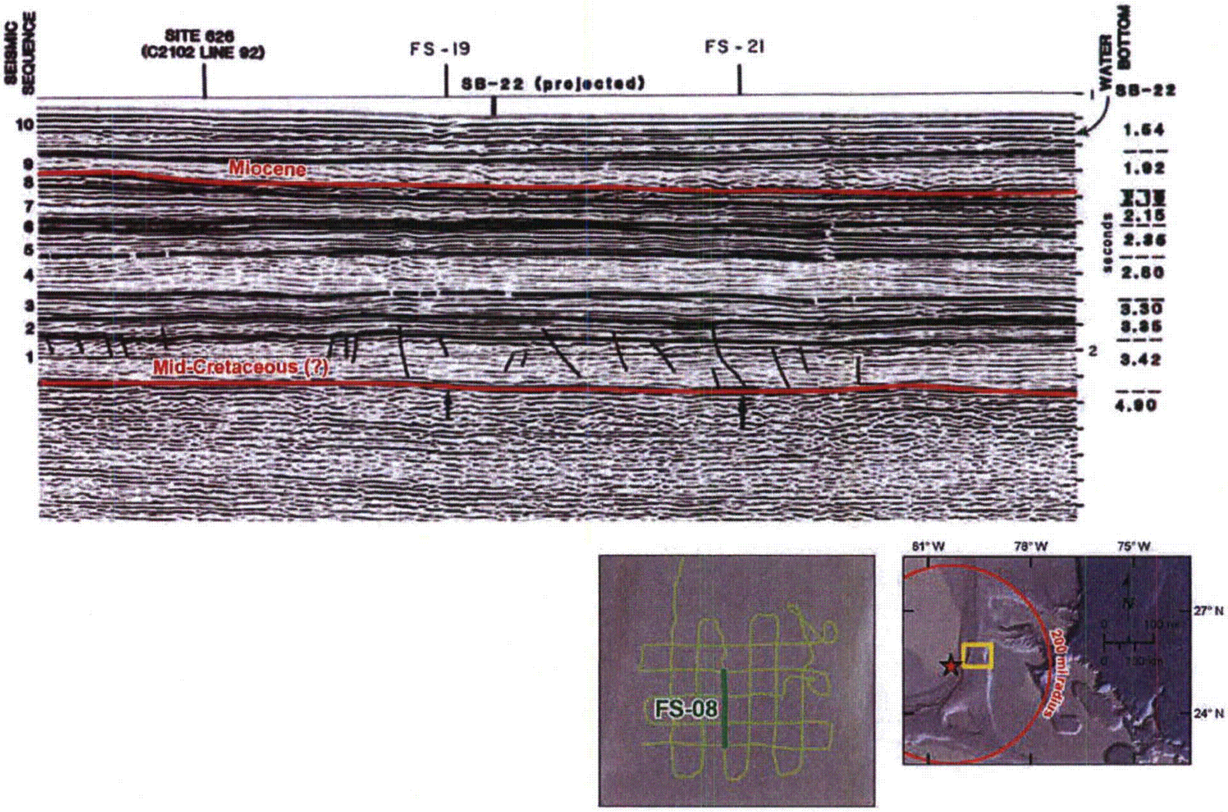
interval, which has a 0.05 mm/yr fold uplift rate (Reference 479). This could be the result of intermittent fold uplift (e.g., Reference 479) or sedimentary processes, such as localized bottom-current erosion and sediment compaction (e.g., Reference 501). The preponderance of data indicate that this structure is Tertiary in age, predominantly active in the Eocene, with waning activity throughout the Miocene. The fold may be rooted in Jurassic evaporites, the Punta Allegre formation (References 307 and 477), which could account for this structure's apparent longevity without clear tectonic mechanisms.

Cuban Fold-and-Thrust Belt

North American passive margin strata are deformed in a series of north-vergent imbricate thrusts and anticlines along the northern edge of Cuba (Figures 2.5.1-248, 2.5.1-251, 2.5.1-252, 2.5.1-279, 2.5.1-280, and 2.5.1-281). These faults and folds are exposed onshore, particularly in western Cuba, but imaged with seismic data offshore, within about 20 miles (32 kilometers) of the Cuban coastline (References 221, 484, and 485) (Figure 2.5.1-248). Syn-tectonic strata of foreland and piggyback basins are well dated onshore and indicate that the thrust faulting is Eocene in age (References 220, 485, and 439). **In two offshore seismic lines, Reference 497 indicates that north-vergent thrusts terminate either above an Upper Cretaceous horizon (Figure 2.5.1-281), or just below a Tertiary horizon (Figure 2.5.1-280).** Based upon a series of north-northeast-trending seismic lines extending north from the Cuban shoreline in the Straits of Florida, Moretti et al. (Reference 484) conclude that the foreland fold and thrust belt developed in the Eocene and indicate that post-tectonic Tertiary and Quaternary sediments are undeformed by the thrusts. **For example, in Figure 2.5.1-287, seismic horizons are not traced near the imbricate thrusts, but the faults terminate upward between 0.3 and 0.7 seconds below the seafloor (two-way travel time).** Moretti et al. (Reference 484) do note occasional Miocene reactivations of either the early Tertiary thrusts or Jurassic normal faults. On the basis of well-dated Eocene syn-tectonic strata, published structural interpretations indicating unfaulted Quaternary strata above these structures offshore, and unfaulted Pleistocene and younger terraces along the northern edge of Cuba (Reference 847) (Figure 2.5.1-282), these faults are concluded to be Tertiary in age and not capable tectonic structures.

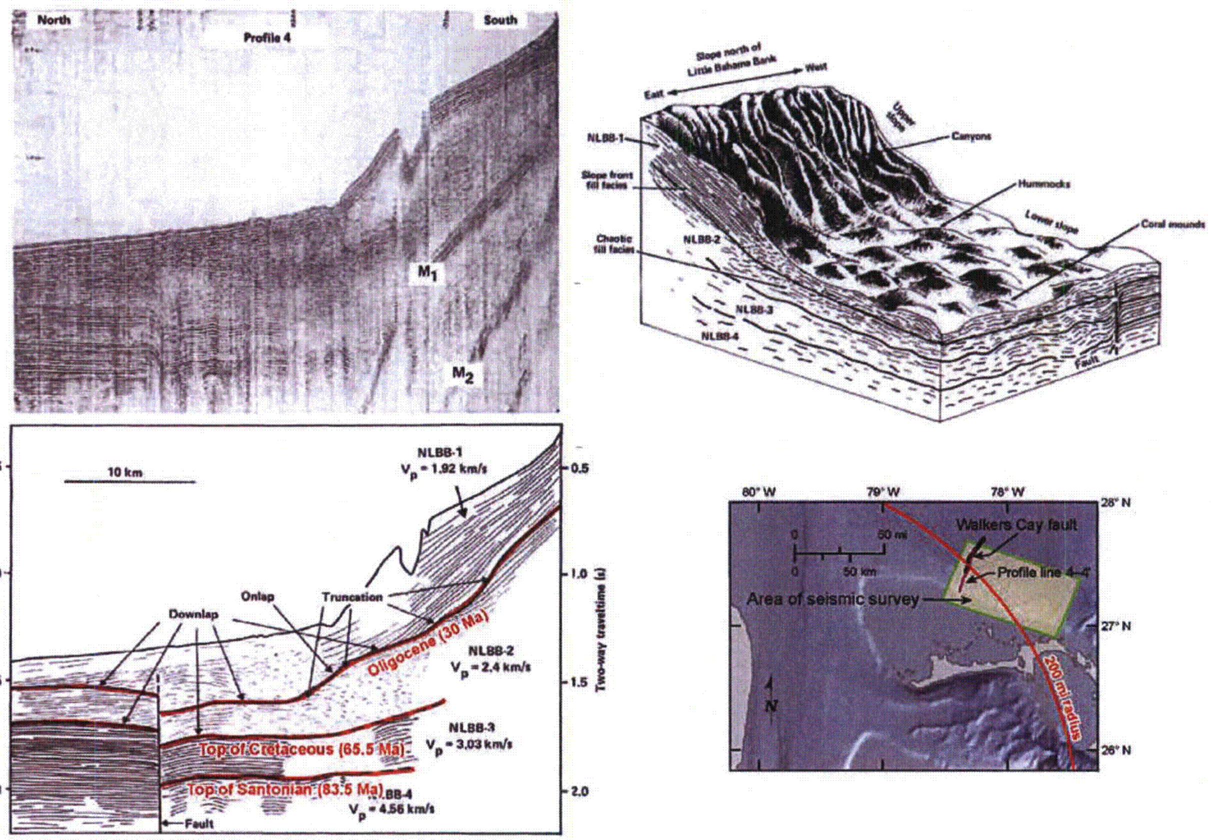
FSAR Figures 2.5.1-274, 275, 276, 277, 278, 280, 281, and 287 will be replaced with the revised figures shown below in a future revision of the FSAR.

Figure 2.5.1-274 Interpreted Versions of the Southern Half of Profile FS-08 in the Straits of Florida



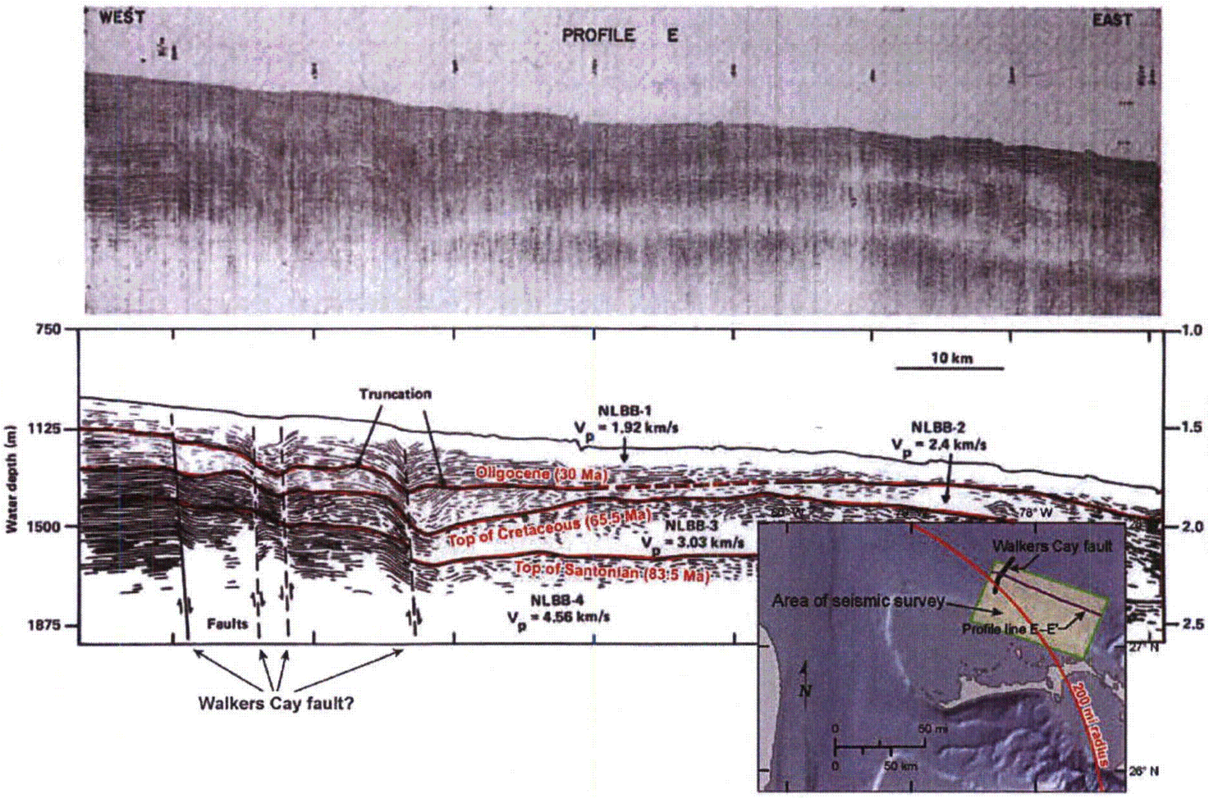
Note: Red star denotes Turkey Point Units 6 & 7.
Modified from: Reference 785

Figure 2.5.1-275 Seismic Line and Interpretation across the Walkers Cay Fault



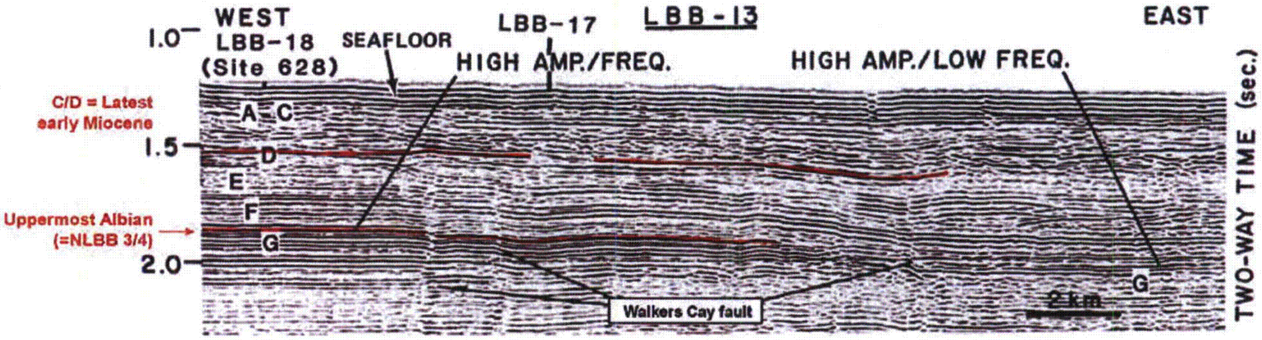
Modified from: Reference 791

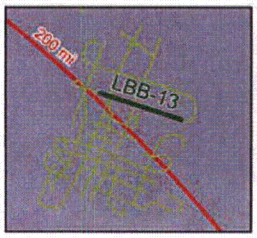
Figure 2.5.1-276 Seismic Line and Interpretation across the Walkers Cay Fault

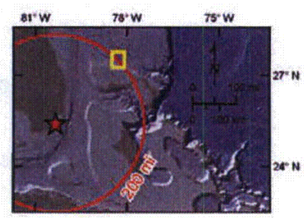


Source: Reference 791

Figure 2.5.1-277 Seismic Line along Edge of Little Bahama Bank and Walkers Cay Fault

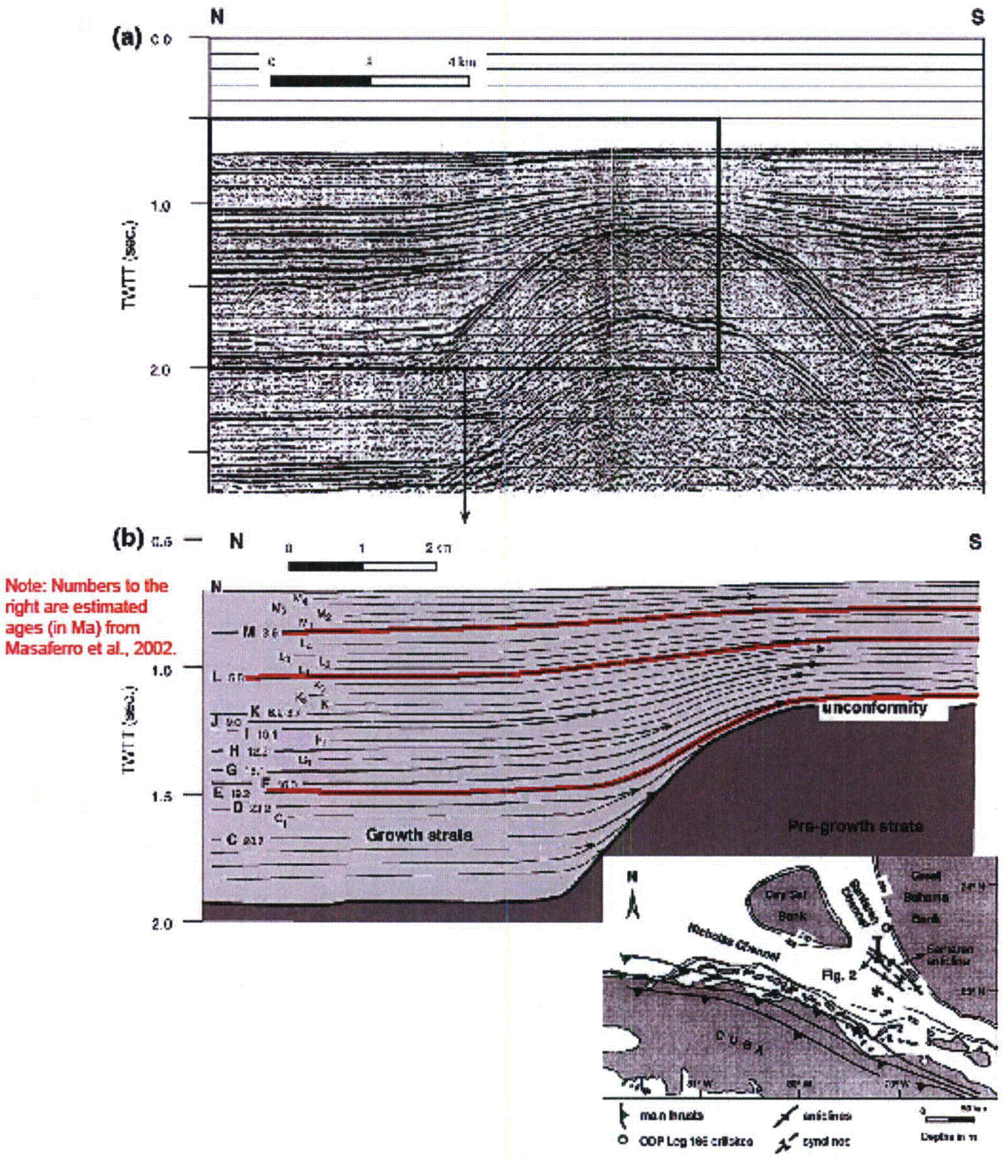






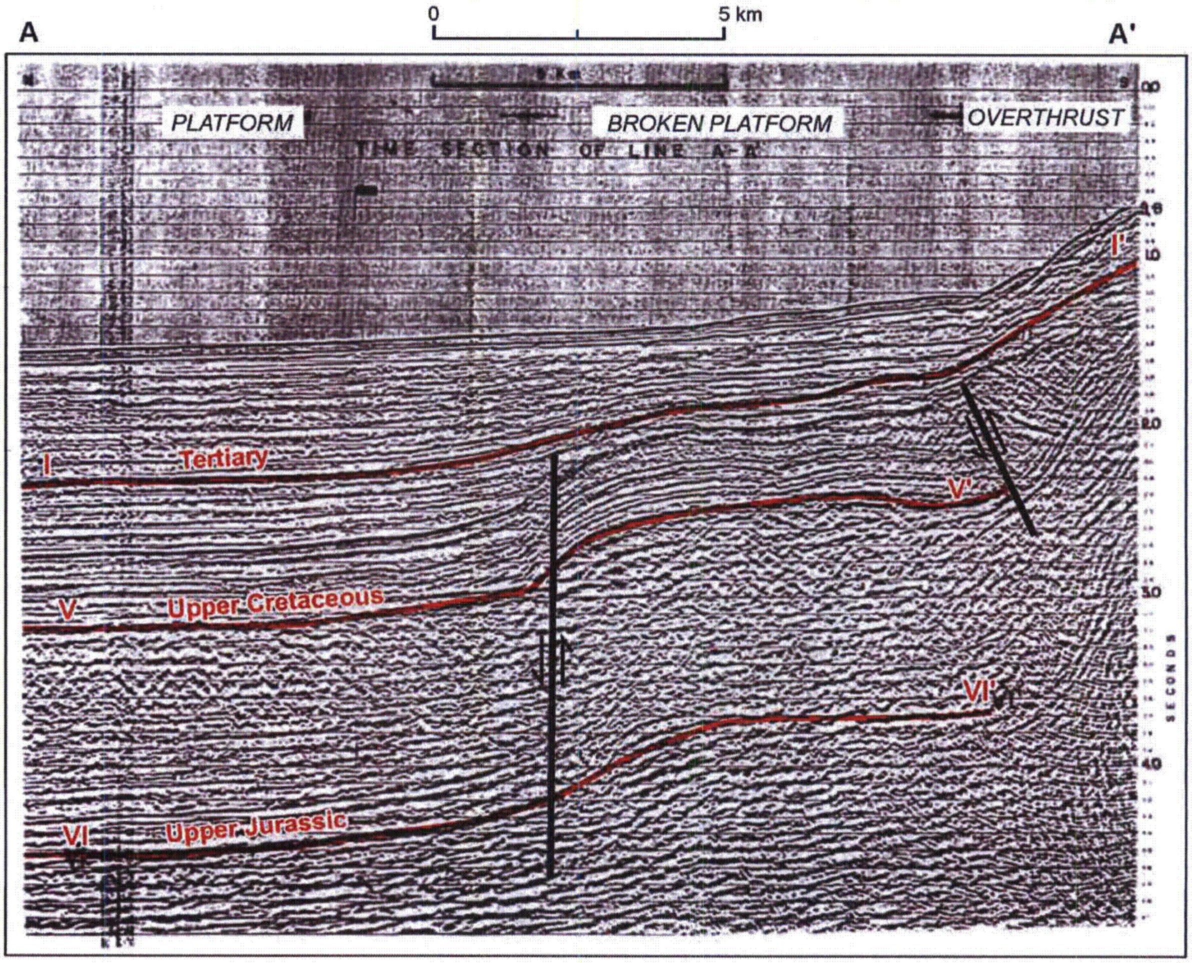
Note: Red star denotes Turkey Point Units 6 & 7.
Modified from: Reference 785

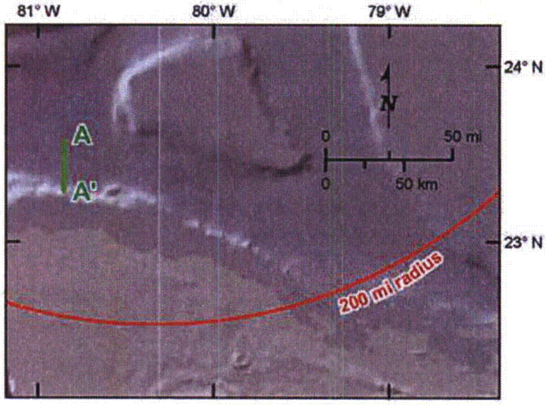
Figure 2.5.1-278 Seismic Line and Interpretation across the Santaren Anticline



Source: Reference 479

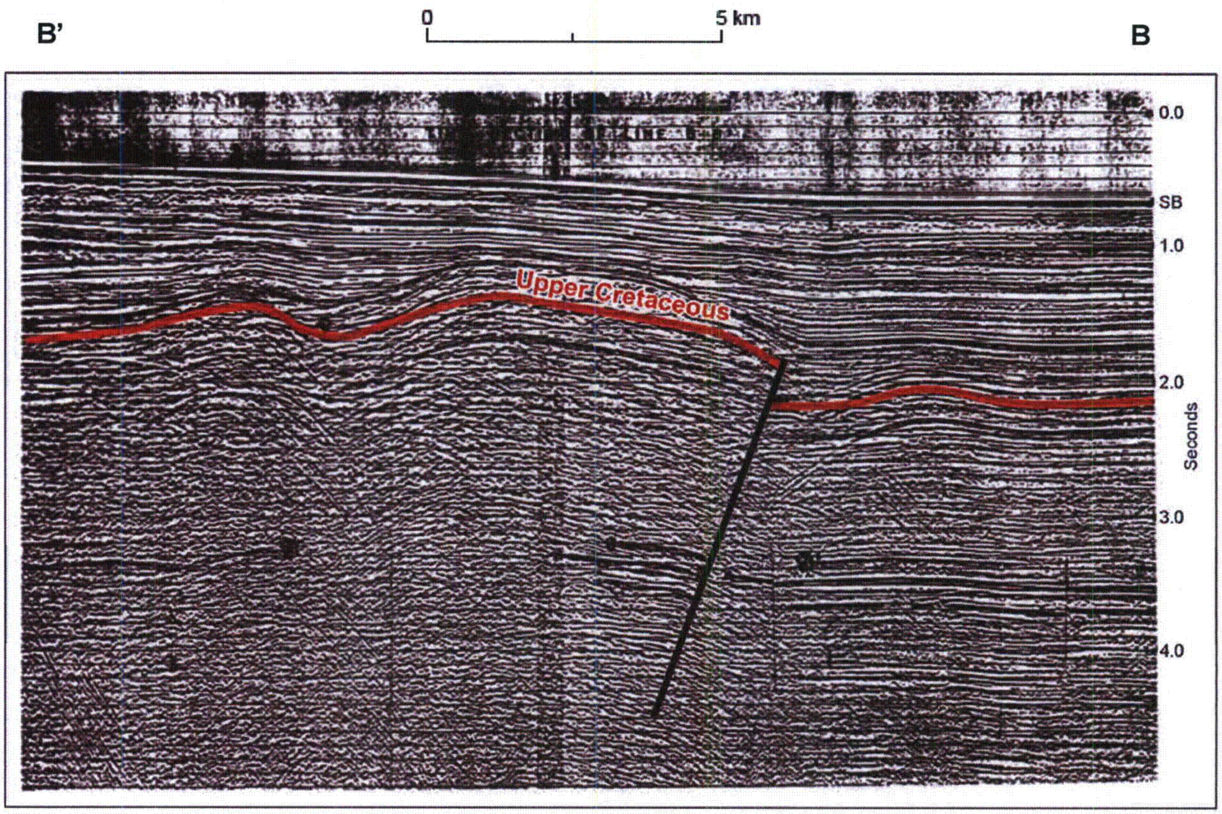
Figure 2.5.1-280 Offshore Interpreted Seismic Line, Cuban Thrust Belt

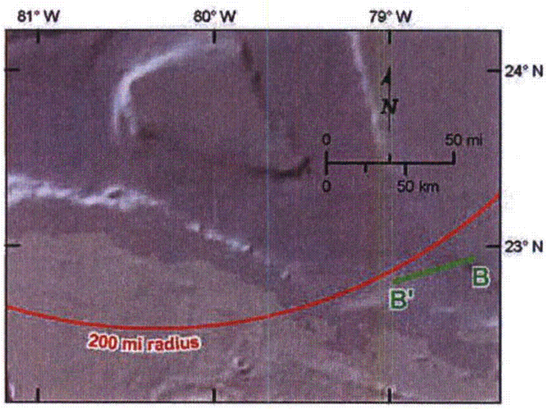




Modified from: Reference 497

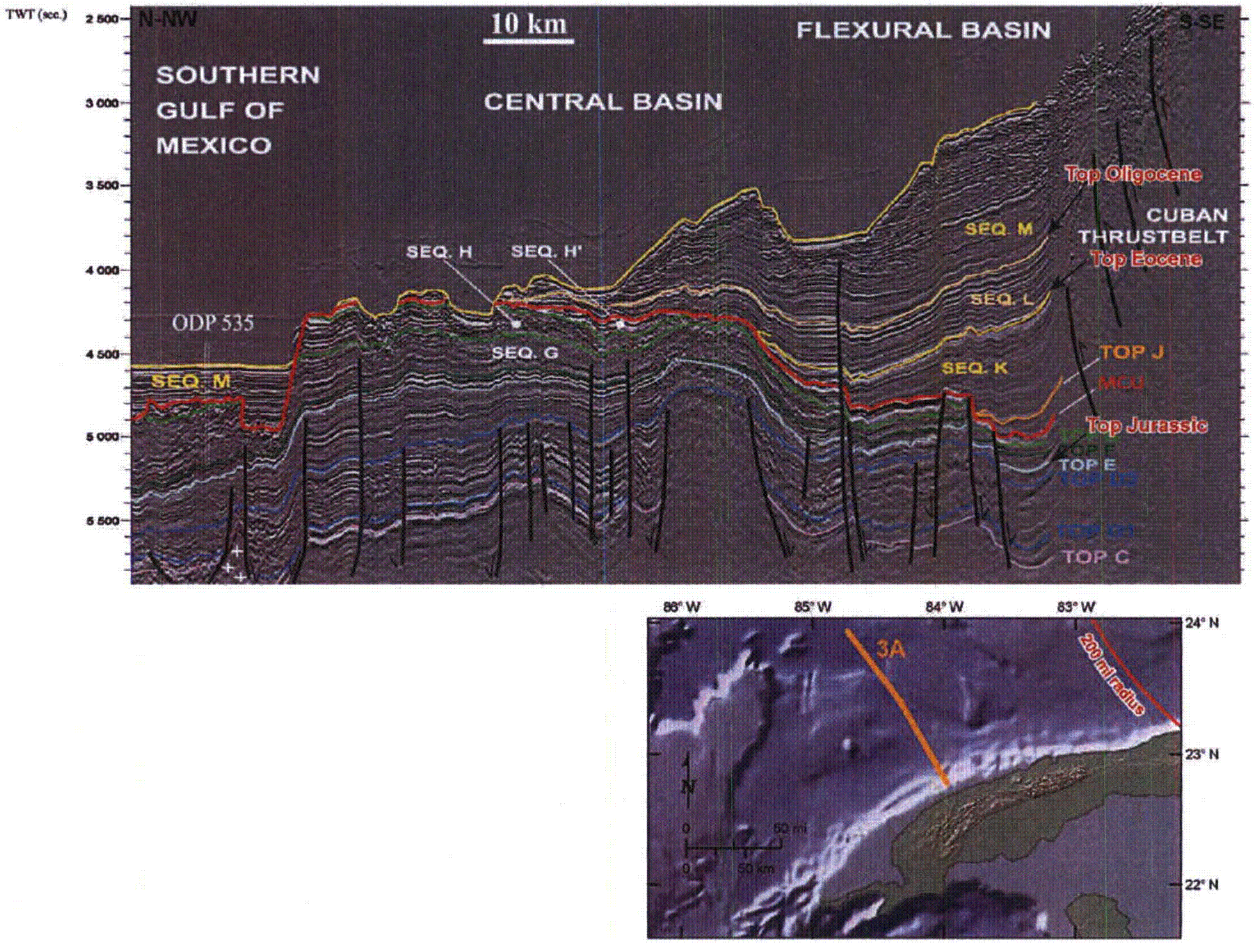
Figure 2.5.1-281 Offshore Interpreted Seismic Line, Cuban Thrust Belt





Modified from: Reference 497

Figure 2.5.1-287 Interpreted Seismic Line across Cuban Thrust Belt, Line 3A



Modified from: Reference 484

ASSOCIATED ENCLOSURES:

None

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

SRP Section: 02.05.01 - Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 2 (RGS2)

NRC RAI Number: 02.05.01-21 (eRAI 6024)

FSAR Section 2.5.2.4.4.3.2, states that an area source model is used for Cuba because of the lack of knowledge on fault behavior and slip rates for Cuban faults with which to support assessment of fault-specific sources. In order to evaluate the possibility of capable tectonic sources within the site region and in accordance with 10 CFR 100.23 please provide a detailed geologic discussion of tectonic features and their potential impact on the PSHA.

FPL RESPONSE:

The inclusion of individual fault sources in a probabilistic seismic hazard analysis (PSHA) requires some knowledge of each fault source's geometry, maximum-magnitude (Mmax), and earthquake recurrence rates. The decision to model intraplate Cuba as an areal source, as opposed to multiple fault sources or a combination of fault and areal sources, is a result of insufficient information available for individual faults in Cuba with which to characterize fault source parameters, especially slip rate. Available geologic mapping and literature provide ambiguous, and sometimes conflicting, information on fault activity, geometry, potential segmentation, and in some cases, existence. The geologic basis for the decision to model intraplate Cuba as a single areal source zone, including an evaluation of the possible ranges of technically defensible source characterizations for faults in Cuba, is discussed further in this response. The potential impacts of alternate areal source and fault characterizations on the PSHA are discussed in the response to RAI 02.05.02-04.

Similar to the central and eastern United States (CEUS), several faults are mapped within intraplate Cuba, but evidence documenting late Quaternary movement for many of these faults is lacking. Tectonic features in Cuba formed under different tectonic regimes and stress conditions than the present intraplate environment. A thorough review of literature failed to reveal paleoseismic data for any fault in Cuba. Similarly, a review of literature and geologic maps did not reveal evidence demonstrating late Quaternary activity of many faults within intraplate Cuba, even though this is asserted by some authors (e.g., Cotilla-Rodriguez et al. 2007 (FSAR 2.5.1 Reference 494)). Therefore, significant assumptions are required to categorize geologic structures as capable tectonic sources as defined in RG 1.208 or seismogenic sources for use in PSHA.

Collectively, the significant uncertainties in all of the key seismic source parameters would lead to a very speculative seismic source characterization for intraplate Cuba faults. The decision to model intraplate Cuba as a single areal source zone, as opposed to including multiple fault sources, was based on recognition of insufficient information, and in some cases conflicting information available from geologic maps and other studies, with which to constrain fault parameters. In many ways, Cuba is analogous to the central and eastern United States (CEUS), where relatively low rates of seismicity occur in crust deformed largely during old collisional events. Earthquakes in Cuba do not appear to correlate strongly with faults, many of which lack definitive geologic constraints on the timing of last movement.

The remainder of this response is divided into three sections. First, published geologic data and observations of faults in Cuba are described, with an emphasis on those features located within intraplate Cuba away from the modern plate boundary. The second section of this response describes uncertainty and alternate interpretations associated with faults and tectonic features in this region of Cuba. Finally, the third section of this response describes development of inputs for a hazard sensitivity calculation performed to assess the potential impact of fault sources in Cuba on the Turkey Point Units 6 & 7 PSHA. The input parameters for this Cuba fault source hazard sensitivity calculation were developed through the use of the senior seismic hazard analysis committee (SSHAC) Level 2 methodology (SSHAC 1997) (FSAR 2.5.2 Reference 318). The results and conclusions of the seismic hazard sensitivity calculation are presented in the response to RAI 02.05.02-04.

Geologic Data and Observations of Tectonic Features

This section presents an overview of geologic data and observations from published literature and geologic maps of Cuba highlighting what is known, and what is not known, about faults in intraplate Cuba away from the modern plate boundary. The faults described below are listed in alphabetical order and include all of the faults in intraplate Cuba away from the modern plate boundary identified by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) as "seismoactive", plus the Pinar and Surcubana faults, as depicted in Figures 1A through 1C. Responses to other RAIs that provide information on faults in Cuba include RAIs 02.05.01-22 through 02.05.01-33.

<u>Baconao fault</u>

The Baconao fault is a northwest-striking fault located in southeastern Cuba (Figure 1C). At its nearest point, the Baconao fault is approximately 330 miles (530 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) provide only minimal discussion of this fault, but describe it as "better defined in its eastern part, where it has a clear expression mainly in relief and significant seismic activity at the intersection with the [Oriente fault zone]."

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Baconao fault as active, based on geologic map relations, geomorphology, and its possible association with seismicity. Cotilla-Rodriguez et al. (2007, p. 515) (FSAR 2.5.1 Reference 494) describe the Baconao fault as "normal and reverse type with left strike-slip." Cotilla-Rodriguez et al. (2007, p. 513) (FSAR 2.5.1 Reference 494) note that, along the easternmost portion of the fault near the modern plate boundary, there are "vast, continuous and abrupt escarpments and many distorted and broken fluvial terraces of the Quaternary and Pleistocene." These observations, coupled with the proximity to the modern plate boundary (i.e., Oriente fault; Figure 1C), suggest that the eastern portion of the Baconao fault may be Quaternary active.

Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) list five earthquakes that they suggest may have occurred on the Baconao fault, all of which occurred between 1984 and 1987. Each of these five earthquakes is assigned Medvedev-Sonheuer-Karnik (MSK) intensity IV (approximate Modified Mercalli Intensity (MMI) IV) (Cotilla-Rodriguez et al. 2007) (FSAR 2.5.1 Reference 494). As shown on Figure 1C, however, there is little to no seismicity from the Phase 2 earthquake catalog along much of the length of the Baconao fault, especially along the northwestern two-thirds of its length northwest of the intersection of the Nipe fault. It should be noted that the Phase 2 catalog is a declustered catalog that includes earthquakes of M_w 3 and larger. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Baconao fault is not shown on Case and Holcombe's (1980) (FSAR 2.5.1 Reference 480) 1:2,500,000 scale map of the Caribbean. Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848), however, show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba. This unnamed fault is located in the vicinity of the Baconao fault and is depicted cutting Oligocene-Miocene strata, but covered by apparently unfaulted mid-Quaternary-age strata (Perez-Othon and Yarmoliuk 1985) (FSAR 2.5.1 Reference 848). According to mapping by Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848), the Baconao fault appears to be offset in a right-lateral sense by two strands of the northeast-striking Nipe fault. As an inset to their geologic map, Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) provide an additional map that shows their estimates of fault ages in Cuba. A modified version of their inset map is provided as Figure 2 accompanying this response. The inset map presented in Figure 2 was modified by enhancing the color-coding of the Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) age estimates and by adding fault name labels based on their relative locations. Most of the fault name labels added to the inset map are queried, however, indicating the uncertainty regarding which faults are, and which are not, shown on the inset map. If the unnamed fault depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba represents the Baconao fault, as we have assumed on Figure 2, then they indicate a Neogene-Quaternary age for the southeastern one-third of the Baconao fault. The northwestern two-thirds of the Baconao fault as shown on Figure 1C does not clearly appear on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map (Figure 2).

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Oliva Gutierrez 1989 plate III.1.2-3) and a 1:2,000,000 scale neotectonic map of Cuba (Oliva Gutierrez 1989 plate III.2.4-8). No fault names appear on these two maps so it is not clear whether the Baconao fault is shown. The geologic map of Cuba from this atlas shows an approximately 30-mile-long (50-km-long), northwest-striking fault near Santiago de Cuba that may be the Baconao fault, but this fault is restricted to southernmost Cuba, southeast of the Nipe fault. This fault appears to cut middle Eocene strata. Likewise, the neotectonic map of Cuba from this atlas shows an approximately 45-mile-long (75-km-long), northwest-striking fault in the same area of southernmost Cuba that could be the Baconao fault. The Baconao fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11). The Baconao fault is shown and labeled on Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba.

Camaguey Fault

The Camaguey fault is a northeast-striking fault located in southeastern Cuba (Figures 1B and 1C). At its nearest point, the Camaguey fault is approximately 330 miles (530 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) describe the Camaguey fault as a "regional transverse fault with lateral displacement that affects the whole crust and constitutes the boundary between two megablocks" and that "cuts young as well as old sequences." On their Figure 5, Garcia et al. (2003) (FSAR 2.5.1 Reference 489) show the Camaguey fault as a normal fault with unspecified dip direction and sense of throw. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) also note that "the gravimetric and magnetic fields show apparent inflections."

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) classify the Camaguey fault as active based on the possible association of seismicity with the fault. Cotilla-Rodriguez et al. (2007, p. 514) (FSAR 2.5.1 Reference 494) describe the Camaguey fault as a sinistral strike-slip fault with an almost vertical plane associated with a low "level of seismic activity." They list ten earthquakes that they suggest may have occurred on the Camaguey fault. Three of these earthquakes are assigned MSK intensity III – IV (approximately MMI III – IV), with the remaining seven unspecified (Cotilla-Rodriguez et al. 2007) (FSAR 2.5.1 Reference 494). As shown on Figures 1B and 1C, however, there is little to no seismicity from the Phase 2 earthquake catalog located along the length of the Camaguey fault, with the possible exception of a single, minor-magnitude earthquake near the northeastern end of the fault. Alternatively, this minor earthquake may be associated with the northwestern end of the Baconao fault or some other unmapped structure (Figure 1C). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Camaguey fault is not consistently shown on geologic and tectonic maps of Cuba. For example, it is not labeled on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba, Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba, the Nuevo Atlas Nacional de Cuba 1:1,000,000 scale geologic map (Oliva Gutierrez 1989 plate III.1.2-3), and van Hinsbergen et al.'s (2009) (FSAR 2.5.1 Reference 500) mapping of the Camaguey area. The Camaguey fault is depicted and labeled on the 1:2,000,000 scale lineament map from the national atlas (Oliva Gutierrez 1989 plate III.3.1-11) and shown but not labeled on the 1:2,000,000 scale neotectonic map from the same atlas (Oliva Gutierrez 1989 plate III.2.4-8). Because they do not label faults by name, it is not clear whether the Camaguey fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Camaguey fault (Figure 2).

Cochinos Fault

The Cochinos fault is a north- (Hall et al. 2004; Cotilla-Rodriguez et al. 2007) (FSAR 2.5.1 References 770 and 494) to north-northwest-striking (Mann et al. 1990) (FSAR 2.5.1 Reference 493) fault in south-central Cuba. Figures 1A and 1B show the location of the Cochinos fault after Hall et al. (2004) (FSAR 2.5.1 Reference 770). As mapped by Hall et al. (2004) (FSAR 2.5.1 Reference 770), the fault at its nearest point is approximately 205 miles (330 km) from the Turkey Point Units 6 & 7 site. Alternatively, mapping by Cotilla-

Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) suggests this fault may extend northward to within 175 miles (280 km) of the site, whereas mapping by Mann et al. (1990) (FSAR 2.5.1 Reference 493) indicates a closest distance of approximately 210 miles (340 km). The Cochinos fault is the only onshore feature in intraplate Cuba identified as "neotectonic" by Mann et al. (1990) (FSAR 2.5.1 Reference 493) (FSAR Figure 2.5.1-286). They map the Cochinos fault as two parallel, north-northwest-striking normal faults that form a graben (FSAR Figure 2.5.1-286). The morphology of Bahia de Cochinos is consistent with this interpretation and suggests the possibility of fault control on the landscape.

Cotilla-Rodriguez et al. (2007, pp. 514-515) (FSAR 2.5.1 Reference 494) describe the - Cochinos fault as a "normal fault with a few inverse type sectors which demonstrates transcurrence to the left" and "normal and reverse type with left strike-slip." Recorded seismicity near the Cochinos fault is sparse. They list six earthquakes that they suggest may have occurred on the Cochinos fault. The largest of these is the December 16, 1982 Ms 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_w 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 1A and 1B). Based on the similarity in location, magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (2007) (FSAR Reference 494) manuscript. The remaining five earthquakes that Cotilla-Rodriguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) associate with the Cochinos fault "are all of low [and unspecified] intensity." In the Phase 2 earthquake catalog, the 1982 earthquake is located approximately 3 miles (5 km) northwest of the Cochinos fault trace (Figures 1A and 1B). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) suggest that the 1982 earthquake may instead have occurred on the Habana-Cienfuegos fault. In addition to the 1982 earthquake, the Phase 2 earthquake catalog shows only four other earthquakes within 20 miles (32 km) of the Cochinos fault, the largest of which is assigned M_w 4.1 (Figures 1A and 1B). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) classify the Cochinos fault as active based on the possible association of seismicity with the fault. Cotilla-Rodríguez et al. (2007, p. 514) (FSAR 2.5.1 Reference 494) provide no geologic evidence for activity on the Cochinos fault and describe the fault as "covered by young sediments." Indeed, the most detailed geologic maps inspected in the area (1:250,000 scale) show no fault cutting Miocene and younger strata (Pushcharovskiy et al. 1988) (FSAR 2.5.1 Reference 846). Because they do not label faults by name, it is not clear whether the Cochinos fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Cochinos fault (Figure 2). Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba shows and labels the approximately 60-mile-long (100-km-long) Cochinos fault. The southern approximately 50 miles (80 km) of this fault are shown as a dashed line. Garcia et al. (2003) (FSAR 2.5.1 Reference 489) provide no discussion of the Cochinos fault.

The Cochinos fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989). The 1:1,000,000 scale geologic map of Cuba from this atlas (Oliva Gutierrez 1989 plate III.1.2-3) shows an approximately 87-mile-long (140-km-long) unnamed fault in the vicinity of the Cochinos fault that extends from Cuba's northern coast where it is mapped in Pliocene-age deposits southward into the Bahia de Cochinos. The southernmost 18 miles (30 km) of this fault are shown by a dashed line. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Oliva Gutierrez 1989 plate III.2.4-8) shows an approximately 87-mile-long (140-km-long) unnamed fault in the vicinity of the Cochinos fault, the southernmost 30 miles (50 km) of which is offshore southern Cuba and shown by a dashed line. To the north, this fault on the neotectonic map is truncated by the Hicacos fault. The Cochinos fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11). The 1:1,000,000 scale geomorphic map from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate IV.3.2-3) shows an approximately 37-mile-long (60-km-long) unnamed fault in the vicinity of the Cochinos fault. The map explanation indicates that this fault cuts a Quaternary-age marine abrasion platform that is at an elevation of either 2 – 3 m or 5 – 7 m above sea level. They do not provide explanation for the lack of specificity in elevation of the platform nor do they provide a precise age for the Quaternary abrasion platform.

Cubitas Fault

The Cubitas fault is a northwest-striking, steeply south-dipping fault located in southeastern Cuba (Figures 1B and 1C). At its nearest point, the Cubitas fault is approximately 270 miles (435 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) describe the Cubitas fault as a "deep fault that constitutes a portion of the Cuban marginal suture and is considered to be the main structure in central Cuba. It is cut by the Camaguey and the La Trocha transverse faults, where seismicity is documented." They associate the 1974 Ms 4.5 MSK VII Esmeralda earthquake (month and day unspecified) with the Cubitas fault.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Cubitas fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (2007, pp. 514-515) (FSAR 2.5.1 Reference 494) describe the Cubitas fault as "an almost vertical normal fault with some sectors of inverse type" and as "normal and reverse type." They describe large scarps associated with this fault, but do not provide additional descriptions of the scarps. They assign a Pliocene to Quaternary age for this fault. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) list fifteen earthquakes that they suggest may have occurred on the Cubitas fault. Eight of these earthquakes are assigned MSK intensity III – V (approximately MMI III – V), with the remaining seven unspecified (Cotilla-Rodriguez et al. 2007) (FSAR 2.5.1 Reference 494). The Phase 2 earthquake catalog includes several low-magnitude earthquakes that may be spatially associated with the northwestern half of the Cubitas fault (Figures 1B and 1C). The central and southeastern portions of the fault appear largely devoid of seismicity. The Phase 2 earthquake catalog indicates M_w 4.0 and M_w 5.1 earthquakes occurred approximately 15 miles (24 km) south of the mapped trace near the northwestern end of the fault in 1974 and 1984, respectively, which may be associated with the Cubitas fault. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Van Hinsbergen et al. (2009) (FSAR 2.5.1 Reference 500) describe the Cubitas fault as a post-Middle Eocene, south-dipping normal fault that forms a steep slope along the southern margin of the Cubitas Hills. They describe approximately 650 feet (200 m) of uplift associated with the Cubitas Hills that post-dates deposition of Pliocene-Pleistocene (?) fluvial deposits north of the hills. If this interpretation is correct, then this uplift may have occurred in the hanging wall of the Cubitas fault, which may be Quaternary-active (van Hinsbergen et al. 2009) (FSAR 2.5.1 Reference 500).

Pushcharovskiy et al. 1988 (FSAR 2.5.1 Reference 846) do not label the Cubitas fault on their 1:250,000 scale geologic map. Pushcharovskiy (1989) (FSAR 2.5.1 Reference 847) shows the Cubitas fault as an approximately 50-mile-long (85-km-long), south-dipping thrust fault on the 1:500,000 scale tectonic map. Because they do not label faults by name, it is not clear whether the Cubitas fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Cubitas fault (Figure 2).

The Cubitas fault does not appear on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3), but seemingly does appear as an unnamed fault on the 1:2,000,000 scale neotectonic map from this same atlas (plate III.2.4-8). The 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11) labels an approximately 50-mile-long (85-km-long) feature as the Cubitas fault.

Guane Fault

The subsurface Guane fault is a northeast-striking fault in western Cuba (Figure 1A). At its nearest point, the Guane fault is approximately 230 miles (370 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (2003) (FSAR 2.5.1 Reference 489) provide no discussion of the Guane fault.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Guane fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) describe the Guane fault as a "large and complex structure totally covered by young sediments in the Palacios Basin" that is "predominantly vertical with left transcurrence." They list nineteen earthquakes that they suggest may have occurred on the Guane fault, many of which are listed by year only without month, day, intensity, and magnitude information. The largest of these is the January 23, 1880 M_w 6.1 San Cristobal earthquake. In the Phase 2 earthquake catalog, seismicity in the vicinity of the Guane fault is sparse, but other light- to moderate-magnitude earthquakes within 20 miles (32 km) of the fault include the May 20, 1937 M_w 5.1, December 20, 1937 M_w 5.1, October 12, 1944 M_w 4.0, and September 11, 1957 M_w 4.0 earthquakes (Figure 1A). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Based on their review of aerial photographs and satellite imagery, Cotilla-Rodriguez and Cordoba-Barba (2010, p. 186) note two rivers in the Palacios Basin (Bayate and San Cristobal rivers) that show, in plan view, what they call "fluvial inflections" that they interpret as the result of surface deformation associated with the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (2010, p. 186) indicate this allows for "the identification of an SW-NE alignment on the south plain of Pinar del Rio, corresponding to the Guane fault, whith *[sic]* was responsible for the San Cristobal earthquake on the 28.01.1880." However, other rivers along strike to the northeast and southwest do not appear to show such inflections. Moreover, Cotilla-Rodriguez et al. (2007, p. 516) indicate the Guane fault is "totally covered by young sediments in the Palacios Basin." Likewise, Cotilla-Rodriguez and Cordoba-Barba (2011, p. 501) indicate the Guane fault "is located under ample thicknesses of sediments of the plain in southern Pinar del Rio." The Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) and Cotilla-Rodriguez and Cordoba-Barba (2011) studies do not specify a burial depth for the Guane fault, but seemingly are at odds with Cotilla-Rodriguez and Cordoba-Barba's (2010) interpretation of surface manifestation of deformation.

Cotilla-Rodriguez and Cordoba-Barba (2011) describe historical accounts of the January 23, 1880 earthquake, including first-hand observations of earthquake damage in San Cristobal, Candelaria, and elsewhere in the region. They note that the most severe and concentrated damage was located not in the mountainous regions of the Sierra del Rosario and Sierra de los Organos near the Pinar fault (discussed below), but rather within the Palacios Basin near the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (2011) cite this as evidence that the 1880 earthquake occurred on the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (2011, p. 514) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Alternatively, however, the pattern of 1880 damage could be explained by possible focusing of seismic waves within the basin, possible hanging-wall focusing effects, possible liquefaction, or possible differences in population density and building styles. In other words, the pattern of 1880 damage is not conclusive evidence that the earthquake occurred on the Guane fault, as opposed to on the Pinar fault or other structure.

The Guane fault is not depicted on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba. Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba in the vicinity of the Guane fault that cuts Miocene strata, but is covered by unfaulted Pliocene-Pleistocene units. Because they do not label faults by name, it is not clear whether the Guane fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Guane fault (Figure 2). The Guane fault does not seem to appear on any maps in the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989).

<u>Habana-Cienfuegos Fault</u>

The Habana-Cienfuegos fault is a northwest-striking, left-lateral strike-slip fault in western and central Cuba (Figures 1A and 1B). At its nearest point, the Habana-Cienfuegos fault is approximately 220 miles (355 km) from the Turkey Point Units 6 & 7 site. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) map the Habana-Cienfuegos fault as extending offshore in northern Cuba, where it terminates at or south of the Nortecubana fault, with which it forms a "morphostructural knot" (FSAR 2.5.1 Reference 494, p. 516) (Figures 1A and 1B). Offshore of southern Cuba, the Habana-Cienfuegos fault is shown as intersected and terminated by the Surcubana fault in a similar "morphostructural knot" (Figures 1A and 1B, and Figure 5 of FSAR 2.5.1 Reference 494). Cotilla-Rodriguez et al. (2007) (FSAR

2.5.1 Reference 494) indicate that the Habana-Cienfuegos fault is expressed in the topography in the northwest at Havana Bay and in the southeast at Cienfuegos Bay.

Garcia et al. (2003) (FSAR 2.5.1 Reference 489) provide minimal discussion of the Habana-Cienfuegos fault. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) indicate "although the earthquakes reported in Havana and some locations of its province cannot be attributed to the western portion of the Norte Cubana seismic region, the seismic activity of the Havana fault system is still under debate." Further to the southeast, Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) indicate that the Cienfuegos fault "coincides with a deep fault located under younger tectonic sequences, it does not have a well-defined character."

In the Phase 2 earthquake catalog, seismicity is sparse in the vicinity of the Habana-Cienfuegos fault (Figures 1A and 1B). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) list nineteen earthquakes that they suggest may have occurred on the Habana-Cienfuegos fault, many of which are listed by year only without month, day, intensity, and magnitude information. The largest of these earthquakes is the December 16, 1982 Ms 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_w 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 1A and 1B). Based on the similarity in location, magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (2007) (FSAR Reference 494) manuscript. In the Phase 2 earthquake catalog, this earthquake is located approximately 7 miles (11 km) north of the Habana-Cienfuegos fault trace (Figure 1A). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) alternatively suggest that this earthquake may have occurred on the Cochinos fault instead. They also associate a Ms 2.5 earthquake and nine MSK intensity III – V earthquakes (approximately MMI III – V) with the Habana-Cienfuegos fault. Cotilla-Rodriquez et al. (2007) (FSAR 2.5.1 Reference 494) suggest that the March 9, 1995, Ms 2.5 earthquake could have occurred on the Habana-Cienfuegos fault or on the nearby Guane fault. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Habana-Cienfuegos fault is not shown on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba and Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba. Because they do not label faults by name, it is not clear whether the Habana-Cienfuegos fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Habana-Cienfuegos fault (Figure 2).

The 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3) shows an approximately 25-mile-long (40-km-long) unnamed fault near Havana in the vicinity of the northwestern-most portion of the Habana-Cienfuegos fault as shown on Figure 1A. Similarly, the 1:2,000,000 scale neotectonic map of Cuba from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.2.4-8) shows an approximately 37-mile-long (60-km-long) unnamed fault in the same vicinity, the southeastern 12 miles (20 km) of which is shown as a dashed line. Neither of these maps from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plates III.2-3 and III.2.4-8) shows a fault extending from Havana southeastward to the southern coast of Cuba, as shown by Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494).

Hicacos fault

The Hicacos fault is an east-northeast-striking fault in north-central Cuba (Figure 1A). At its nearest point, the Hicacos fault is approximately 155 miles (250 km) south of the Turkey Point Units 6 & 7 site. Based on mapping by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494), the Hicacos fault is the nearest fault in Cuba to the site identified as active by these authors. Some publications (FSAR 2.5.1 Reference 769) refer to this fault as the Matanzas fault.

Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) provide minimal discussion of the Hicacos fault. They indicate it is "a deep fault above Paleocene-Quaternary formations, splitting the ophiolites sequence that makes the main Cuban watershed deviate abruptly, causing different types of fluvial networks." Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) state that the "earthquakes reported in Matanzas and more recently in the Varadero-Cardenas area are associated with this structure." They provide no additional information regarding these earthquakes.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Hicacos fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) describe the Hicacos fault as a "normal fault, transcurrent to the left" that is "expressed throughout the Peninsula de Hicacos and is internal in the island territory by the eastern edge of Matanzas Bay, delineating very well the Matanzas Block." Further to the west-southwest, Cotilla-Rodriguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) indicate that the Hicacos fault is "weakly represented" in the geomorphology.

Seismicity in the vicinity of the Hicacos fault is sparse (Figures 1A and 1B). The nearest epicenters from the Phase 2 earthquake catalog to the Hicacos fault are four co-located M_w 3.1 to 3.7 earthquakes that occurred near the central portion of the fault in 1812, 1852, 1854, and 1970. Another earthquake occurred in 1777 with M_w 3.7, located on strike with, but approximately 7 miles (11 kilometers) southwest of, the mapped fault trace. Likewise, Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate sparse seismicity near the Hicacos fault, and note that no focal mechanisms are associated with earthquakes in the vicinity of this fault. According to Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494), historical accounts suggest 10 earthquakes of less than or equal to MSK intensity V (approximately MMI V) occurred in the vicinity of the Hicacos fault (FSAR 2.5.1 Reference 494). However, the association of these earthquakes with the Hicacos fault or another mapped or unmapped fault is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba and the paucity of available focal plane solutions.

Case and Holcombe's (1980) (FSAR 2.5.1 Reference 480) 1:2,500,000 scale map of the Caribbean region shows segments of the Hicacos fault cutting upper Tertiary rocks. Perez-

Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) 1:500,000 scale geologic map of Cuba shows an unnamed fault in the vicinity of the Hicacos fault that extends from Matanzas for approximately 50 miles (80 kilometers) to the southwest. Because they do not label faults by name, it is not clear whether the Hicacos fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba. They indicate, however, a Mesozoic age for an unnamed fault in the vicinity of the northeastern-most portion of the Hicacos fault (Figure 2). Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba shows an unnamed fault cutting lower Miocene rocks in the vicinity of the central Hicacos fault as shown on Figure 1A, but their mapping does not extend this fault as far northeast as the north coast of Cuba. The locally northeast-trending shoreline and a narrow peninsula near Matanzas are notably linear and on-trend with the fault, likely influencing where the fault is mapped in other representations. Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba shows the northeastern extent of the Hicacos fault similar to the depiction shown in Figure 1A, and terminating to the southwest at Cuba's southern coast.

The Hicacos fault is depicted differently on different maps from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989). The 1:1,000,000 scale geologic map from this atlas (Oliva Gutierrez 1989 plate III.1.2-3) shows an unnamed, northeast-striking, approximately 25-mile-long (40-kilometer-long) fault in the in the vicinity of the Hicacos fault. This unnamed fault is mapped within lower to middle Miocene-age deposits and does not appear to cut Holocene-age deposits near Matanzas at the northeastern end of the fault. The 1:1,000,000 scale geomorphic map from this atlas (Oliva Gutierrez 1989 plate IV.3.2-3) shows an unnamed fault offshore along the narrow peninsula that may be the Hicacos fault, but this offshore fault does not extend onshore to the southwest. The Hicacos fault is labeled on the lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11) as an approximately 110-mile-long (175-km-long), northeast-trending feature that extends from near Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas on Cuba's north coast. On the lineament map, the northeastern-most 20 miles (35 km) of this feature are shown as a dashed line. The 1:2,000,000 scale neotectonic map from this atlas (Oliva Gutierrez 1989 plate III.2.4-8) shows an unnamed, northeast-striking fault in the vicinity of the Hicacos fault that extends from Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas, and offshore where it is terminated by an unnamed fault that likely is the Nortecubana fault.

Various researchers describe elevated marine terraces west of Matanzas Bay near the Hicacos fault along Cuba's north coast. Continuous and planar geomorphic surfaces like these can be used as Quaternary strain markers with which to assess the presence of tectonic deformation. Ducloz (1963) and Shanzer et al. (1975) provide observations of Pleistocene-age terraces in this region, including the Terraza de Seboruco terrace, which is currently a few meters above modern sea level. Both Ducloz (1963) and Shanzer et al. (1975) speculate that Pleistocene-age terraces in this region may have formed as the result of both tectonic uplift and global fluctuations in sea level.

More recent studies, however, conclude that tectonic uplift is not required to explain the present elevation of the Pleistocene-age Terraza de Seboruco terrace west of Matanzas Bay and near the Hicacos fault. Toscano et al.'s (1999) radiometric age dating of coral samples collected from the Terraza de Seboruco terrace indicates this surface formed at approximately 120 – 140 ka. Based on these ages, they associate the Terraza de Seboruco terrace with the global Substage 5e sea level high-stand at approximately 122 ka. Toscano et al. (1999) also observe that this terrace in the Matanzas area is just a few meters above mean sea level, similar to the elevation of other Substage 5e reef deposits throughout "stable" portions of the Caribbean, and therefore can be explained solely by changes in sea level. Toscano et al. (1999) conclude that "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba." Similarly, Pedoja et al. (2011) investigated late Quaternary coastlines worldwide and observe minor uplift relative to sea level of approximately 0.2 mm/yr, even along passive margins, outpacing eustatic sea level decreases by a factor of four. They suggest that, when accounting for eustatic changes in sea level, the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco terrace) has been uplifted at an average rate that ranges from approximately 0.00 to 0.04 mm/yr over the last approximately 122 ka, consistent with uplift rates observed from other stable margins worldwide. If the effects of eustasy are ignored, Pedoja et al.'s (2011) data allow for an uplift rate at Matanzas of approximately 0.06 mm/yr over the last approximately 122 ka, following this "conservative" (Pedoja et al. 2011, p. 5) approach.

Whereas recent studies indicate that tectonic uplift is not required to explain the present elevation of the Terraza de Seboruco terrace west of Matanzas Bay (e.g., Toscano et al. 1999; Pedoja et al. 2011), these data do not preclude activity on the Hicacos fault. As described above, the location and extent of the Hicacos fault differs between various geologic maps and published figures, so it is unclear whether the Hicacos fault is overlain by the Terraza de Seboruco terrace. Furthermore, if the sense of slip on the Hicacos fault were primarily strike-slip as opposed to dip-slip, it could be difficult to observe surface manifestation of fault-related deformation on the Terraza de Seboruco terrace.

La Trocha Fault

The La Trocha fault is a northeast-striking fault in central Cuba (Figure 1B). At its nearest point, the La Trocha fault is approximately 260 miles (420 km) from of the Turkey Point Units 6 & 7 site. Rosencrantz (1990) (FSAR 2.5.1 Reference 529) maps a northeast-striking structure across the Yucatan basin south of Cuba (FSAR Figure 2.5.1-286) and interprets it as the southwestern extension of the La Trocha fault.

Garcia et al. (2003) (FSAR 2.5.1 Reference 489) provide minimal discussion of the La Trocha fault. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) indicate it is a "deep fault more than 180 km long, with neotectonic transcurrent activity" and "its seismicity is documented by the earthquakes in the Santi Spiritus region." They also indicate that the La Trocha fault is expressed in geophysical data, but they do not elaborate.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) assign the La Trocha fault an age of Pliocene-Quaternary and also suggest a possible association with seismicity. Cotilla-Rodriguez et al. (2007, p. 517) (FSAR 2.5.1 Reference 494) describe the La Trocha fault as "a fault zone transcurrent to the left with a large angle." They suggest a possible association between three earthquakes of less than or equal to MSK intensity V (approximately MMI V) and the La Trocha fault. The Phase 2 earthquake catalog shows very sparse seismicity associated with the La Trocha fault (Figure 1B). The largest earthquakes from the Phase 2 earthquake catalog near the La Trocha fault are the March 10, 1952 M_w 4.0 and January 1, 1953 M_w 4.3 events. Cotilla-Rodriguez et al. (2007) (FSAR

2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Leroy et al. (2000) (FSAR 2.5.1 Reference 499) interpret the La Trocha fault as the northern transform limb of a proto-Cayman spreading center that was active in the early Eocene (53 Ma) and was abandoned by 49 Ma. This interpretation is the result of the southward migration of the left-lateral strike slip faults that make up the Caribbean-North America plate boundary (e.g., Mann et al. 1995) (FSAR 2.5.1 Reference 639).

The La Trocha fault is not shown on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba. Review of Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) maps in the vicinity where Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) map the La Trocha fault indicates no northeast-striking faults cutting Miocene and younger strata. Potentially, this structure is buried by the overlying strata and could be pre-middle Miocene in age. Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) tectonic map of Cuba, however, clearly depicts and labels the La Trocha fault with extent and location similar to the La Trocha fault shown in Figure 1B. Because they do not label faults by name, it is not clear whether the La Trocha fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Neogene-Quaternary age for an unnamed fault in the vicinity of the La Trocha fault (Figure 2).

The La Trocha fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989). The 1:1,000,000 scale geologic map of Cuba from this atlas (Oliva Gutierrez 1989 plate III.1.2-3) does not include the La Trocha fault. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Oliva Gutierrez 1989 plate III.2.4-8) shows an unnamed fault in the vicinity of the La Trocha fault. This unnamed fault is mapped as terminating northward at the northern coast of Cuba. The 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11) depicts and labels the La Trocha fault as an approximately 90-mile-long (150-km-long), northeast-trending feature that extends from Cuba's southern to its northern coast.

Las Villas Fault

The Las Villas fault is a northwest-striking fault in central Cuba (Figure 1B). At its nearest point, the Las Villas fault is approximately 155 miles (250 km) south of the Turkey Point Units 6 & 7 site. Pardo (2009, p. 316) (FSAR 2.5.1 Reference 439) maps the Las Villas fault as a south-dipping thrust with up to approximately 18 miles (30 km) of horizontal displacement. According to Pardo (2009) (FSAR 2.5.1 Reference 439), the Las Villas fault displaces middle Eocene units, but exhibits greater displacement of older units, indicating that most of its movement was pre-middle Eocene.

Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) describe the Las Villas fault as a "deep fault that divides the younger coastal formations of the north from the older ones of the south, it appears as a negative anomaly in the gravimetric map and with positive and negative anomalies in the magnetic field. Medium-magnitude seismicity is associated with this fault."

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Las Villas fault as active based on its possible association with seismicity and geomorphic expression.

Cotilla-Rodríguez et al. (2007, p. 517) (FSAR 2.5.1 Reference 494), however, provide only the following minimal description of the Las Villas fault:

> "This fault maintains the prevailing strike of the island on the southern part of the Alturas del Norte de Las Villas, from the surroundings of the Sierra Bibanasi to the Sierra de Jatibonico. It is a normal type fault with a large angle, with inverse type sectors. It is intercepted to the east by the La Trocha fault. Its outline has young eroded scarps. It is of Pliocene-Quaternary age. The associated seismic events are: 15.08.1939 (Ms = 5.6); 01.01.1953 (I = 5 MSK); I = 4 MSK; (03.02.1952 and 25.05.1960), 22.01.1983 (I = 3 MSK); and noticeable without specification 04.01.1988."

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) do not describe their basis for concluding that the Las Villas fault is Pliocene–Quaternary in age and they do not provide reference to other publications that provide this information. Likewise, Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) do not provide additional discussion of the "young eroded scarps", nor do they provide reference to other publications that provide this information. It is not clear from this limited description if these are fault scarps formed directly by recent slip on the Las Villas fault or if they are fault-line scarps formed by recent differential erosion along the fault trace. It is also possible that these "young eroded scarps" formed by preferential erosion of sheared rocks within the fault zone. Based on the scant information provided in Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494), it is not possible to distinguish between these alternatives. There are no known paleoseismic trench studies or detailed geomorphic assessments of the Las Villas fault with which to assess recent earthquake activity on this fault. Where faults exhibit scarps in young deposits or surfaces, such as the Baconao fault in southernmost Cuba, Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) provide clear description and do not include "eroded" in the description.

Figure 1B indicates moderately sparse seismicity from the Phase 2 earthquake catalog that may be roughly aligned with the Las Villas fault, as mapped by Pardo (2009) (FSAR 2.5.1 Reference 439). A total of 33 earthquakes from the Phase 2 earthquake catalog are located within approximately 6 miles (10 km) of the Las Villas fault along its length. Of these, 29 are located northeast of the trace of this southwest-dipping fault, with the remaining four located southwest of the fault trace. The largest earthquake near the Las Villas fault is the August 12, 1873 M_w 5.1 earthquake, located approximately 3 miles (5 km) northeast of the fault (Figure 1B). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate focal mechanisms for these earthquakes are unavailable, so it is not possible to assess whether these possibly roughly aligned epicenters occurred on the Las Villas fault or on another fault or faults. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) suggest that the largest recorded earthquake associated with the Las Villas fault is the Ms 5.6 event on August 15, 1939 (listed in the Phase 2 earthquake as M_w 5.84). Based on the fault mapping of Pardo (2009) (FSAR 2.5.1 Reference 439) and the location of this earthquake from the Phase 2 earthquake catalog, however, this earthquake is located approximately 20 miles (32 km) northeast of this southwest-dipping fault (Figure 1B), suggesting a fault other than the Las Villas ruptured during this event.

Review of geologic mapping (Case and Holcombe 1980; Perez-Othon and Yarmoliuk 1985; Pushcharovskiy et al. 1988) (FSAR 2.5.1 References 480, 848, and 846) reveals that no units of Quaternary age are faulted, but the coarse scale of mapping (1:250,000 to 1:2,500,000) does not preclude recent activity. Because they do not label faults by name, it is not clear whether the Las Villas fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Las Villas fault (Figure 2).

The Las Villas fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Oliva Gutierrez 1989 plate III.2.4-8) shows an unnamed fault in the vicinity of the Las Villas fault. Likewise, the 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11) depicts and labels the Las Villas fault as an approximately 120-mile-long (190-km-long), northwest-trending feature.

Nipe Fault

The Nipe fault is a northeast-striking fault in southern Cuba (Figure 1C) that separates the mountainous Sierra Maestra province on the east from the Camaguey terrane on the west. At its nearest point, the Nipe fault is approximately 420 miles (675 km) from the Turkey Point Units 6 & 7 site. Other names for this fault include the Cauto, Cauto-Nipe, Guacanayabo, and Nipe-Guacanayabo fault.

Leroy et al. (2000) (FSAR 2.5.1 Reference 499) and Rojas-Agramonte et al. (2008) (FSAR 2.5.1 Reference 445) interpret the Nipe fault as the southern transform limb of the early Cayman spreading center. In their models, the Nipe fault was abandoned by the early Oligocene (approximately 20 Ma) as the plate boundary shifted south to its present location at the Oriente fault.

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Nipe fault as active based on possible association of seismicity with the fault and gross geomorphic expression. Cotilla-Rodriguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) describe the Nipe fault as "a fault system with transcurrence to the left" whose "outline is labeled by several epicenters" including "some epicentral swarms" near its northeastern end. The Phase 2 earthquake catalog shows sparse seismicity associated with the Nipe fault (Figure 1C). The largest earthquakes in the vicinity of the fault include the August 3, 1926 M_w 5.3 and July 19, 1962 M_w 5.36 earthquakes (Figure 1C). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Unnamed faults in the vicinity of the Nipe fault are shown on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) 1:500,000 scale geologic map of Cuba. Because they do not label faults by name, it is not clear whether the Nipe fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the mapped position of the Nipe fault (Figure 2). Unnamed faults in the vicinity of the Nipe fault also are shown on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba. Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba depicts and labels the Nipe fault as the "Cauto-Nipe" fault.

The Nipe fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Oliva Gutierrez 1989 plate III.2.4-8), however, shows two sub-parallel, unnamed faults in the vicinity of the Nipe fault. The 1:2,000,000 scale lineament map from this atlas (Oliva Gutierrez 1989 plate III.3.1-11) labels two faults as "Cauto I" and "Cauto II" in the vicinity of the Nipe fault. On this map, Cauto I strikes northeast and extends from Cuba's southern to its northern coast. Cauto II is more northerly striking and is truncated by Cauto I.

<u>Nortecubana Fault</u>

The Nortecubana fault system is the main structure within the Cuban fold-and-thrust belt offshore of, and near-shore to, northern Cuba (Figures 1A, 1B, and 1C). The Nortecubana fault system dips south with a dip angle that varies along strike. At its nearest point, the Nortecubana fault system is approximately 150 miles (240 km) from the Turkey Point Units 6 & 7 site.

The role of the Nortecubana thrust in the evolution of the Caribbean-North America plate boundary has been interpreted in different ways. The Nortecubana fault system may represent the ancestral subduction zone that was abandoned as the plate boundary shifted southward towards its current location south of Cuba. Alternatively, the Nortecubana thrust fault has been interpreted to represent the frontal decollement of an accretionary wedge associated with the collision of the Greater Antilles Arc and the North America plate south of Cuba (Iturralde-Vinent et al. 2008; Pardo 2009) (FSAR 2.5.1 References 786 and 439). Regardless of its ancestral origins, the Nortecubana fault system underlies the preponderance of folding and deformation within and just north of Cuba, which is collectively referred to as the Cuban fold-and-thrust belt. Wells drilled directly offshore of northeastern Cuba have encountered faults and repeated stratigraphy indicating Eocene thrusting (Pardo 2009) (FSAR 2.5.1 Reference 439), and seismic reflection data have imaged northward thrusting of basin deposits (Sheridan et al. 1988) (FSAR 2.5.1 Reference 307). Seismic lines typically indicate that the offshore north-vergent thrusts are draped by unfaulted late Tertiary to Quaternary sediments (Echevarria-Rodriguez 1991; Moretti et al. 2003; Saura et al., 2008) (FSAR Figures 2.5.1-279, -280, -282, -287, and -288).

Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) characterize the Nortecubana fault as active based on its possible association with seismicity. They note that the preponderance of this seismic activity is associated with eastern portions of the fault nearest the modern plate boundary. In the Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL, seismicity along the west and central portions of the Nortecubana fault is sparse (Figures 1A and 1B), relative to the easternmost portion of the fault (Figure 1C). The Phase 2 earthquake catalog includes a M_w 6.29 earthquake that occurred on February 28, 1914 off the north coast of southeastern Cuba (Figure 1C). Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) suggest this earthquake occurred on the Nortecubana fault. Due to the absence of a permanent seismic monitoring network in Cuba, however, this epicenter is poorly located. The given location, at approximately 4 miles (6 km) north-northeast of the south-dipping Nortecubana fault (and approximately 400 miles (640 km) from the Turkey Point Units 6 & 7 site), suggests that this earthquake could have occurred on another fault. Due to uncertainties in the locations of the 1914 earthquake as well as the fault, this does not preclude the 1914 earthquake from having occurred on the Nortecubana fault. No focal mechanism or depth determination for this earthquake is available with which to help identify the causative fault. It is unlikely that an earthquake of this magnitude would have ruptured to surface of the ocean floor but, even if it had, bathymetric data are insufficient to assess the presence of a submarine fault scarp and no detailed submarine paleoseismic studies are available for the region. Thus, it is not possible to definitively state whether the 1914 earthquake occurred on the Nortecubana or another fault.

The submarine Nortecubana fault typically does not appear on regional surface geologic maps. For example, the Nortecubana fault is not shown on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) 1:500,000 scale geologic map, Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3). This fault, however, is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba shows the Nortecubana fault as an unnamed, discontinuous, dashed line north of Cuba. The 1:2,000,000 scale neotectonic and lineament maps from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plates III.2.4-8 and III.3.1-11) show but do not label the Nortecubana fault as solid and dashed lines, respectively. Because they do not label faults by name, it is not clear whether the Nortecubana fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Nortecubana fault (Figure 2).

<u>*Pinar Fault*</u>

The Pinar fault is a northeast-striking, steeply southeast-dipping fault in western Cuba (Figure 1A). As mapped by Tait (2009) (FSAR 2.5.1 Reference 448) and shown on Figure 1A, the Pinar fault is located, at its nearest point, approximately 205 miles (330 km) from the Turkey Point Units 6 & 7 site. As mapped by Garcia et al. (2003) (FSAR 2.5.1 Reference 489), the Pinar fault is approximately 200 miles (320 km) southwest of the site at its nearest point. As mapped by Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494), the Pinar fault is approximately 225 miles (360 km) southwest of the site at its nearest point. Rosencrantz (1990) (FSAR 2.5.1 Reference 529) maps a series of offshore faults along the eastern Yucatan Platform and tentatively indicates they could be the offshore southwestern extension of the Pinar fault.

The Sierra del Rosario in western Cuba displays a prominent and fairly linear southeast-facing mountain front, suggesting the possibility of recent or ongoing uplift associated with the Pinar fault. There are, however, conflicting opinions in the literature regarding whether the Pinar fault is active. Garcia et al. (2003, p. 2,571) (FSAR 2.5.1 Reference 489) note the Pinar fault is grossly expressed as a prominent escarpment and suggest the Pinar fault "was reactivated in the Neogene-Quaternary" and may have produced the January 23, 1880 M_w 6.13 earthquake (Figure 1A). Cotilla-Rodríguez et al. (2007, p. 516) (FSAR 2.5.1 Reference 494) describe the Pinar fault as having "very nice relief expression" but conclude it is "inactive." Cotilla-Rodríguez et al. (2007) (FSAR 2.5.1 Reference 494) provide no evidence in support of their assessment but suggest that the 1880 earthquake instead occurred on the subsurface Guane fault, which is subparallel to the Pinar fault and is located within the Los Palacios basin to the southeast (Figure 1A). Cotilla-Rodriguez and Cordoba-Barba (2011) cite historical accounts of the severity and distribution of earthquake-related damage as evidence that the January 23, 1880 earthquake occurred on the Guane fault instead of the Pinar fault. Cotilla-Rodriguez and Cordoba-Barba (2011, p. 514) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Gordon et al. (1997) (FSAR 2.5.1 Reference 697) describe multiple phases of deformation in western Cuba in general and on the Pinar fault in particular. Gordon et al. (1997, p. 10,078-10,079) (FSAR 2.5.1 Reference 697) are unable to constrain the upper bound of the age of most-recent deformation on the Pinar fault "because lower Miocene rocks were the youngest rocks from which observations were made."

The Phase 2 earthquake catalog indicates that a M_w 6.13 earthquake occurred on January 23, 1880 in western Cuba in the vicinity of the Pinar and Guane faults (Figure 1A). The epicenter of this poorly located, pre-instrumental earthquake is approximately 7 miles (11 km) south of the trace of the steeply southeast-dipping Pinar fault and approximately 5 miles (8 km) north of the Guane fault. As Garcia et al. (2003) (FSAR 2.5.1 Reference 489) suggest, however, locational uncertainties for historical earthquakes in Cuba could be on the order of 15 to 20 kilometers or more. Based on available information, it is not possible to definitively state whether the 1880 earthquake occurred on the Guane fault, the Pinar fault, or another fault in the region. No focal mechanism or depth determination for the 1880 earthquake is available with which to help identify the causative fault. Moreover, no paleoseismic trench studies or detailed tectonic geomorphic assessments are available for the Pinar fault, Guane fault, or other faults in the region. The Phase 2 earthquake catalog indicates generally sparse seismicity in the vicinity of the Pinar fault (Figure 1A). There does not appear to be an alignment of epicenters along the Pinar fault, but rather sparse earthquakes appear distributed throughout western Cuba both north and south of the fault in the Sierra del Rosario mountains and the Palacios Basin. The Phase 2 earthquake catalog indicates that additional minor- to moderate-magnitude (M_w 4 to 5.1) earthquakes occurred in western Cuba near the Pinar and Guane faults in 1896, 1937, 1944, and 1957 (Figure 1A).

The Pinar fault is depicted on many regional scale maps of Cuba, including numerous maps in the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989) and Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba. Available geologic mapping at scales between 1:250,000 and 1:1,000,000 is consistent with an active Pinar fault. These data do not, however, require that the Pinar fault is active. Generally, there is a lack of young deposits mapped along the Pinar fault with which to assess the age of its most-recent slip. Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic mapping shows an unnamed fault in the vicinity of the Pinar fault that, along most of its length, juxtaposes Jurassic-age limestones of the Arroyo Cangre and San Cayetano formations on the northwest against Paleogene-age deposits on the southeast. This map shows the southernmost 3 miles (5 km) of the fault as a dashed line that juxtaposes Jurassic limestone on the northwest against upper Pliocene to lower

Pleistocene undifferentiated alluvial and marine deposits, which may constitute evidence for activity. Along strike immediately to the south near Playa de Galafre on Cuba's southern coast, however, the fault is covered by the same upper Pliocene to lower Pleistocene unit with no apparent deformation (Pushcharovskiy et al. 1988) (FSAR 2.5.1 Reference 846). Along the central portion of the fault near Pinar del Rio, Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic mapping shows an approximately 4-mile-long (6-km-long) section where weakly cemented upper Pliocene-lower Pleistocene undifferentiated alluvial and marine deposits on the southeast are fault-juxtaposed against middle Jurassic Arroyo Cangre formation on the northwest. This map relationship may indicate that the Plio-Pleistocene deposits are faulted. Alternatively, the Plio-Pleistocene deposits may have been deposited against pre-existing topography along the fault, and therefore possibly post-date the age of most-recent faulting. Based on the crude scale of mapping, it is unclear which of these alternative interpretations is correct.

Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) present geologic mapping of Cuba at a scale of 1:500,000. Their map does not include fault names, but shows a fault in the vicinity of the Pinar fault that generally juxtaposes Jurassic-age rocks on the northwest against Eocene to Miocene rocks on the southeast. Near Pinar del Rio, they map a small patch of Pliocene- to Pleistocene-age conglomerates that apparently are correlative with Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) upper Pliocene to lower Pleistocene undifferentiated alluvial and marine deposits in the same area and described above. According to Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) mapping, and unlike Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) mapping, these Plio-Pleistocene deposits extend very close to, but are not in contact with, the fault. Instead, Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) show Jurassic-age limestone in fault contact with Eocene-age rocks in this area. Farther to the northeast near Los Palacios, Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) show an approximately 1- to 2-mile-long (2- to 4-km-long) stretch along the central section of the fault where Quaternary alluvial deposits are juxtaposed against Jurassic carbonate rocks. The resolution of Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) mapping is insufficient to determine whether these Quaternary alluvial deposits are faulted or if they were deposited against pre-existing topography along the fault, and therefore possibly post-date the age of most-recent faulting. As an inset to their geologic map, Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) provide an additional map that shows their estimates of fault ages in Cuba. On their inset map of fault ages in Cuba, Perez-Othon and Yarmoliuk (1985) (FSAR 2.5.1 Reference 848) assign a Neogene-Quaternary age to a northeast-striking fault that is presumed to be the Pinar fault (the inset map does not include fault names). Despite this Neogene-Quaternary age on the inset map, their 1:500,000 scale geologic map shows unnamed northwest-striking faults, to which they assign a Paleogene age on their inset map, as offsetting the younger Pinar fault.

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Oliva Gutierrez 1989 plate III.1.2-3). No fault names appear on this map, but a fault in the vicinity of the Pinar fault is shown as juxtaposing Jurassic carbonate rocks on the northwest against Miocene and older rocks on the southeast. Due to the crude scale at which this map is presented, however, it is not possible to constrain with certainty the age of faulting.

This atlas also includes a 1:2,000,000 scale neotectonic map of Cuba (Oliva Gutierrez 1989 plate III.2.4-8) that defines "zones of maximum neotectonic gradient" and classifies them as "moderate", "intense", or "very intense". Only the modern plate boundary offshore southern Cuba is classified as "very intense" in this scheme. No fault names appear on this map, but a fault in the vicinity of the Pinar fault is shown within an "intense" zone.

Surcubana Fault

At its nearest distance, the Surcubana fault as mapped by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) is located approximately 230 miles (370 km) from the site (Figures 1A through 1C). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) do not include the Surcubana fault in their list of twelve "seismoactive" faults in Cuba and this fault generally is not described by other studies of faulting in Cuba (e.g., Garcia et al. 2003; Iturralde-Vinent et al. 2008; Pardo 2009) (FSAR 2.5.1 References 489, 786, and 439).

In the Phase 2 earthquake catalog, seismicity is sparse along and near the Surcubana fault, with only a dozen or so earthquakes located within approximately 20 miles (30 km) of the more than 500-mile-long (800-km-long) trace (Figures 1A through 1C). Of these earthquakes, all are low to moderate magnitude and most are located at the southeastern end of the fault near the active plate boundary and may instead be associated with the Oriente fault. The closest earthquakes to the central and western sections of the Surcubana fault from the Phase 2 earthquake catalog are located at approximately 81° west longitude (Figures 1A and 1B). The first of these is located approximately 5 miles (8 km) north of the trace and occurred on March 27, 1964 with M_w 3.7. The second is located approximately 3 miles (5 km) south of the trace and occurred on October 22, 2005 with M_w 3.8. Because they do not label faults by name, it is not clear whether the Surcubana fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Surcubana fault (Figure 2).

Like the Nortecubana fault, the submarine Surcubana fault typically does not appear on regional surface geologic maps. For example, the Surcubana fault is not shown on Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.1.2-3). This fault is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba shows the Surcubana fault as an unnamed, discontinuous, dashed line south of Cuba. The 1:2,000,000 scale neotectonic map from the Nuevo Atlas Nacional de Cuba (Oliva Gutierrez 1989 plate III.2.4-8) shows, but does not label, the Surcubana fault as a solid line. The lineament map from the same atlas (Oliva Gutierrez 1989 plate III.3.1-11) shows but does not label the Surcubana fault as discontinuous and dashed lines.

Uncertainty Associated with Published Geologic Data and Alternate Interpretations Associated with Fault Characterizations

Fault sources in a PSHA need to be characterized by assigning values and weights to geometry, Mmax, and earthquake recurrence rate. This second section of the response describes three main sources of uncertainty or data gaps associated with faults in intraplate

Cuba, away from the plate boundary, that present challenges for characterizing these faults as fault sources in the PSHA. These are: (1) the coarse scale of available geologic mapping; (2) poorly located earthquakes with highly uncertain estimates of magnitude; and (3) the lack of fault-specific paleoseismic studies for faults in Cuba. Especially problematic for the characterization of potential fault sources is the lack of recurrence and slip rate information for faults in intraplate Cuba.

Coarse Scale of Geologic Mapping

Available geologic and tectonic maps for Cuba generally are small in scale, including Case and Holcombe's (1980) (FSAR 2.5.1 Reference 480) 1:2,500,000 scale map of the Caribbean, Perez-Othon and Yarmoliuk's (1985) (FSAR 2.5.1 Reference 848) 1:500,000 scale geologic map of Cuba, Pushcharovskiy et al.'s (1988) (FSAR 2.5.1 Reference 846) 1:250,000 scale geologic map of Cuba, Pushcharovskiy's (1989) (FSAR 2.5.1 Reference 847) 1:500,000 scale tectonic map of Cuba, and geologic, tectonic, and geomorphic maps from the Nuevo Atlas Nacional de Cuba (Oliva Guitierrez 1989) that range in scale from 1:1,000,000 to 1:2,000,000. As such, they are not well suited for use in neotectonic evaluations. These are, however, the best-available maps that cover the whole of Cuba. Larger-scale maps are available in the published literature for selected areas of Cuba, but these are limited in extent, variable in quality, and most were not developed for use in neotectonic evaluations, but rather for stratigraphic or other geologic studies.

Poorly Located Earthquakes

Figures 1A through 1C show epicenters from the Phase 2 earthquake catalog and faults in Cuba. The Phase 2 earthquake catalog is declustered and includes earthquakes of M_w 3 and greater. These earthquakes include both instrumentally located earthquakes and pre-instrumental earthquakes whose locations are based on historical felt intensity reports. The accuracy of the instrument-derived earthquake locations is limited by the lack of permanent seismic recording stations in Cuba, especially for lower-magnitude earthquakes. In fact, many of the earthquake magnitudes and locations from the instrumental era are intensity-based as well, and therefore the uncertainties in locations of Cuba earthquakes are both high and variable. The accuracy of intensity-based locations is a function of the number and reliability of felt reports, the population density and distribution, and other factors. Even for earthquakes with well-constrained intensity centers there remains ambiguity in the location of the epicenter because of possible seismic wave directivity effects and other seismologic phenomena, including localized amplification of seismic waves from site effects such as basin structure.

Earthquake location errors are not shown on Figures 1A through 1C because the data with which to estimate these errors for each earthquake are not available. According to Cotilla-Rodriguez et al. (2007, p. 518) (FSAR 2.5.1 Reference 494), the "epicenter determination [for earthquakes] in the western, central, and central-eastern [portions of Cuba] have limitations because of scarce or no permanent seismic stations." The accuracy of the pre-instrumental earthquakes in Cuba is limited by the fact that felt intensity reports are restricted to onshore areas and are concentrated in near-coastal areas where population density historically is greater than the interior of the island. Both of these factors potentially bias the locations of pre-instrumental earthquakes to coastal and near-shore Cuba. Regarding the locations of pre-instrumental earthquakes in Cuba, Garcia et al. (2003, p.

2,569) (FSAR 2.5.1 Reference 489) state that, "Taking into account the complexity of the Cuban tectonic environment, the poor knowledge about the kinematic evolution of the principal fault systems, and the uncertainty in the hypocentral location of historical events (uncertainty of 15 - 20 kilometers or more in the historical coordinates is reasonable), it is impossible to associate earthquakes with individual faults." Cotilla-Rodriguez and Cordoba-Barba (2011, pp. 502-503) state, "The Cuban macroseismic catalogs possess a variable quality from one event to the next. Even though some earthquakes have been studied enough to elaborate isoseismal maps, with the resulting increase in reliability in placing the epicenter, the majority have scarce data, preventing a single association with another seismogenic zone...What is known about the seismicity is very incomplete but it becomes more detailed as one moves from west to east." This is consistent with the description in FSAR Subsection 2.5.2.1.3, which states that most earthquakes in the Cuba catalog (Alvarez et al. 1999) (FSAR 2.5.2 Reference 205), whose magnitudes have been obtained from macroseismic data, do not have well constrained locations and depend on inherently subjective information.

One of the primary lines of evidence used by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) in their assessment of active faults in Cuba is the possible association of seismicity with individual faults. Historical and instrumentally recorded earthquakes in Cuba are poorly located, however, and this along with the limited number of focal mechanisms for earthquakes in intraplate Cuba precludes the association of earthquakes with mapped faults. Cotilla-Rodriguez et al. (2007, p. 327) (FSAR 2.5.1 Reference 494) state, "the detailed association between destructive earthquakes and active tectonic features is extremely complex and not known in depth...there is not a close correlation of seismic events with individual faults in Cuba." Furthermore, Cotilla-Rodriguez et al. (2007, p. 331) (FSAR 2.5.1 Reference 494) state, "most [historical, pre-instrumental earthquakes] have scarce data and do not permit a clear association to a seismic zone. There is no uniform knowledge about the historical seismicity of Cuba."

In fact, many of the earthquakes cited by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) as evidence for fault activity are low intensity events, some of which are listed by year only without month, day, intensity, and/or magnitude information. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) do not provide details regarding their earthquake information. Therefore, it is difficult to independently evaluate the degree of association of these earthquakes with the faults.

Lack of Fault-Specific Paleoseismic Studies

The faults in intraplate Cuba have ambiguous data constraining the occurrence of large earthquakes. There are no historical observations of surface rupturing earthquakes in intraplate Cuba. A thorough review of literature performed for the Turkey Point Units 6 & 7 COL, along with discussions with local resource experts, failed to reveal paleoseismic data documenting the occurrence of late Quaternary surface-rupturing earthquakes in intraplate Cuba. Likewise, there are no fault-specific neotectonic studies or detailed geologic map relations from intraplate Cuba that provide constraints on fault slip rates. In fact, Cotilla-Rodriguez et al. (2007, p. 509) (FSAR 2.5.1 Reference 494) state "regions like Cuba with a relatively low poor record of historical and instrumental seismicity require neotectonic field work."

Collectively, the significant uncertainties or lack of constraints on slip rate information would lead to a very speculative seismic source characterization of intraplate Cuba faults. As described above, the lack of information on the recurrence of large earthquakes on these faults and the lack of fault slip-rate data are especially problematic. In cases where fault slip rate data are unavailable, seismic sources commonly are modeled as areal zones instead of discrete fault sources. The response to RAI 02.05.02-04 describes hazard sensitivity calculations performed using alternate areal source configurations for Cuba.

Inputs for Hazard Sensitivity Calculation Using Intraplate Cuba Fault Sources

Thissection of this response describes the characterization of Cuba fault sources for use in a hazard sensitivity calculation performed to assess the potential impact of intraplate Cuba faults on the Turkey Point Units 6 & 7 PSHA. As described above and in response to RAI 02.05.01-32, it is unclear which, if any, of the faults in intraplate Cuba are capable tectonic sources. Based on the available data, however, the possibility of Quaternary activity on intraplate Cuba faults cannot be precluded. For this reason, a hazard sensitivity calculation was performed to assess the potential impact of intraplate Cuba fault sources on the PSHA for the Turkey Point Units 6 & 7 site. The results and conclusions of this and other Cuba seismic hazard sensitivity calculations are presented in the response to RAI 02.05.02-04.

The input parameters for this hazard sensitivity calculation were developed through the use of the senior seismic hazard analysis committee (SSHAC) Level 2 methodology (SSHAC 1997) (FSAR 2.5.2 Reference 318). The subsections below describe the SSHAC Level 2 methodology and the resulting seismic source characterization parameters for use in the fault sources sensitivity study.

Three SSHAC studies support the Turkey Point Units 6 & 7 PSHA, only one of which is described in detail in the current response:

- The first SSHAC study was conducted to develop the seismic source characterization for the northern Caribbean region and Cuba. This first study is described in FSAR Subsection 2.5.2.4.4.3 and in the response to RAI 02.05.02-03.
- A second SSHAC study was performed to support the selection of ground motion prediction equations (GMPEs) for the Caribbean region, as described in response to RAI 02.05.02-02.
- A third SSHAC study is described in the current response and was conducted to assess the hazard sensitivity of various modeling decisions regarding Cuba seismic sources.

Specifically, the third SSHAC study described in this response was used to constrain conservative source parameters for use in hazard sensitivity calculations for: (1) possible intraplate Cuba fault sources; and (2) alternative depictions of areal seismic sources for intraplate Cuba. The current response focuses on the characterization of possible fault sources in intraplate Cuba. RAI response 02.05.02-04 provides discussion of the alternative areal source approaches for Cuba, as well as the results of both fault source and alternative areal source hazard sensitivity calculations.

Description of the SSHAC Level 2 Methodology

The SSHAC developed a formal process for conducting expert assessments and the use of expert judgment to incorporate uncertainties in PSHA (SSHAC 1997) (FSAR 2.5.2 Reference 318). The goal of the SSHAC process is to "represent the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study" (SSHAC 1997, p. 21) (FSAR 2.5.2 Reference 318). The SSHAC defines four levels of effort for capturing the range of uncertainty by the informed technical community (ITC). These are termed Levels 1 through 4. With each increasing level, there is increasing direct involvement of the ITC and, thus, increasing confidence and documentation that the center, body, and range of uncertainty in the technically defensible interpretations have been captured. Regardless of level of study, however, the goal of the SSHAC process is "to provide a representation of the informed scientific community's view of the important components and issues and, finally, the seismic hazard" (SSHAC 1997, p. 26) (FSAR 2.5.2 Reference 318). The goal of the SSHAC Level 2 study described in this response is slightly different, however, in that it was conducted to develop source characterizations for use in hazard sensitivity studies.

The SSHAC Level 2 process utilizes an individual, team, or company to act as the Technical Integrator (TI). In a SSHAC Level 2 study, the TI is responsible for reviewing data and literature and contacting experts who have developed interpretations or who have specific knowledge of the seismic sources. The TI interacts with these experts to identify issues and interpretations, and to "evaluate the viability and credibility of the various hypotheses with an eye toward capturing the range of interpretations, their credibilities, and uncertainties" (SSHAC 1997, p. 27) (FSAR 2.5.2 Reference 318). For the SSHAC Level 2 effort described in this response, the TI team comprised Dean Ostenaa, Roland LaForge, Scott Lindvall, and Ross Hartleb.

Participatory peer review throughout this SSHAC Level 2 process was provided by Robert Creed. Mr. Creed's activities continued throughout the course of the study, and included review of: (1) the list of experts to be contacted during the process (Table 1); (2) the questionnaire distributed to experts (Enclosure A); (3) incorporation of expert responses into hazard sensitivity calculations; and (4) conclusions drawn from the sensitivity calculations.

A total of eleven experts were contacted by the TI team with questions regarding the sensitivity calculations. These experts include geologists, seismologists, and hazard analysts from Cuba, the U.S., and elsewhere (Table 1). Nine of these experts were provided a standardized questionnaire outlining the goals of the study and listing specific questions to be addressed. A copy of this questionnaire is provided as Enclosure A to this response. Two of the experts (Toscano and Zapata) were contacted by the TI team prior to development of the questionnaire with specific questions related to those experts' areas of expertise. A summary of feedback from the experts is shown in Tables 2A through 2G. The level of detail provided to the TI team by the experts varies (Table 1). Some experts provided thoughtful, detailed responses and interacted with the TI team, whereas other experts provided only brief responses. Four experts either declined to participate or did not respond at all.

For many of the issues raised in the questionnaire, there is general agreement among the experts. For example, most experts acknowledge the lack of data with which to determine late Quaternary slip rates for possibly active faults in intraplate Cuba and most acknowledge that this presents a modeling challenge. The experts do, however, generally emphasize the importance of considering possible fault sources in the hazard sensitivity calculation. Similarly, when asked about the potential for double counting when fault sources are layered on top of the existing Cuba areal source zone, most experts who responded to this question (question #5 in Tables 2A through 2G) acknowledge that this approach may lead to over-estimating the contribution to site hazard from Cuba. It should be noted, however, that one expert (Wong) opines that, given the low slip rates assigned to Cuba fault sources, the impact of double counting may be minimal.

For other issues raised in the questionnaire, there is disagreement among the experts. For example, one expert (Cotilla-Rodriguez) indicates in his answer to question #2 (Table 2B) that the Pinar fault should not be included as a fault source because, in his view, the Pinar fault is not active. Cotilla-Rodriguez instead suggests that the Guane fault is active and produced the January 23, 1880 earthquake in western Cuba. Garcia et al. (2003) (FSAR 2.5.1 Reference 489), however, suggest the opposite, such that they consider the Pinar fault as active and the source of the 1880 earthquake, and they do not describe the Guane fault as a potential seismic source. Because of the uncertainty regarding whether the Pinar and/or Guane faults are active, the TI team elected to include both of these faults as sources in the hazard sensitivity calculation, each, conservatively, with a probability of activity of 1.0.

Acknowledging the lack of slip rate data for faults in intraplate Cuba, one expert (Wong, see questions #2 and 3 in Table 2F) suggests two possible approaches for constraining slip rates for fault sources: (1) assessment of satellite imagery and geomorphic expression; and (2) comparing observed seismic moment release from the Phase 2 earthquake catalog for Cuba with the predicted moment release from sensitivity fault sources, given assumed slip rates, geometries, and magnitudes for those fault sources. In response to these suggestions, the TI team considered gross geomorphic expression when assigning slip rates to fault sources and also performed a calculation of composite recurrence and moment rate for fault sources and compared the results to those from observed seismicity. This calculation is discussed in more detail in the response to RAI 02.05.02-04, with results summarized here: Using the median modeled slip rates on fault sources (Table 3), the predicted recurrence of M_w 7 earthquakes in intraplate Cuba is one every approximately 500 years. This is consistent with the fact that no earthquake of M_w 7 or greater has occurred in intraplate Cuba for at least the last approximately 500 years. Using the high limit of modeled slip rates on fault sources (Table 3), the predicted recurrence of M_w 7 earthquakes in intraplate Cuba is one every approximately 50 years, which suggests the high slip rates over-predict the occurrence of large earthquakes observed in Cuba. In addition, the median and high modeled slip rates for fault sources yield moment rates that exceed the observed moment rate from observed seismicity by factors of approximately 0.9 and 9, respectively. Thus, this calculation suggests that the median modeled slip rates for fault sources in intraplate Cuba may be appropriate. This calculation also suggests that the high limits on modeled slip rates for PSHA sensitivity studies including fault sources in intraplate Cuba may be very conservative. The TI team acknowledges that fault-based moment rates need not be equivalent to those derived from observed seismicity. This comparison of moment rates served to help inform the TI team's judgment on the selection of slip rates for the sensitivity fault sources.

Some experts suggest that we consider alternate approaches to assessing the seismic hazard from Cuba. For example, one expert (Coppersmith) suggests that we consider an "embedded faults" approach like that used in the recent seismic source characterization developed for the B.C. Hydro project (McCann et al. 2009). Embedded faults are PSHA model elements that localize seismic moment at rates based on the observed seismicity moment rate within an areal source, with the remaining fraction of the seismic moment rate assigned to the areal source as a background rate. This approach is developed for the case where localizing the seismic moment release at specific locations within the areal source is favored along features or structures that lack data regarding their activity, slip rate, etc. The TI team considered this approach, but implemented other ways of modeling the Cuba areal sources as described in response to RAI 02.05.02-04.

An additional approach recommended by two experts (Slejko and Wong, see their responses to question #4 in Tables 2D and 2F, respectively) is that the TI team consider a "smoothed" seismicity approach for the Cuba region. In this approach, recurrence parameters would be defined for a given location in consideration of the pattern of historical seismicity within some distance and with some distance-dependent weighting. This approach would model seismic hazard from observed seismicity in Cuba as an alternative to using areal sources with uniform recurrence parameter characterization. Specifically, Slejko recommends an approach like that used by "Garcia et al." (presumably Garcia et al. 2008 [FSAR 2.5.1 Reference 490], a study on which he is a co-author); Wong recommends a Gaussian smoothing approach. These approaches were considered by the TI team, but were not implemented in the current seismic hazard sensitivity calculations as discussed in the response to RAI 02.05.02-04.

Seismic Source Characterization of Cuba Faults for Hazard Sensitivity Calculation

Based on the review of published literature and interaction with experts, the TI team developed a seismic source characterization for intraplate Cuba fault sources for use in a hazard sensitivity calculation described in the response to RAI 02.05.02-04 to assess the impact on hazard at the Turkey Point Units 6 & 7 site. The input parameters for the Cuba fault sources are described below and summarized in Table 3.

- Probability of Activity: For the purpose of the hazard sensitivity calculation, it is assumed that each of the Cuba faults listed in Table 3 is a capable tectonic source with a probability of activity of 1.0. This is a conservative decision given the available geologic data. For example, some of the modeled faults are located near the active plate boundary in southeastern Cuba where uplifted marine terraces are apparent, indicating the likelihood of fault activity. On the other hand, other modeled faults in northern Cuba are located at significant distances from the active plate boundary where data from the 5e marine terrace (e.g., Toscano et al. 1999) suggest the lack of recent or ongoing tectonic uplift.
- Fault Sources and Geometries: Intraplate Cuba fault sources include Cotilla-Rodriguez et al.'s (2007) (FSAR 2.5.1 Reference 494) seismoactive faults in Cuba, plus the Pinar

fault. For the purpose of the hazard sensitivity calculation, it is assumed that all of these faults are capable tectonic sources. Faults shown on Figures 1A through 1C that are not included in the sensitivity calculation include: (1) the Oriente fault, because it is already included as a discrete fault source in the FSAR seismic source model; and (2) the Surcubana fault, because it is not considered active by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) and generally is not described by other studies of faulting in Cuba.

The Nortecubana fault is divided into three sensitivity fault sources, the Nortecubana West, Nortecubana Central, and Nortecubana East fault sources. The rationale for this division comes from Cotilla-Rodriguez and Cordoba-Barba (2010, p. 190), who state, "The fault NCF...has three segments: Western (from Cabo de San Antonio to the Peninsula de Hicacos), Central (from Peninsula de Hicacos to Cauto-Nipe), and Eastern (from Cauto-Nipe to the Punta de Masi)."

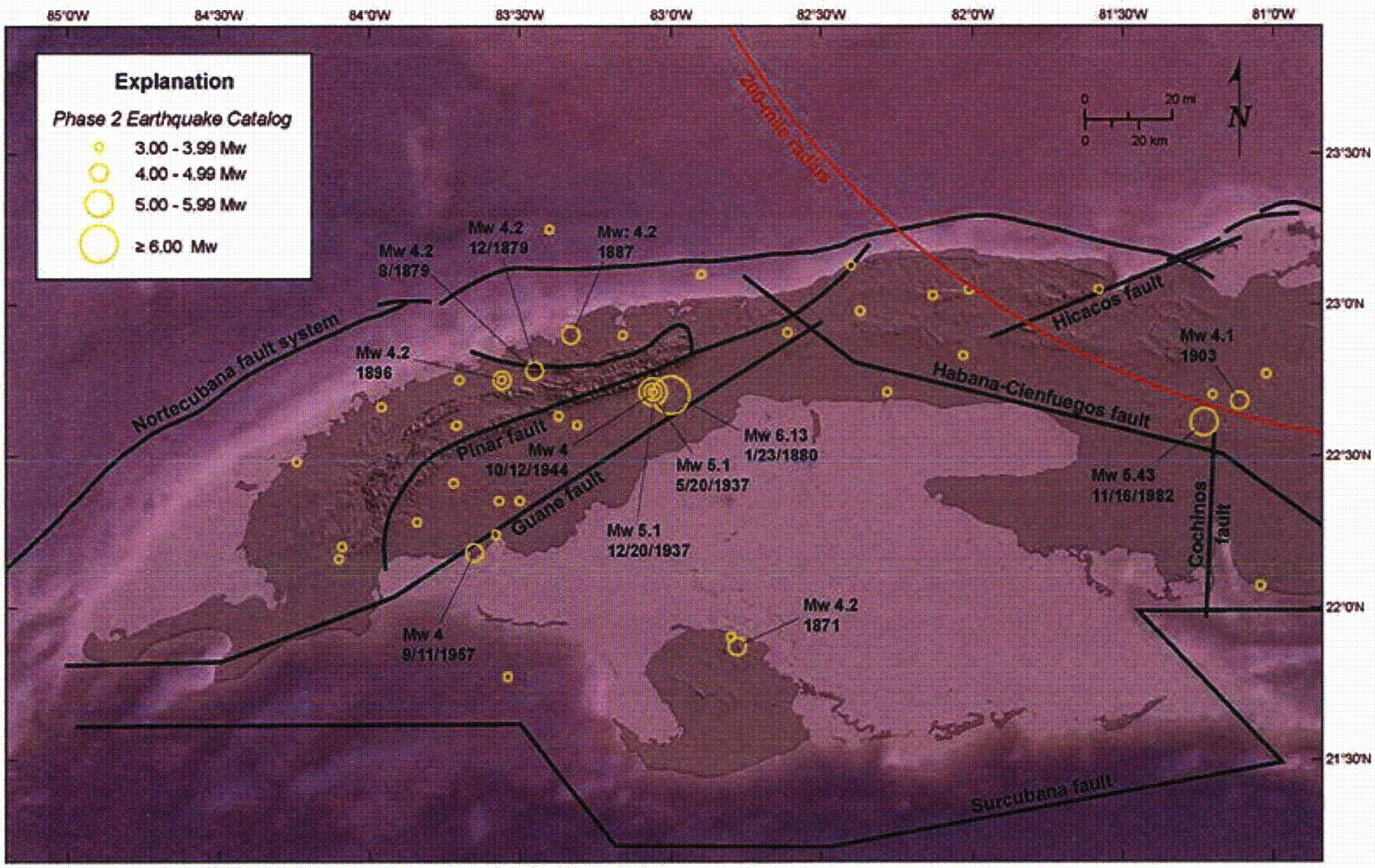
The Baconao fault is divided into two sensitivity fault sources, the Baconao Northwest and the Baconao Southeast fault sources. The basis for this division is the abrupt change in strike of the fault between these sources (Figures 1C and 3), and the greater evidence from the southeast portion of the fault supporting possible Quaternary activity.

Seismogenic depth for all fault sources in the hazard sensitivity calculation extends from 0-15 km. All fault sources are modeled with vertical dip angle, except the three Nortecubana fault sources, all of which are modeled as dipping 30° to the south.

- Maximum Magnitude Assessment: Modeled magnitude distribution [and weight] for all of the Cuba sensitivity fault sources is M_w 7.0 [0.5], 7.3 [0.5]. These values and weights are the same as those used in the FSAR for the Cuba areal source zone. The maximum magnitude (Mmax) values for the sensitivity fault sources are higher than those presented in published literature. For example, Garcia et al.'s (2003) (FSAR 2.5.1 Reference 489) Table 4 shows the range of Mmax values for fault sources in intraplate Cuba (their sources 1 through 24) from their study and previous studies, which range from M_w 5.0 to 7.0, with many at the middle to low end of this range.
- Slip Rate Assessment: There are no data to directly determine late Quaternary slip rates for potential Cuba sensitivity fault sources. For most sensitivity fault sources, slip rates in mm/yr [and weights] are assigned as 0.001 [0.33], 0.01 [0.34], 0.1 [0.33]. For the three sensitivity fault sources most proximal to the modern plate boundary, higher slip rates are assigned as 0.01 [0.1], 0.1 [0.5], 1.0 [0.4]. These slip rate distributions span orders of magnitude, reflecting the lack of data and considerable uncertainty. It is assumed that all slip is seismogenic.
- Recurrence Model: For the purpose of the hazard sensitivity calculation for Cuba fault sources, a characteristic earthquake recurrence model (Youngs and Coppersmith, 1985) is assumed for the Cuba sensitivity fault sources, but with no contribution from the exponential portion of the recurrence curve at lower magnitudes.

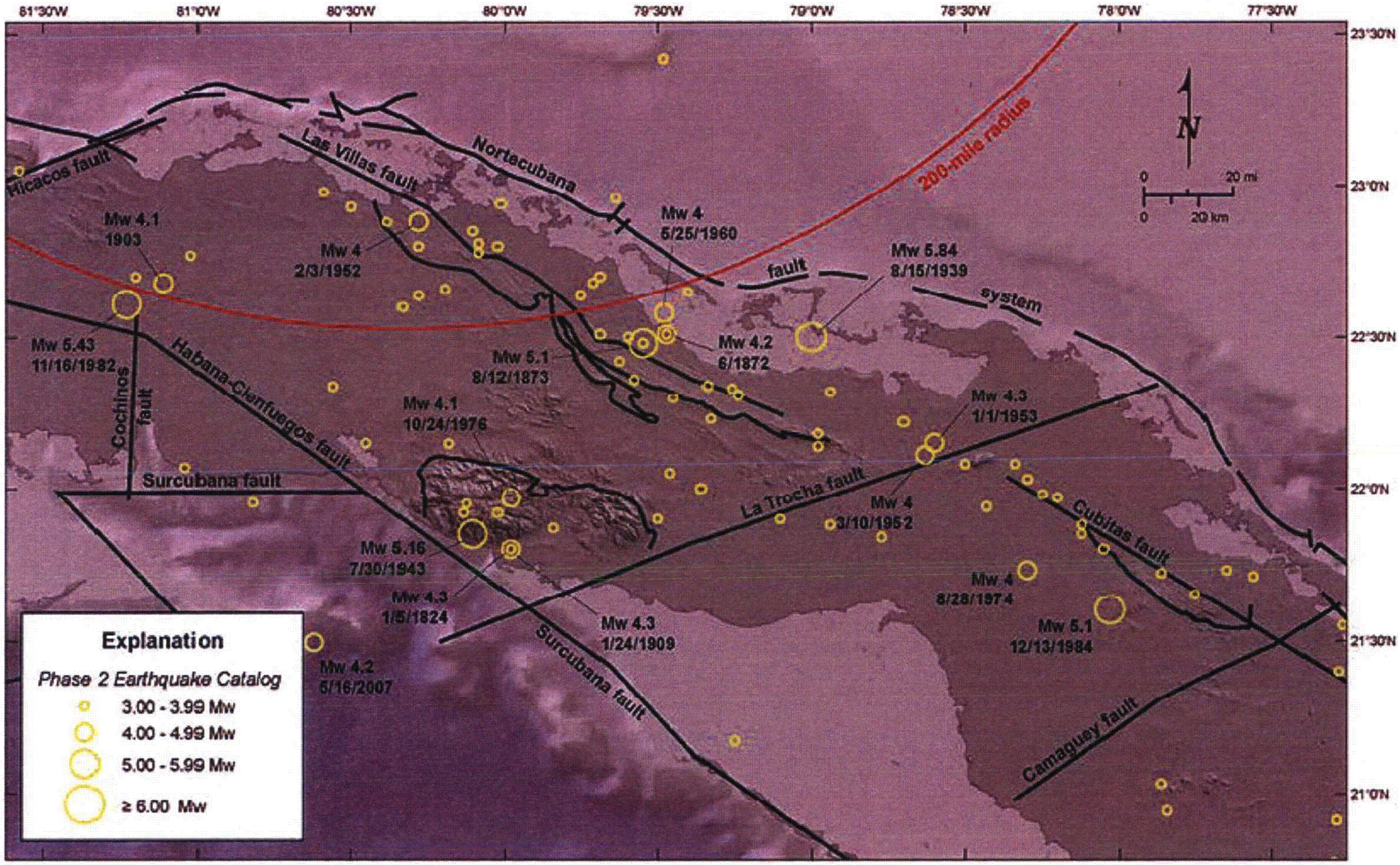
Results and Conclusions from the Hazard Sensitivity Calculation

The results and conclusions of this and other Cuba seismic hazard sensitivity calculations regarding alternative Cuba areal sources are presented in the response to RAI 02.05.02-04.



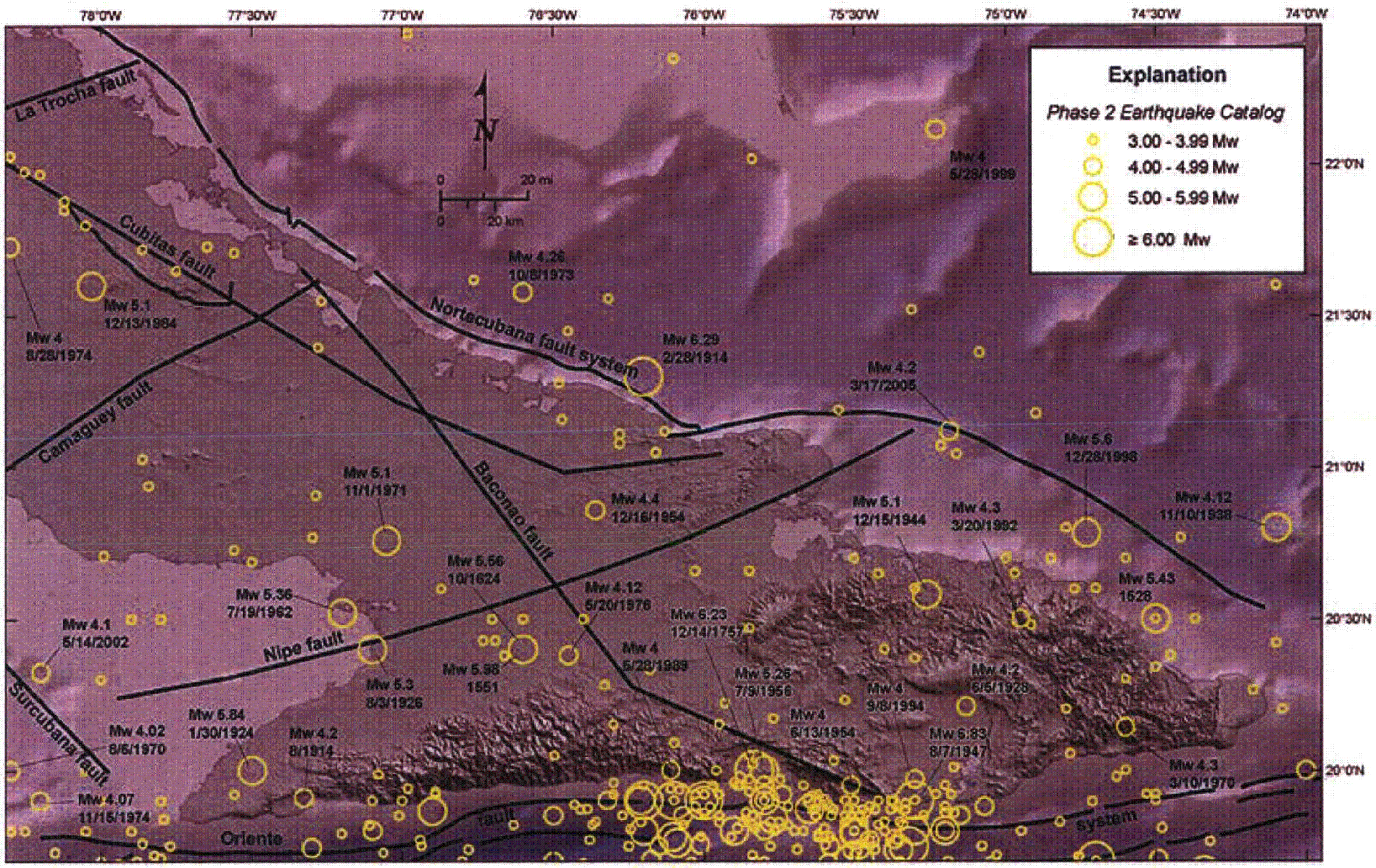
Note: Multiple sources were used to compile this map, including: FSAR References 2.5.1-492, -494, -448, and -439.

Figure 1A Fault Map of Western Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog



Note: Multiple sources were used to compile this map, including: FSAR References 2.5.1-492, -494, -448, and -439.

Figure 1B Fault Map of Central Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog



Note: Multiple sources were used to compile this map, including: FSAR References 2.5.1-492, -494, -448, and -439.

Figure 1C Fault Map of Southeastern Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog

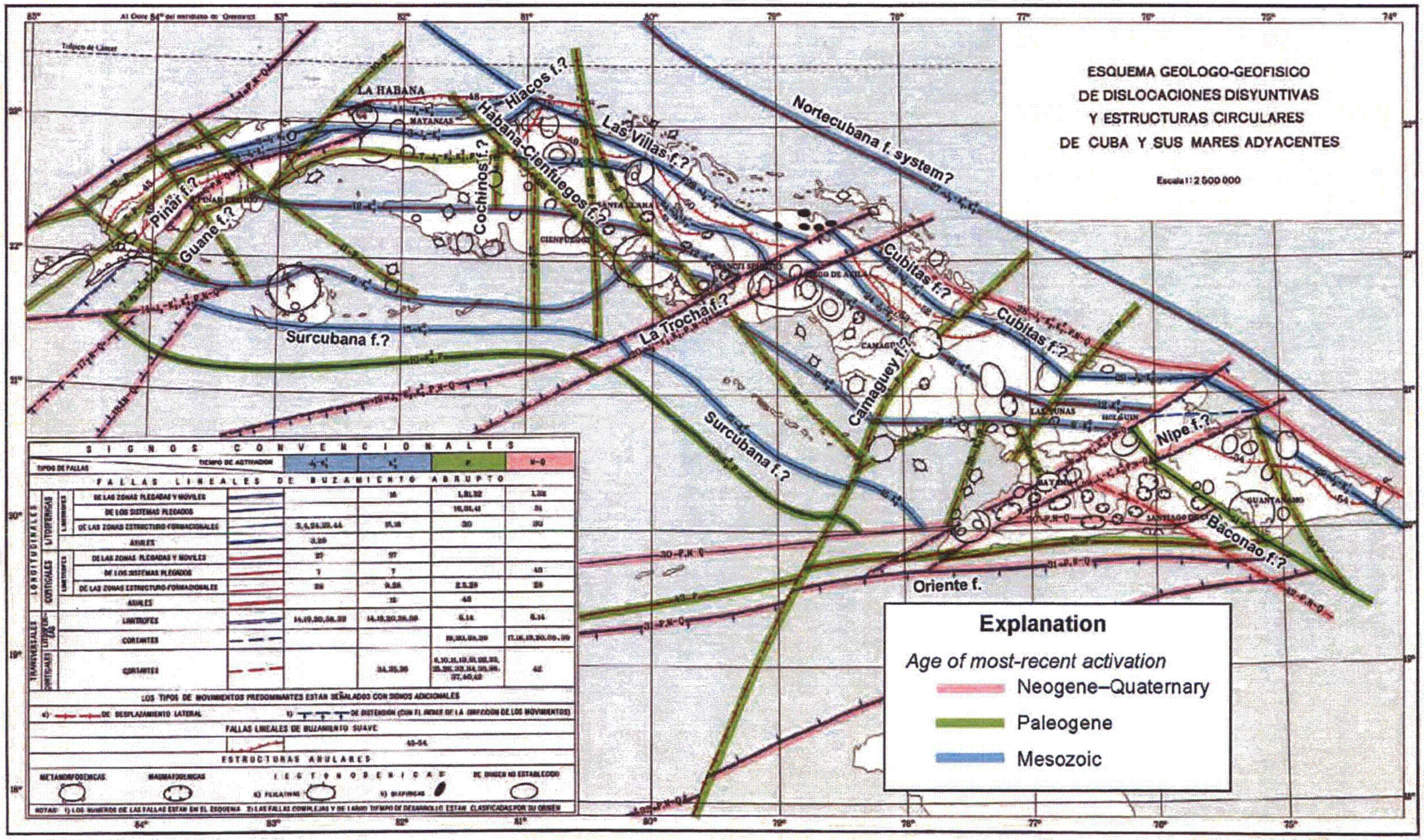


Figure 2 Map of Estimated Ages of Faults in Cuba (Modified after Perez-Othon and Yarmoliuk 1985) (FSAR 2.5.1 Reference 848)

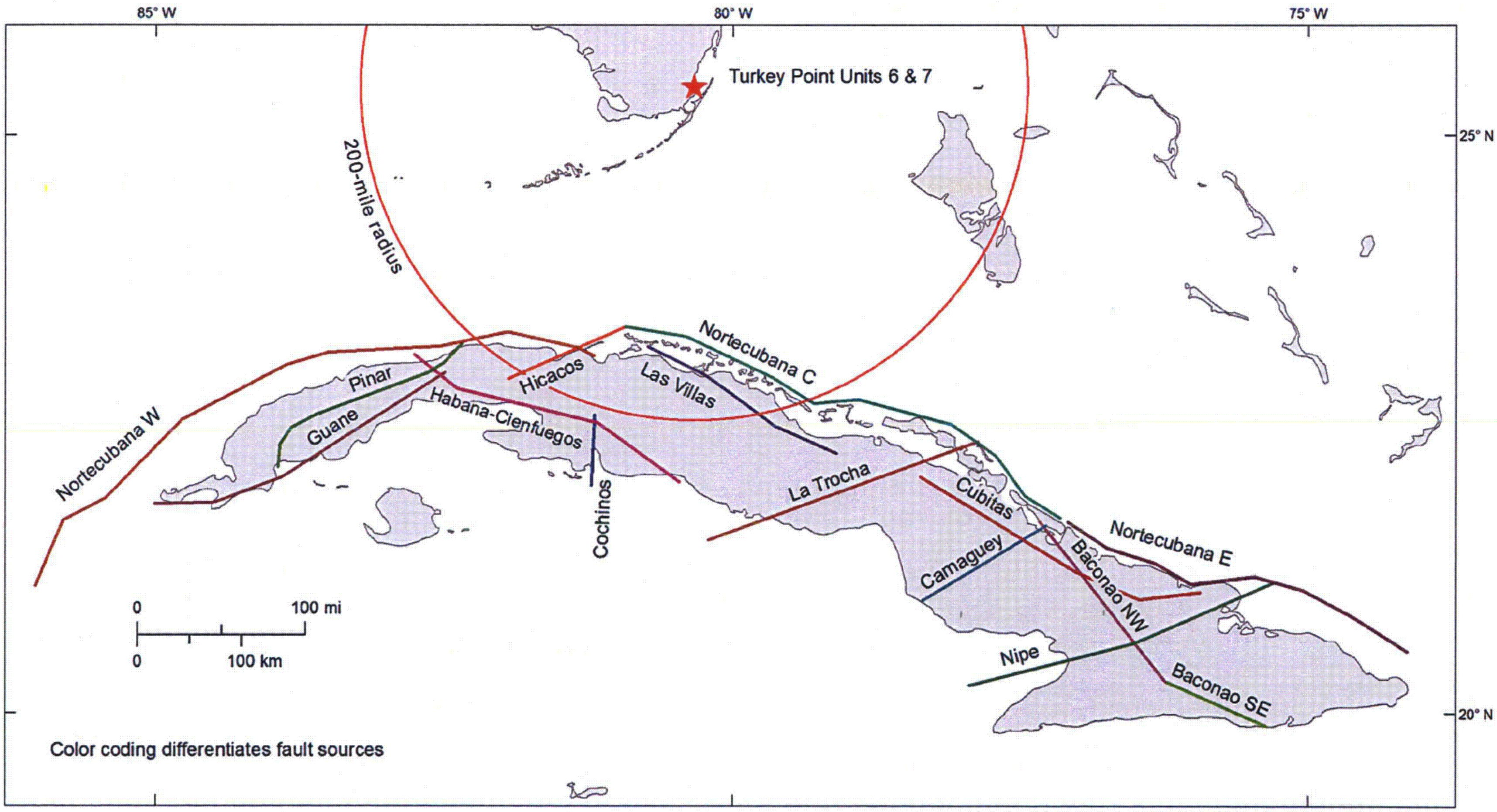


Figure 3 Map of Intraplate Cuba Fault Sources for Hazard Sensitivity Calculation

Table 1. Experts Contacted for the SSHAC Level 2 Study in Support of Cuba Hazard Sensitivity Calculations

Expert	Affiliation	Expertise	Response
Coppersmith, Kevin	Coppersmith Consulting	Seismic hazard modeling, seismic source characterization	Email response
Cotilla Rodriguez, Mario Octavio	Departamento de Física de la Tierra y Astrofísica, Facultad de Ciencias Físicas, Universidad Complutense de Madrid (Madrid, Spain)	Cuba faults and neotectonics	Detailed email response.
Garcia, Julio	Centro Nacional de Investigaciones Sismológicas (CENAIS) (Havana, Cuba)	Seismic hazard modeling in Cuba	No response.
Hanson, Kathryn	AMEC	Seismic hazard modeling, seismic source characterization	Declined to participate.
Ituralde-Vinent, Manuel	Museo Nacional de Historia Natural (Havana, Cuba) and Departamento de Geociencias, Instituto Superior Politécnico J. A. Echeverría (Havana, Cuba)	Geology of Cuba	No response.
Moreno Toiran, Bladimir	Inst. Of Solid Earth Physics, University of Bergen (Norway) and Centro Nacional de Investigaciones Sismologicas (CENAIS) (Santiago de Cuba, Cuba)	Seismology and geophysics of Cuba	Email response.
Slejko, Dario	Istituto Nazionale di Oceanografia e di Geofisica Sperimetale (OGS) (Trieste, Italy)	Seismic hazard modeling in Cuba	Detailed email response.
Toscano, Marguerite*	Department of Paleobiology, Smithsonian Institute	Marine terrace mapping and dating in northern Cuba	Email response and telephone conversation regarding marine terraces in northern Cuba.
Wong, Ivan	URS Corporation	Seismic hazard modeling, seismic source characterization	Detailed email responses.
Youngs, Robert	AMEC	Seismic hazard modeling	Declined to participate.
Zapata Balanque, Jose Allejandro*	Universidad de Oriente (Santiago de Cuba, Cuba)	Cuba faults and neotectonics	Email response regarding plans for future paleoseismic studies in Cuba.

***Expert contacted prior to development of the standardized questionnaire**

Table 2A. Summary of Feedback from SSHAC Level 2 Expert Kevin Coppersmith

Date of response: 11/26/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	N/A
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	N/A
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	N/A
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	N/A
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	N/A
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	N/A
Other comments	Consider an "embedded faults" approach like that used in the B.C. Hydro SSC project.

Table 2B. Summary of Feedback from SSHAC Level 2 Experts Mario Octavio Cotilla Rodriguez

Date of response: 11/25/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	Yes, but highlighting the Guane fault and Nortecubana fault (Central-Northern Cuba).
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	Do not consider Pinar fault as source. Increase weight of the Nortecubana (central) and Guane fault sources, if included.
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	Not possible, given the limitations to "scientific access" in Cuba. I have not been able to, and neither have other Spanish colleagues of mine.
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	Apply both models and then select the one that best fits the real data.
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	Indeed, there is an error from overlaying.
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	Correct. Mapped faults must be considered.
Other comments	Seismic sources in intraplate Cuba are significantly less active and shorter than at plate boundary. No reliable information on fault slip rates. Variable catalog completeness across Cuba.

Table 2C. Summary of Feedback from SSHAC Level 2 Experts Bladimir Moreno Toiran

Date of response: 12/7/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	N/A
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	N/A
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	N/A
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	N/A
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	N/A
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	N/A
Other comments	First we need to know if the proposed power plant is a nuclear plant. If so we hope all the information possible is available to conduct an adequate design of the plant. Keep in mind that any accident would have implications in our country. The proposed area is an area of low seismicity according to our historical records. The northern areas of Cuba (closest to the proposed site) show recent seismic activity and even though historical and recorded earthquakes have not exceeded 6.0 Richter magnitude, it should be studied to greater detail; for example, establishing GPS polygons to estimate deformation rates, conducting paleoseismological studies, etc. As a company, we provide specialized consulting through Cuban Company Cubatecnica and in this case we suggest you consult our specialists. We await your comments.

Table 2D. Summary of Feedback from SSHAC Level 2 Expert Dario Slejko

Date of response: 11/29/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	Recommend areal sources with rates computed from low seismicity extrapolated to high seismicity as far as the Mmax derived from Wells and Coppersmith on fault rupture length (deduced from segmented, if possible, or total fault length).
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	No opinion.
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	No recommendation.
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	Prefer 6 zones to 1. Consider alternative existing models (e.g., Garcia et al.).
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	I see a double counting problem and would prefer to extrapolate observed seismicity rates to larger magnitudes according to geological and geodetic indications.
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	Alternative source models have considered narrow areal sources. The use of a fault model is very appealing but, in my opinion, dangerous if not supported by strong evidence because it increases hazard around the fault but decreases remarkably the expected ground motion far away, where you are actually interested to estimate it.
Other comments	N/A

Table 2E. Summary of Feedback from SSHAC Level 2 Experts Marguerite Toscano

Date of response: 5/24/2012 (email and telephone discussion)

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	N/A
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	N/A
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	N/A
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	N/A
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	N/A
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	N/A
Other comments	The northern coast of Cuba is a constructional reef environment with no evidence for recent or ongoing tectonic uplift. Describes "sad state" of science in Cuba: little contact with larger scientific community and exchange of ideas, lack of funding and equipment.

Table 2F. Summary of Feedback from SSHAC Level 2 Experts Ivan Wong

Date of responses: 11/27/2012, 12/4/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	Use of regional source zone is appropriate. Recommend: (1) calculate composite recurrence for fault sources and compare to historical record; and (2) test sensitivity of hazard to one of the 1 mm/yr faults. I agree with your use of a large Mmax for the background seismicity. In this sense, I think the word "background" is misleading because your zone is not only addressing the hazard from true background earthquakes (those associated with buried faults) but also faults that probably have surface expression but just have not been identified to date.
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	Slip rate distributions seem broad enough given lack of data. Recommend aerial photo or satellite image analysis. It appears the range of the slip rates you are using might be too extreme? A recurrence for M 7 of only 55 years seems particularly too short even if your historical record is poor. Certainly there would be a record of the large events for a few centuries?
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	Fault geomorphology could help.
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	If historical record good enough, Gaussian smoothing should be used in lieu of zones. If good information to divide the region into large zones, then I would do so as well and assign some weight. Even if there is a single zone, I would include with some weight to address the issue of stationarity. Breaking up a region into zones is just another way of smoothing as you recognize. So if your 6 zones is giving you lower hazard, then so will smoothing. Smoothing takes the subjectivity out of creating zones but if you have a good basis for the 6 zones, fine with me. The difference in hazard between smoothing and your 6 zones will depend on the size of your zones and the width of the smoothing window you're using. How you capture nonstationarity is to me an important issue given the historical record is so poor. I assume that is why you are using a single uniform zone as well? The rest of your approach as described below seems reasonable in terms of capturing the epistemic.
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	For the modeled fault slip rates, double-counting likely not an issue. Doing the comparison in Q1 response may provide some guidance.
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	Excluding fault sources you may under-estimate the hazard. How much of the historical seismicity is associated with known active faults is important question. Given that the largest event to date is only M 6.4, I would guess most of the historical seismicity is background.
Other comments	N/A

Table 2G. Summary of Feedback from SSHAC Level 2 Experts Jose Allejandro Zapata Balanque

Date of response: 8/2/2012

Question	Response
1. Given the lack of slip rate information for faults in Cuba, is it appropriate to model seismic hazard in Cuba using fault sources, or is it more appropriate to assume that potential active faults (known or unknown) are captured by background sources (similar to what is done in the central and eastern United States) or some other modeling approach?	N/A
2. Are the assumed slip rate distributions (listed in Table 1) appropriate for constraining hazard from Cuba faults sources (shown in Figure 1), assuming they are capable tectonic sources?	N/A
3. Without data to better estimate slip rates, are you aware of any approaches that can be used bound fault slip rate distributions for Cuba faults?	N/A
4. Is it more appropriate to model non-fault related seismic hazard from Cuba as: (1) a single zone with a uniform rate, (2) a six-zone model that isolates areas with higher and lower rates of seismicity, or (3) another approach?	N/A
5. If fault sources (driven by assumed slip rates) were layered on top of the Cuba areal zone model (driven by historic seismicity rates), are we introducing a problem of double counting? Do you feel that the potential for double counting is a significant or insignificant issue in this case?	N/A
6. If we don't add fault sources to account for faults that may be active in Cuba, do we risk underestimating hazard, or does the areal zone (or zones) capture some of the fault hazard, assuming a fraction of seismicity in background zone was produced by the mapped faults?	N/A
Other comments	Trenching results from Pinar and possibly other faults not expected until 2014 or later. Source of 1881 *(sic: 1880)* earthquake remains unclear.

Table 3. Summary of Seismic Source Parameters for Intraplate Cuba Fault Sources for Hazard Sensitivity Calculation

Sensitivity Fault Source	Dip	Rupture Depth Range (km)	Length (km)	Magnitude (M_w) [and weight]	Slip Rate (mm/yr) [and weight]
Baconao SE	90°	0-15	101	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Baconao NW	90°	0-15	191	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Camaguey	90°	0-15	131	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cochinos	90°	0-15	68	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cubitas	90°	0-15	283	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Guane	90°	0-15	292	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Habana-Cienfuegos	90°	0-15	269	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Hicacos	90°	0-15	114	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
La Trocha	90°	0-15	257	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Las Villas	90°	0-15	197	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nipe	90°	0-15	292	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Nortecubana West	30° S	0-15	595	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nortecubana Central	30° S	0-15	441	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nortecubana East	30° S	0-15	340	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Pinar	90°	0-15	215	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]

This response is PLANT SPECIFIC.

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ASSOCIATED COLA REVISIONS:

The text of FSAR Subsection 2.5.1.1.1.3.2.4 will be revised as shown below in a future FSAR revision:

2.5.1.1.1.3.2.4 Cuba

This subsection discusses available geological and geophysical information pertaining to seismic hazard characterization for Cuba. While only a small portion of northern Cuba is within the site region, a discussion of the regional structures on the entire island is presented. Within the past ten years, international groups have published research conducted in Cuba, though many of these concentrate on geochemistry of the arc-related rocks (e.g., Reference 488), rather than any potential recent faulting or seismicity. From a seismic hazard perspective, ~~major fault zones~~ **potential seismic sources** in Cuba ~~have been~~ **are** summarized by Garcia et al. (References 489 and 490) and Cotilla-Rodríguez (Reference 494) to support seismic hazard mapping.~~; however, in the most recent probabilistic seismic hazard analysis (PSHA) by Garcia et al. (Reference 490) seismic source models include areal source zones rather than fault sources given the significant uncertainty in characterization of the seismic potential of Cuban faults.~~

The major geologic units and their stratigraphic relations are described in Subsection 2.5.1.1.1.2.3. The plate tectonic history of Cuba and the northern Caribbean, ~~which discusses~~ **including** the origin and emplacement timing of the geologic units, are discussed in Subsection 2.5.1.1.3.

Structures of Cuba

Most regional faults in Cuba, particularly in northern Cuba, are north-directed thrusts or east- to northeast-striking strike-slip faults responsible for transferring the Cretaceous Greater Antilles Arc onto the Bahama Platform (Figures 2.5.1-247, 2.5.1-~~252~~**250**, and 2.5.1-~~265~~**251**). ~~Maps and publications generally indicate that the upper Eocene and younger strata are not deformed in central and northern Cuba by regional tectonic structures (References 440, 439, 492, and 847). However, t~~The Oriente fault zone, located directly off the southern coast of the island forms the boundary between the modern North America Plate and the Gonâve microplate, and is a capable tectonic ~~fault~~**source**. The Oriente fault zone is discussed further in Subsection 2.5.1.1.2.3.1.2, and its characterization in the Cuba and northern Caribbean seismic source model is described in Subsection 2.5.2.4.4.3~~ (Figure 2.5.1-202)~~.

~~Summaries of the tectonic events of the Eocene to Recent only mention the development of the Oriente-Swan fault system (Reference 440). Iturralde-Vinent (Reference 440) also indicates that late Eocene to Recent deposits are slightly deformed by normal faults and minor strike-slip faults, mentioning the Pinar, La Trocha, Camaguey, and Nipe faults by name but providing no further detailed information regarding the age of displaced units. A neotectonic map compiled for Cuba identifies only the Cochinos fault and structures in south easternmost Cuba as active, and these active structures are not depicted extending within the site region (Reference 493) (Figure 2.5.1-247).~~ In an effort to explain seismicity that continues on intraplate Cuba, 12 faults on the island of Cuba ~~have been~~ **are** designated **by Cotilla-Rodriguez et al. (Reference 494)** as "active" ~~(Reference 494)~~

based on their ambiguous definition of the term. ~~, but that published~~ **For many faults in intraplate Cuba, the Cotilla-Rodriguez et al.'s (Reference 494)** analysis does not provide sufficient information to conclude that a structure is **a** capable **tectonic source according to RG 1.208**. Table 2.5.1-204 provides a summary of these and other regional fault zones of Cuba. Available geologic and tectonic maps are 1:250,000 (Reference 846) and 1:500,000 scale (References 848 and 847)~~, respectively,~~ and therefore do not have sufficient detail to properly characterize fault activity based on map relations alone. Available information for the ~~six~~ regional Cuban faults that extend to within the site region, and several that lie beyond it, is summarized below.

~~Domingo Fault~~

~~At its nearest point, the low-angle Domingo fault is located 175 miles (282 kilometers) south of the Units 6 & 7 site. This northwest-striking, south-dipping thrust fault carried the Cretaceous arc and serpentinites over the carbonate platform rocks and can be considered the former suture between North America and Caribbean plates (References 439 and 440) (Figure 2.5.1-247). The Domingo fault does not cut the uppermost Eocene and younger sedimentary units, and is late Eocene in age (References 440 and 439). A myriad of other thrusts are mapped in detail (though not shown Figure 2.5.1-247), which imbricate both the autochthonous and allochthonous units on the island (Reference 439). On 1:250,000 scale maps and interpreted cross sections, these faults also do not cut the uppermost Eocene and younger deposits, and so are not Quaternary in age (References 439, 497, 440, and 846) (Figure 2.5.1-248).~~

~~Nortecubana Fault System~~

~~The Nortecubana fault system is the arcuate thrust system that marks the northern extent of south-dipping thrusts associated with the collision of the Greater Antilles Arc and the Bahama Platform. The fault system is located north of the Domingo fault and entirely offshore, and therefore detailed geologic mapping along this fault zone is not available. However, wells drilled directly offshore of northeastern Cuba have encountered thrusts and repeated stratigraphy indicating Eocene thrusting (Reference 439), and seismic reflection data has imaged northward thrusting of basin deposits (Reference 307). Seismic lines typically indicate that the offshore north-vergent thrusts are draped by unfaulted late Tertiary to Quaternary sediments (References 497 and 484) (Figure 2.5.1-279, 2.5.1-287, 2.5.1-288, 2.5.1-282, and 2.5.1-280). At its nearest point, the Nortecubana fault is approximately 150 miles (241 kilometers) from the Units 6 & 7 site. Garcia et al. (Reference 489) describe offshore seismic reflection profiles showing up to 984 feet (300 meters) of vertical displacement associated with the Nortecubana fault, but do not provide constraints on the timing of the most-recent fault slip. Cotilla-Rodríguez et al. (Reference 494) indicate that the Nortecubana Fault Trench is expressed in the bathymetry north of Cuba, but this does not constitute direct evidence for activity. Ongoing seismicity is concentrated near its intersection with the Oriente fault in easternmost Cuba near the plate boundary and substantially decreases westward into the site region (References 489 and 494). Within the site region, there is no direct evidence that earthquakes occur on the Nortecubana fault.~~

~~Hicacos Fault~~

~~At its nearest point, the northeast-striking Hicacos fault is approximately 155 miles (249 kilometers) south of the Units 6 & 7 site (Reference 494) (Figure 2.5.1-247). Garcia et al.~~

~~(Reference 489) report intermittent geomorphic expression along the Hicacos fault trace. Additionally, Garcia et al. (Reference 489) describe the Hicacos fault as "…a deep fault above Paleocene-Quaternary formations" (p. 2571), but the exact meaning of this statement is unclear. Cotilla-Rodríguez et al. (Reference 494) do not provide any geologic evidence for activity and indicate a lack of instrumental seismicity associated with the Hicacos fault. Five pre-instrumental earthquakes of intensity MMI (Modified Mercalli Intensity) V and less are located in the general vicinity of the Hicacos fault, but the locations of these events are highly uncertain (Reference 494). Geologic maps of the region show segments of the Hicacos fault cutting upper Tertiary rocks (Reference 480).More detailed geologic maps do not map the Hicacos fault at the surface, but the shoreline and a narrow peninsula in the vicinity of the fault are notably linear (Reference 846) and these features probably influence where the fault is mapped in other representations (e.g., Reference 480).~~

~~*Cochinos Fault*~~

~~At its nearest point, the north-northwest-striking Cochinos fault is approximately 175 miles (282 kilometers) south of the Units 6 & 7 site (Reference 494), though it is most commonly mapped as only extending to within 210 miles (338 kilometers) of the site (Reference 480) (Figure 2.5.1-247). Cotilla-Rodríguez et al. (Reference 494) provide no geologic evidence for activity and describe the Cochinos fault as "covered by young sediments" (p. 514). Indeed, the most detailed geologic maps inspected in the area (1:250,000 scale) show no fault cutting Miocene and younger strata (Reference 846). A neotectonic map of the Caribbean identifies the Cochinos as a normal fault (Reference 493) (Figure 2.5.1-286). The Cochinos fault is variously described as a "normal fault with a few inverse type sectors" (Reference 494; p. 514) and "normal and reverse type with left strike-slip" (Reference 494; p. 515), but no basis is provided for these ambiguous statements. The Cochinos fault appears to be geographically associated with sparse instrumental seismicity, but these earthquakes are poorly located and no focal mechanisms are available. Garcia et al. (Reference 489) provide no geologic evidence that the Cochinos fault is active.~~

~~*Las Villas Fault*~~

~~The Las Villas fault is mapped as a south-dipping, northwest-striking thrust, with up to approximately 19 miles (30 kilometers) of horizontal displacement (Reference 439), located approximately 170 miles (274 kilometers) south of the Units 6 & 7 site in central Cuba (Figure 2.5.1-247). The Las Villas fault displaces middle Eocene units, but exhibits greater displacement of older units, indicating that most of its movement was pre-middle Eocene (Reference 439). According to Cotilla-Rodríguez et al. (Reference 494), the Las Villas fault has "young eroded scarps" (p. 517), but it is not clear if these features represent erosional fault scarps or if they were formed directly by recent slip on the Las Villas fault. Cotilla-Rodríguez et al. (Reference 494) variously describe the Las Villas fault as a "normal fault" (p. 517) and a "normal and reverse type" fault (p. 515) that "is of Pliocene-Quaternary age" (p. 517), but provide no geologic or other evidence for this age assessment. Review of geologic mapping (References 846, 480, and 848) reveals that no units of Quaternary age are faulted but the coarse scale of mapping does not preclude recent activity. Garcia et al. (Reference 489) indicate the Las Villas fault is delineated by a negative gravity anomaly, but provide no geologic evidence for activity. Cotilla-Rodríguez et al. (Reference 494) describe a single instrumental event (1939) in the vicinity of the Las Villas fault for which no~~

~~focal mechanism is available, and historical accounts of four events of intensity MMI V and less are all poorly located.~~

~~*Pinar Fault*~~

~~The Pinar fault is a left-lateral, northeast-striking Tertiary strike-slip structure (Reference 220). As mapped by Garcia et al. (Reference 489), the Pinar fault is approximately 197 miles (317 kilometers) southwest of the Units 6 & 7 site at its nearest point (Figure 2.5.1-247). Cotilla-Rodríguez et al. (Reference 494), however, map the Pinar fault as approximately 225 miles (362 kilometers) southwest of the site at its nearest point. Mapping indicates that the fault generally cuts lower to middle Miocene and older strata, but shows a 6.5 kilometers segment of the structure forming the boundary of (and potentially cutting) an upper Pliocene to lower Pleistocene unit (Reference 846). However, along strike, the fault is covered by the same upper Pliocene to lower Pleistocene unit (Reference 846). Crosscutting sets of striae on the fault indicate that the initial strike-slip movement was overprinted by dip-slip kinematics (Reference 485). Cotilla-Rodríguez et al. (Reference 494) describe the Pinar fault as having "...very nice relief expression" but conclude it is "inactive" (p. 516). Cotilla-Rodríguez et al. (Reference 494) provide no evidence in support of this assessment. Garcia et al. (Reference 489) note the Pinar fault is grossly expressed as a prominent escarpment and suggest the Pinar fault "was reactivated in the Neogene-Quaternary" (p. 2571) and may have produced the January 22, 1880 M 6.0 earthquake. Detailed examination of outcrops along the structure indicates that it developed first as a thrust in the Paleocene, but this was overprinted by the dominant phase of deformation, sinistral strike-slip faulting in the early Eocene (References 697 and 220) (Figure 2.5.1-289). Rosencrantz (Reference 529) mapped a series of offshore faults along the eastern Yucatan Platform and tentatively indicates they could be the offshore extension of the Pinar fault and responsible for Paleocene rifting.~~

~~*Habana-Cienfuegos Fault*~~

~~This northwest-striking left-lateral strike-slip fault is located in western and central Cuba (Figure 2.5.1-288). This fault is not shown on Reference 480 or the 1:250,000 scale geologic map of Cuba (Reference 846). However, a dashed (postulated) structure on the 1:500,000 scale geologic map (Reference 848) is depicted as cutting Miocene strata, but covered by unfaulted Pleistocene strata. Cotilla-Rodríguez et al. (Reference 494) conclude this structure is active based upon an association with poorly located seismicity.~~

~~*Guane Fault*~~

~~The Guane fault is located in western Cuba and is covered by sediments of the Los Palacios Basin (Figure 2.5.1-251). This northeast-striking structure is not depicted on the 1:250,000 scale geologic map (Reference 846). However, a dashed (postulated) structure on the 1:500,000 scale geologic map is depicted cutting Miocene strata, but covered by unfaulted Pliocene-Pleistocene units (Reference 848). Cotilla-Rodríguez et al. (Reference 494) conclude it is active based upon potential association with seismicity.~~

~~*La Trocha Fault*~~

~~The northeast-striking La Trocha fault is located outside of the site region in east-central Cuba (Figure 2.5.1-247). Cotilla-Rodríguez et al. (Reference 494) assign the La Trocha fault an age of Pliocene-Quaternary, although Leroy et al. (Reference 499) interpret it as~~

~~being the northern transform limb of a proto-Cayman spreading center that was active in the early Eocene (53 Ma) and was abandoned by 49 Ma (Reference 499). This interpretation is the result of the southward migration of the left-lateral strike slip faults that make up the Caribbean-North America plate boundary (e.g., Reference 639). Projections of the Cretaceous to Eocene ophiolitic suture zone (roughly coincident with the Domingo fault) are shown left-laterally offset by the structure (e.g., Reference 847). No available geologic maps show any northeast-striking faults cutting the Miocene and younger strata in the vicinity of where this fault should be located (e.g., Reference 846). Potentially, this structure is buried by the strata and would be pre-middle Miocene in age. Rosencrantz (Reference 529) maps a northeast-striking structure across the Yucatan basin and interpret it as the offshore extension of the sinistral La Trocha Fault.~~

~~*Camaguey Fault*~~

~~Most geologic maps do not show a regional northeast-striking fault such as the Camaguey fault at the surface, including the 1:250,000 scale geologic map (References 846, 500, and 847). However, on tectonic compilations it is located outside of the site region (Figures 2.5.1-247 and 2.5.1-251) and is assigned a Paleogene age (Reference 848). The Camaguey fault, like the La Trocha or Pinar fault, is interpreted as accommodating eastward rotation and translation of the Caribbean Plate before the development of the Oriente fault system (Reference 445). Cotilla-Rodríguez et al. (Reference 494) assess the Camaguey fault as active based on possible association of microseismicity with this fault.~~

~~*Cubitas Fault*~~

~~Near the Camaguey fault, the Cubitas fault is a northwest-striking normal fault that forms the southern boundary of an area of higher topography (Figure 2.5.1-288). It is described as post-middle Eocene in age and suggested to be partially responsible for up to 200 meters uplift of hills, possibly after the deposition of Plio-Pleistocene fluvial terraces (Reference 500). Cotilla-Rodríguez et al. (Reference 494) note that the Cubitas fault is associated with large scarps and assign it a Pliocene-Quaternary age.~~

~~*Nipe Fault*~~

~~The northeast-striking Nipe fault (named Cauto, Cauto-Nipe, Guacanayabo, or Nipe-Guacanayabo fault in various publications; referred to as Nipe fault here) separates the mountainous Sierra Maestra province from the Camaguey terrane (Figures 2.5.1-251 and 2.5.1-247). This structure is not mapped at the surface on available geologic maps (References 846 and 848). Leroy et al. (Reference 499) and Rojas-Agramonte et al. (Reference 445) interpret it as being the southern transform limb of the early Cayman spreading center (Figure 2.5.1-250). In their model (and that of Reference 445) the fault was abandoned by the early Oligocene (20 Ma) as the plate boundary shifted south to the Oriente fault, where it is today. Cotilla-Rodríguez et al. (Reference 494) assess the Cauto-Nipe fault as active based on possible association of microseismicity with this fault. However, they do not describe stratigraphic, geomorphic, or other evidence for Quaternary activity.~~

~~The Baconao fault is a northwest-striking fault, located in southeastern Cuba (Figure 2.5.1-288). Cotilla-Rodríguez et al. (Reference 494) indicate that it may have normal, reverse, and left-lateral strike-slip kinematics. This fault is not shown on the Case and Holcombe (Reference 480) or the 1:250,000 scale geologic maps (Reference 846). However, a dashed (postulated) structure on the 1:500,000 scale geologic map is depicted cutting Oligocene-Miocene strata, but covered by unfaulted Pleistocene strata (Reference 848). It may deform Pleistocene and Quaternary terraces and is associated with poorly located seismicity (Reference 494).~~

Baconao fault

The Baconao fault is a northwest-striking fault located in southeastern Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 3). At its nearest point, the Baconao fault is approximately 330 miles (530 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489, p. 2,571) provide only minimal discussion of this fault, but describe it as "better defined in its eastern part, where it has a clear expression mainly in relief and significant seismic activity at the intersection with the [Oriente fault zone]."

Cotilla-Rodríguez et al. (Reference 494) characterize the Baconao fault as active, based on geologic map relations, geomorphology, and its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494, p. 515) describe the Baconao fault as "normal and reverse type with left strike-slip." Cotilla-Rodriguez et al. (Reference 494, p. 513) note that, along the easternmost portion of the fault near the modern plate boundary, there are "vast, continuous and abrupt escarpments and many distorted and broken fluvial terraces of the Quaternary and Pleistocene." These observations, coupled with the proximity to the modern plate boundary (i.e., Oriente fault; Figure 2.5.1-247), suggest that the eastern portion of the Baconao fault may be Quaternary active.

Cotilla-Rodriguez et al. (Reference 494) list five earthquakes that they suggest may have occurred on the Baconao fault, all of which occurred between 1984 and 1987. Each of these five earthquakes is assigned Medvedev-Sonheuer-Karnik (MSK) intensity IV (approximate Modified Mercalli Intensity (MMI) IV) (Reference 494). As shown on Figure 2.5.1-368 Sheet 3, however, there is little to no seismicity from the Phase 2 earthquake catalog along much of the length of the Baconao fault, especially along the northwestern two-thirds of its length northwest of the intersection of the Nipe fault. It should be noted that the Phase 2 catalog is a declustered catalog that includes earthquakes of M_w 3 and larger. Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Baconao fault is not shown on Case and Holcombe's (Reference 480) 1:2,500,000 scale map of the Caribbean. Perez-Othon and Yarmoliuk (Reference 848), however, show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba. This unnamed fault is located in the vicinity of the Baconao fault and is depicted cutting Oligocene-Miocene strata, but covered by apparently unfaulted mid-Quaternary-age strata (Reference 848). According to mapping by Perez-Othon and Yarmoliuk (Reference 848), the Baconao fault appears to be offset in a right-lateral

sense by two strands of the northeast-striking Nipe fault. As an inset to their geologic map, Perez-Othon and Yarmoliuk (Reference 848) provide an additional map that shows their estimates of fault ages in Cuba. A modified version of their inset map is provided as Figure 2.5.1-369. The inset map presented in Figure 2.5.1-369 was modified by enhancing the color-coding of the Perez-Othon and Yarmoliuk (Reference 848) age estimates and by adding fault name labels based on their relative locations. Most of the fault name labels added to the inset map are queried, however, indicating The uncertainty regarding which faults are, and which are not, shown on the inset map. If the unnamed fault depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba represents the Baconao fault, as is assumed on Figure 2.5.1-369, then they indicate a Neogene-Quaternary age for the southeastern one-third of the Baconao fault. The northwestern two-thirds of the Baconao fault as shown on Figure 2.5.1-368 Sheet 3 does not clearly appear on Perez-Othon and Yarmoliuk's (Reference 848) inset map (Figure 2.5.1-369).

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Reference 944, plate III.1.2-3) and a 1:2,000,000 scale neotectonic map of Cuba (Reference 944, plate III.2.4-8). No fault names appear on these two maps so it is not clear whether the Baconao fault is shown. The geologic map of Cuba from this atlas shows an approximately 30-mile-long (50-km-long), northwest-striking fault near Santiago de Cuba that may be the Baconao fault, but this fault is restricted to southernmost Cuba, southeast of the Nipe fault. This fault appears to cut middle Eocene strata. Likewise, the neotectonic map of Cuba from this atlas shows an approximately 45-mile-long (75-km-long), northwest-striking fault in the same area of southernmost Cuba that could be the Baconao fault. The Baconao fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11). The Baconao fault is shown and labeled on Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba.

Camaguey Fault

The Camaguey fault is a northeast-striking fault located in southeastern Cuba (Figures 2.5.1-247, 2.5.1-251, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). At its nearest point, the Camaguey fault is approximately 330 miles (530 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489, p. 2,571) describe the Camaguey fault as a "regional transverse fault with lateral displacement that affects the whole crust and constitutes the boundary between two megablocks" and that "cuts young as well as old sequences." On their Figure 5, Garcia et al. (Reference 489) show the Camaguey fault as a normal fault with unspecified dip direction and sense of throw. Garcia et al. (Reference 489, p. 2,571) also note that "the gravimetric and magnetic fields show apparent inflections."

Cotilla-Rodríguez et al. (Reference 494) classify the Camaguey fault as active based on the possible association of seismicity with the fault. Cotilla-Rodriguez et al. (Reference 494, p. 514) describe the Camaguey fault as a sinistral strike-slip fault with an almost vertical plane associated with a low "level of seismic activity." They list ten earthquakes that they suggest may have occurred on the Camaguey fault. Three of these earthquakes are assigned MSK intensity III – IV (approximately MMI III – IV), with the remaining seven unspecified (Reference 494). As shown on Figures

2.5.1-368 Sheet 2 and 2.5.1-368 Sheet 3, however, there is little to no seismicity from the Phase 2 earthquake catalog located along the length of the Camaguey fault, with the possible exception of a single, minor-magnitude earthquake near the northeastern end of the fault. Alternatively, this minor earthquake may be associated with the northwestern end of the Baconao fault or some other unmapped structure (Figure 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Camaguey fault is not consistently shown on geologic and tectonic maps of Cuba. For example, it is not labeled on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba, Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba, the Nuevo Atlas Nacional de Cuba 1:1,000,000 scale geologic map (Reference 944, plate III.1.2-3), and van Hinsbergen et al.'s (Reference 500) mapping of the Camaguey area. The Camaguey fault is depicted and labeled on the 1:2,000,000 scale lineament map from the national atlas (Reference 944, plate III.3.1-11) and shown but not labeled on the 1:2,000,000 scale neotectonic map from the same atlas (Reference 944, plate III.2.4-8). Because they do not label faults by name, it is not clear whether the Camaguey fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Camaguey fault (Figure 2.5.1-369).

Cochinos Fault

The Cochinos fault is a north- (References 770 and 494) to north-northwest-striking (Reference 493) fault in south-central Cuba. Figures 2.5.1-247, 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2 show the location of the Cochinos fault after Hall et al. (Reference 770). As mapped by Hall et al. (Reference 770), the fault at its nearest point is approximately 205 miles (330 km) from the Turkey Point Units 6 & 7 site. Alternatively, mapping by Cotilla-Rodriguez et al. (Reference 494) suggests this fault may extend northward to within 175 miles (280 km) of the site, whereas mapping by Mann et al. (Reference 493) indicates a closest distance of approximately 210 miles (340 km). The Cochinos fault is the only onshore feature in intraplate Cuba identified as "neotectonic" by Mann et al. (Reference 493) (Figure 2.5.1-286). They map the Cochinos fault as two parallel, north-northwest-striking normal faults that form a graben (Figures 2.5.1-286, 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2). The morphology of Bahia de Cochinos is consistent with this interpretation and suggests the possibility of fault control on the landscape.

Cotilla-Rodriguez et al. (Reference 494, pp. 514-515) describe the Cochinos fault as a "normal fault with a few inverse type sectors which demonstrates transcurrence to the left" and "normal and reverse type with left strike-slip." Recorded seismicity near the Cochinos fault is sparse. They list six earthquakes that they suggest may have occurred on the Cochinos fault. The largest of these is the December 16, 1982 Ms 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_w 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Based on the similarity in location,

magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (Reference 494) manuscript. The remaining five earthquakes that Cotilla-Rodriguez et al. (Reference 494, p. 516) associate with the Cochinos fault "are all of low [and unspecified] intensity." In the Phase 2 earthquake catalog, the 1982 earthquake is located approximately 3 miles (5 km) northwest of the Cochinos fault trace (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) suggest that the 1982 earthquake may instead have occurred on the Habana-Cienfuegos fault. In addition to the 1982 earthquake, the Phase 2 earthquake catalog shows only four other earthquakes within 20 miles (32 km) of the Cochinos fault, the largest of which is assigned M_w 4.1 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Cotilla-Rodríguez et al. (Reference 494) classify the Cochinos fault as active based on the possible association of seismicity with the fault. Cotilla-Rodríguez et al. (Reference 494, p. 514) provide no geologic evidence for activity on the Cochinos fault and describe the fault as "covered by young sediments." Indeed, the most detailed geologic maps inspected in the area (1:250,000 scale) show no fault cutting Miocene and younger strata (Reference 846). Because they do not label faults by name, it is not clear whether the Cochinos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for a northern extension of this fault (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba shows and labels the approximately 60-mile-long (100-km-long) Cochinos fault. The southern approximately 50 miles (80 km) of this fault are shown as a dashed line. Garcia et al. (Reference 489) provide no discussion of the Cochinos fault.

The Cochinos fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map of Cuba from this atlas (Reference 944, plate III.1.2-3) shows an approximately 87-mile-long (140-km-long) unnamed fault in the vicinity of the Cochinos fault that extends from Cuba's northern coast where it is mapped in Pliocene-age deposits southward into the Bahia de Cochinos. The southernmost 18 miles (30 km) of this fault are shown by a dashed line. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Reference 944, plate III.2.4-8) shows an approximately 87-mile-long (140-km-long) unnamed fault in the vicinity of the Cochinos fault, the southernmost 30 miles (50 km) of which is offshore southern Cuba and shown by a dashed line. To the north, this fault on the neotectonic map is truncated by the Hicacos fault. The Cochinos fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11). The 1:1,000,000 scale geomorphic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate IV.3.2-3) shows an approximately 37-mile-long (60-km-long) unnamed fault in the vicinity of the Cochinos fault. The map explanation indicates that this fault cuts a Quaternary-age marine abrasion platform that is at an elevation of either 2 – 3 m or 5 – 7 m above sea

level. They do not provide explanation for the lack of specificity in elevation of the platform nor do they provide a precise age for the Quaternary abrasion platform.

Cubitas Fault

The Cubitas fault is a northwest-striking, steeply south-dipping fault located in southeastern Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). At its nearest point, the Cubitas fault is approximately 270 miles (435 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489, p. 2,571) describe the Cubitas fault as a "deep fault that constitutes a portion of the Cuban marginal suture and is considered to be the main structure in central Cuba. It is cut by the Camaguey and the La Trocha transverse faults, where seismicity is documented." They associate the 1974 Ms 4.5 MSK VII Esmeralda earthquake (month and day unspecified) with the Cubitas fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Cubitas fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494, pp. 514-515) describe the Cubitas fault as "an almost vertical normal fault with some sectors of inverse type" and as "normal and reverse type." They describe large scarps associated with this fault, but do not provide additional descriptions of the scarps. They assign a Pliocene to Quaternary age for this fault. Cotilla-Rodriguez et al. (Reference 494) list fifteen earthquakes that they suggest may have occurred on the Cubitas fault. Eight of these earthquakes are assigned MSK intensity III – V (approximately MMI III – V), with the remaining seven unspecified (Reference 494). The Phase 2 earthquake catalog includes several low-magnitude earthquakes that may be spatially associated with the northwestern half of the Cubitas fault (Figures 2.5.1-368 Sheet 2 and 2.5.1-368 Sheet 3). The central and southeastern portions of the fault appear largely devoid of seismicity. The Phase 2 earthquake catalog indicates M_w 4.0 and M_w 5.1 earthquakes occurred approximately 15 miles (24 km) south of the mapped trace near the northwestern end of the fault in 1974 and 1984, respectively, which may be associated with the Cubitas fault. Cotilla-Rodriguez et al (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Van Hinsbergen et al. (Reference 500) describe the Cubitas fault as a post-Middle Eocene, south-dipping normal fault that forms a steep slope along the southern margin of the Cubitas Hills. They describe approximately 650 feet (200 m) of uplift associated with the Cubitas Hills that post-dates deposition of Pliocene-Pleistocene (?) fluvial deposits north of the hills. If this interpretation is correct, then this uplift may have occurred in the hanging wall of the Cubitas fault, which may be Quaternary-active (Reference 500).

Pushcharovskiy et al. (Reference 846) do not label the Cubitas fault on their 1:250,000 scale geologic map. Pushcharovskiy (Reference 847) shows the Cubitas fault as an approximately 50-mile-long (85-km-long), south-dipping thrust fault on the 1:500,000 scale tectonic map. Because they do not label faults by name, it is not clear whether the Cubitas fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Cubitas fault (Figure 2.5.1-369).

The Cubitas fault does not appear on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3), but seemingly does appear as an unnamed fault on the 1:2,000,000 scale neotectonic map from this same atlas (Reference 944, plate III.2.4-8). The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) labels an approximately 50-mile-long (85-km-long) feature as the Cubitas fault.

Domingo Fault

At its nearest point, the low-angle Domingo fault is located 175 miles (282 kilometers) south of the Turkey Point Units 6 & 7 site. This northwest-striking, south-dipping thrust fault carried the Cretaceous arc and serpentinites over the carbonate platform rocks and can be considered the former suture between North America and Caribbean plates (References 439 and 440) (Figure 2.5.1-247). The Domingo fault does not cut the uppermost Eocene and younger sedimentary units, and is late Eocene in age (References 440 and 439). A myriad of other thrusts are mapped in detail (though not shown Figure 2.5.1-247), which imbricate both the autochthonous and allochthonous units on the island (Reference 439). On 1:250,000 scale maps and interpreted cross sections, these faults also do not cut the uppermost Eocene and younger deposits, and so are not Quaternary in age (References 439, 497, 440, and 846) (Figure 2.5.1-248).

Guane Fault

The subsurface Guane fault is a northeast-striking fault in western Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 1). At its nearest point, the Guane fault is approximately 230 miles (370 km) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489) provide no discussion of the Guane fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Guane fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494, p. 516) describe the Guane fault as a "large and complex structure totally covered by young sediments in the Palacios Basin" that is "predominantly vertical with left transcurrence." They list nineteen earthquakes that they suggest may have occurred on the Guane fault, many of which are listed by year only without month, day, intensity, and magnitude information. The largest of these is the January 23, 1880 M_w 6.1 San Cristobal earthquake. In the Phase 2 earthquake catalog, seismicity in the vicinity of the Guane fault is sparse, but other light- to moderate-magnitude earthquakes within 20 miles (32 km) of the fault include the May 20, 1937 M_w 5.1, December 20, 1937 M_w 5.1, October 12, 1944 M_w 4.0, and September 11, 1957 M_w 4.0 earthquakes (Figure 2.5.1-368 Sheet 1). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Based on their review of aerial photographs and satellite imagery, Cotilla-Rodriguez and Cordoba-Barba (Reference 942, p. 186) note two rivers in the Palacios Basin (Bayate and San Cristobal rivers) that show, in plan view, what they call "fluvial inflections" that they interpret as the result of surface deformation associated with the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 942, p. 186) indicate this allows for "the identification of an SW-NE alignment on the south plain of Pinar del Rio, corresponding to the Guane fault, whith *[sic]* was responsible for

the San Cristobal earthquake on the 28.01.1880." However, other rivers along strike to the northeast and southwest do not appear to show such inflections. Moreover, Cotilla-Rodriguez et al. (Reference 494, p. 516) indicate the Guane fault is "totally covered by young sediments in the Palacios Basin." Likewise, Cotilla-Rodriguez and Cordoba-Barba (Reference 943, p. 501) indicate the Guane fault "is located under ample thicknesses of sediments of the plain in southern Pinar del Rio." The Cotilla-Rodríguez et al. (Reference 494) and Cotilla-Rodriguez and Cordoba-Barba (Reference 943) studies do not specify a burial depth for the Guane fault, but seemingly are at odds with Cotilla-Rodriguez and Cordoba-Barba's (Reference 942) interpretation of surface manifestation of deformation.

Cotilla-Rodriguez and Cordoba-Barba (Reference 943) describe historical accounts of the January 23, 1880 earthquake, including first-hand observations of earthquake damage in San Cristobal, Candelaria, and elsewhere in the region. They note that the most severe and concentrated damage was located not in the mountainous regions of the Sierra del Rosario and Sierra de los Organos near the Pinar fault (discussed below), but rather within the Palacios Basin near the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 943) cite this as evidence that the 1880 earthquake occurred on the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 943, p. 514) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Alternatively, however, the pattern of 1880 damage could be explained by possible focusing of seismic waves within the basin, possible hanging-wall focusing effects, possible liquefaction, or possible differences in population density and building styles. In other words, the pattern of 1880 damage is not conclusive evidence that the earthquake occurred on the Guane fault, as opposed to on the Pinar fault or other structure.

The Guane fault is not depicted on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Perez-Othon and Yarmoliuk (Reference 848) show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba in the vicinity of the Guane fault that cuts Miocene strata, but is covered by unfaulted Pliocene-Pleistocene units. Because they do not label faults by name, it is not clear whether the Guane fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Guane fault (Figure 2.5.1-369). The Guane fault does not seem to appear on any maps in the Nuevo Atlas Nacional de Cuba (Reference 944).

Habana-Cienfuegos Fault

The Habana-Cienfuegos fault is a northwest-striking, left-lateral strike-slip fault in western and central Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2). At its nearest point, the Habana-Cienfuegos fault is approximately 220 miles (355 km) from the Turkey Point Units 6 & 7 site. Cotilla-Rodriguez et al. (Reference 494) map the Habana-Cienfuegos fault as extending offshore in northern Cuba, where it terminates at or south of the Nortecubana fault, with which it forms a "morphostructural knot" (Reference 494, p. 516) (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Offshore of southern Cuba, the Habana-Cienfuegos fault is shown as intersected and terminated by the Surcubana fault in a similar "morphostructural

knot" (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2, and Figure 5 of Reference 494). Cotilla-Rodriguez et al. (Reference 494) indicate that the Habana-Cienfuegos fault is expressed in the topography in the northwest at Havana Bay and in the southeast at Cienfuegos Bay.

Garcia et al. (Reference 489) provide minimal discussion of the Habana-Cienfuegos fault. Garcia et al. (Reference 489, p. 2,571) indicate "although the earthquakes reported in Havana and some locations of its province cannot be attributed to the western portion of the Norte Cubana seismic region, the seismic activity of the Havana fault system is still under debate." Further to the southeast, Garcia et al. (Reference 489, p. 2,571) indicate that the Cienfuegos fault "coincides with a deep fault located under younger tectonic sequences, it does not have a well-defined character."

In the Phase 2 earthquake catalog, seismicity is sparse in the vicinity of the Habana-Cienfuegos fault (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) list nineteen earthquakes that they suggest may have occurred on the Habana-Cienfuegos fault, many of which are listed by year only without month, day, intensity, and magnitude information. The largest of these earthquakes is the December 16, 1982 Ms 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_w 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Based on the similarity in location, magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (Reference 494) manuscript. In the Phase 2 earthquake catalog, this earthquake is located approximately 7 miles (11 km) north of the Habana-Cienfuegos fault trace (Figure 2.5.1-368 Sheet 1). Cotilla-Rodriguez et al. (Reference 494) alternatively suggest that this earthquake may have occurred on the Cochinos fault instead. They also associate a Ms 2.5 earthquake and nine MSK intensity III – V earthquakes (approximately MMI III – V) with the Habana-Cienfuegos fault. Cotilla-Rodriquez et al. (Reference 494) suggest that the March 9, 1995, Ms 2.5 earthquake could have occurred on the Habana-Cienfuegos fault or on the nearby Guane fault. Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Habana-Cienfuegos fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba and Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba. Because they do not label faults by name, it is not clear whether the Habana-Cienfuegos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Habana-Cienfuegos fault (Figure 2.5.1-369).

The 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3) shows an approximately 25-mile-long (40-km-long) unnamed fault near Havana in the vicinity of the northwestern-most portion of the

Habana-Cienfuegos fault as shown on Figure 2.5.1-368 Sheet 1. Similarly, the 1:2,000,000 scale neotectonic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.2.4-8) shows an approximately 37-mile-long (60-km-long) unnamed fault in the same vicinity, the southeastern 12 miles (20 km) of which is shown as a dashed line. Neither of these maps from the Nuevo Atlas Nacional de Cuba (Reference 944, plates III.2-3 and III.2.4-8) shows a fault extending from Havana southeastward to the southern coast of Cuba, as shown by Cotilla-Rodríguez et al. (Reference 494).

Hicacos fault

The Hicacos fault is an east-northeast-striking fault in north-central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 1). At its nearest point, the Hicacos fault is approximately 155 miles (250 km) south of the Turkey Point Units 6 & 7 site. Based on mapping by Cotilla-Rodriguez et al. (Reference 494), the Hicacos fault is the nearest fault in Cuba to the site identified as active by these authors. Some publications Reference 769 refer to this fault as the Matanzas fault.

Garcia et al. (Reference 489, p. 2,571) provide minimal discussion of the Hicacos fault. They indicate it is "a deep fault above Paleocene-Quaternary formations, splitting the ophiolites sequence that makes the main Cuban watershed deviate abruptly, causing different types of fluvial networks." Garcia et al. (Reference 489, p. 2,571) state that the "earthquakes reported in Matanzas and more recently in the Varadero-Cardenas area are associated with this structure." They provide no additional information regarding these earthquakes.

Cotilla-Rodríguez et al. (Reference 494) characterize the Hicacos fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494, p. 516) describe the Hicacos fault as a "normal fault, transcurrent to the left" that is "expressed throughout the Peninsula de Hicacos and is internal in the island territory by the eastern edge of Matanzas Bay, delineating very well the Matanzas Block." Further to the west-southwest, Cotilla-Rodriguez et al. (Reference 494, p. 516) indicate that the Hicacos fault is "weakly represented" in the geomorphology.

Seismicity in the vicinity of the Hicacos fault is sparse (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). The nearest epicenters from the Phase 2 earthquake catalog to the Hicacos fault are four co-located M_w 3.1 to 3.7 earthquakes that occurred near the central portion of the fault in 1812, 1852, 1854, and 1970. Another earthquake occurred in 1777 with M_w 3.7, located on strike with, but approximately 7 miles (11 kilometers) southwest of, the mapped fault trace. Likewise, Cotilla-Rodriguez et al. (Reference 494) indicate sparse seismicity near the Hicacos fault, and note that no focal mechanisms are associated with earthquakes in the vicinity of this fault. According to Cotilla-Rodriguez et al. (Reference 494), historical accounts suggest 10 earthquakes of less than or equal to MSK intensity V (approximately MMI V) occurred in the vicinity of the Hicacos fault (Reference 494). However, the association of these earthquakes with the Hicacos fault or another mapped or unmapped fault is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba and the paucity of available focal plane solutions.

Case and Holcombe's (Reference 480) 1:2,500,000 scale map of the Caribbean region shows segments of the Hicacos fault cutting upper Tertiary rocks. Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map of Cuba shows an unnamed fault in the vicinity of the Hicacos fault that extends from Matanzas for approximately 50 miles (80 kilometers) to the southwest. Because they do not label faults by name, it is not clear whether the Hicacos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba. They indicate, however, a Mesozoic age for an unnamed fault in the vicinity of the northeastern-most portion of the Hicacos fault (Figure 2.5.1-369). Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba shows an unnamed fault cutting lower Miocene rocks in the vicinity of the central Hicacos fault as shown on Figure 2.5.1-368 Sheet 1, but their mapping does not extend this fault as far northeast as the north coast of Cuba. The locally northeast-trending shoreline and a narrow peninsula near Matanzas are notably linear and on-trend with the fault, likely influencing where the fault is mapped in other representations. Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba shows the northeastern extent of the Hicacos fault similar to the depiction shown in Figure 2.5.1-368 Sheet 1, and terminating to the southwest at Cuba's southern coast.

The Hicacos fault is depicted differently on different maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map from this atlas (Reference 944, plate III.1.2-3) shows an unnamed, northeast-striking, approximately 25-mile-long (40-kilometer-long) fault in the vicinity of the Hicacos fault. This unnamed fault is mapped within lower to middle Miocene-age deposits and does not appear to cut Holocene-age deposits near Matanzas at the northeastern end of the fault. The 1:1,000,000 scale geomorphic map from this atlas (Reference 944, plate IV.3.2-3) shows an unnamed fault offshore along the narrow peninsula that may be the Hicacos fault, but this offshore fault does not extend onshore to the southwest. The Hicacos fault is labeled on the lineament map from this atlas (Reference 944, plate III.3.1-11) as an approximately 110-mile-long (175-km-long), northeast-trending feature that extends from near Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas on Cuba's north coast. On the lineament map, the northeastern-most 20 miles (35 km) of this feature are shown as a dashed line. The 1:2,000,000 scale neotectonic map from this atlas (Reference 944, plate III.2.4-8) shows an unnamed, northeast-striking fault in the vicinity of the Hicacos fault that extends from Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas, and offshore where it is terminated by an unnamed fault that likely is the Nortecubana fault.

Various researchers describe elevated marine terraces west of Matanzas Bay near the Hicacos fault along Cuba's north coast. Continuous and planar geomorphic surfaces like these can be used as Quaternary strain markers with which to assess the presence of tectonic deformation. Ducloz (Reference 915) and Shanzer et al. (Reference 923) provide observations of Pleistocene-age terraces in this region, including the Terraza de Seboruco terrace, which is currently a few meters above modern sea level. Both Ducloz (Reference 915) and Shanzer et al. (Reference 923)

speculate that Pleistocene-age terraces in this region may have formed as the result of both tectonic uplift and global fluctuations in sea level.

More recent studies, however, conclude that tectonic uplift is not required to explain the present elevation of the Pleistocene-age Terraza de Seboruco terrace west of Matanzas Bay and near the Hicacos fault. Toscano et al.'s (Reference 946) radiometric age dating of coral samples collected from the Terraza de Seboruco terrace indicates this surface formed at approximately 120 – 140 ka. Based on these ages, they associate the Terraza de Seboruco terrace with the global Substage 5e sea level high-stand at approximately 122 ka. Toscano et al. (Reference 946) also observe that this terrace in the Matanzas area is just a few meters above mean sea level, similar to the elevation of other Substage 5e reef deposits throughout "stable" portions of the Caribbean, and therefore can be explained solely by changes in sea level. Toscano et al. (Reference 946) conclude that "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba." Similarly, Pedoja et al. (Reference 945) investigated late Quaternary coastlines worldwide and observe minor uplift relative to sea level of approximately 0.2 mm/yr, even along passive margins, outpacing eustatic sea level decreases by a factor of four. They suggest that, when accounting for eustatic changes in sea level, the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco terrace) has been uplifted at an average rate that ranges from approximately 0.00 to 0.04 mm/yr over the last approximately 122 ka, consistent with uplift rates observed from other stable margins worldwide. If the effects of eustasy are ignored, Pedoja et al.'s (Reference 945) data allow for an uplift rate at Matanzas of approximately 0.06 mm/yr over the last approximately 122 ka, following this "conservative" (Reference 945, p. 5) approach.

Whereas recent studies indicate that tectonic uplift is not required to explain the present elevation of the Terraza de Seboruco terrace west of Matanzas Bay (References 946 and 945), these data do not preclude activity on the Hicacos fault. As described above, the location and extent of the Hicacos fault differs between various geologic maps and published figures, so it is unclear whether the Hicacos fault is overlain by the Terraza de Seboruco terrace. Furthermore, if the sense of slip on the Hicacos fault were primarily strike-slip as opposed to dip-slip, it could be difficult to observe surface manifestation of fault-related deformation on the Terraza de Seboruco terrace.

La Trocha Fault

The La Trocha fault is a northeast-striking fault in central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 2). At its nearest point, the La Trocha fault is approximately 260 miles (420 km) from of the Turkey Point Units 6 & 7 site. Rosencrantz (Reference 529) maps a northeast-striking structure across the Yucatan basin south of Cuba (Figure 2.5.1-286) and interprets it as the southwestern extension of the La Trocha fault.

Garcia et al. (Reference 489) provide minimal discussion of the La Trocha fault. Garcia et al. (Reference 489, p. 2,571) indicate it is a "deep fault more than 180 km long, with neotectonic transcurrent activity" and "its seismicity is documented by

the earthquakes in the Santi Spiritus region." They also indicate that the La Trocha fault is expressed in geophysical data, but they do not elaborate.

Cotilla-Rodríguez et al. (Reference 494) assign the La Trocha fault an age of Pliocene-Quaternary and also suggest a possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494, p. 517) describe the La Trocha fault as "a fault zone transcurrent to the left with a large angle." They suggest a possible association between three earthquakes of less than or equal to MSK intensity V (approximately MMI V) and the La Trocha fault. The Phase 2 earthquake catalog shows very sparse seismicity associated with the La Trocha fault (Figure 2.5.1-368 Sheet 2). The largest earthquakes from the Phase 2 earthquake catalog near the La Trocha fault are the March 10, 1952 M_w 4.0 and January 1, 1953 M_w 4.3 events. Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Leroy et al. (Reference 499) interpret the La Trocha fault as the northern transform limb of a proto-Cayman spreading center that was active in the early Eocene (53 Ma) and was abandoned by 49 Ma. This interpretation is the result of the southward migration of the left-lateral strike slip faults that make up the Caribbean-North America plate boundary (e.g., Mann et al. [Reference 639]).

The La Trocha fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Review of Pushcharovskiy et al.'s (Reference 846) maps in the vicinity where Cotilla-Rodriguez et al. (Reference 494) map the La Trocha fault indicates no northeast-striking faults cutting Miocene and younger strata. Potentially, this structure is buried by the overlying strata and could be pre-middle Miocene in age. Pushcharovskiy's (Reference 847) tectonic map of Cuba, however, clearly depicts and labels the La Trocha fault with extent and location similar to the La Trocha fault shown in Figure 2.5.1-368 Sheet 2. Because they do not label faults by name, it is not clear whether the La Trocha fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Neogene-Quaternary age for an unnamed fault in the vicinity of the La Trocha fault (Figure 2.5.1-369).

The La Trocha fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map of Cuba from this atlas (Reference 944, plate III.1.2-3) does not include the La Trocha fault. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Reference 944, plate III.2.4-8) shows an unnamed fault in the vicinity of the La Trocha fault. This unnamed fault is mapped as terminating northward at the northern coast of Cuba. The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) depicts and labels the La Trocha fault as an approximately 90-mile-long (150-km-long), northeast-trending feature that extends from Cuba's southern to its northern coast.

Las Villas Fault

The Las Villas fault is a northwest-striking fault in central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 2). At its nearest point, the Las Villas fault is approximately 155 miles (250 km) south of the Turkey Point Units 6 & 7 site. Pardo (Reference 439, p.

316) maps the Las Villas fault as a south-dipping thrust with up to approximately 18 miles (30 km) of horizontal displacement. According to Pardo (Reference 439), the Las Villas fault displaces middle Eocene units, but exhibits greater displacement of older units, indicating that most of its movement was pre-middle Eocene.

Garcia et al. (Reference 489, p. 2,571) describe the Las Villas fault as a "deep fault that divides the younger coastal formations of the north from the older ones of the south, it appears as a negative anomaly in the gravimetric map and with positive and negative anomalies in the magnetic field. Medium-magnitude seismicity is associated with this fault."

Cotilla-Rodríguez et al. (Reference 494) characterize the Las Villas fault as active based on its possible association with seismicity and geomorphic expression. Cotilla-Rodríguez et al. (Reference 494, p. 517), however, provide only the following minimal description of the Las Villas fault:

> **"This fault maintains the prevailing strike of the island on the southern part of the Alturas del Norte de Las Villas, from the surroundings of the Sierra Bibanasi to the Sierra de Jatibonico. It is a normal type fault with a large angle, with inverse type sectors. It is intercepted to the east by the La Trocha fault. Its outline has young eroded scarps. It is of Pliocene-Quaternary age. The associated seismic events are: 15.08.1939 (Ms = 5.6); 01.01.1953 (I = 5 MSK); I = 4 MSK; (03.02.1952 and 25.05.1960), 22.01.1983 (I = 3 MSK); and noticeable without specification 04.01.1988."**

Cotilla-Rodríguez et al. (Reference 494) do not describe their basis for concluding that the Las Villas fault is Pliocene–Quaternary in age and they do not provide reference to other publications that provide this information. Likewise, Cotilla-Rodríguez et al. (Reference 494) do not provide additional discussion of the "young eroded scarps", nor do they provide reference to other publications that provide this information. It is not clear from this limited description if these are fault scarps formed directly by recent slip on the Las Villas fault or if they are fault-line scarps formed by recent differential erosion along the fault trace. It is also possible that these "young eroded scarps" formed by preferential erosion of sheared rocks within the fault zone. Based on the scant information provided in Cotilla-Rodríguez et al. (Reference 494), it is not possible to distinguish between these alternatives. There are no known paleoseismic trench studies or detailed geomorphic assessments of the Las Villas fault with which to assess recent earthquake activity on this fault. Where faults exhibit scarps in young deposits or surfaces, such as the Baconao fault in southernmost Cuba, Cotilla-Rodriguez et al. (Reference 494) provide clear description and do not include "eroded" in the description.

Figure 2.5.1-368 Sheet 2 indicates moderately sparse seismicity from the Phase 2 earthquake catalog that may be roughly aligned with the Las Villas fault, as mapped by Pardo (Reference 439). A total of 33 earthquakes from the Phase 2 earthquake catalog are located within approximately 6 miles (10 km) of the Las Villas fault along its length. Of these, 29 are located northeast of the trace of this southwest-dipping fault, with the remaining four located southwest of the fault trace. The largest

earthquake near the Las Villas fault is the August 12, 1873 M_w 5.1 earthquake, located approximately 3 miles (5 km) northeast of the fault (Figure 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) indicate focal mechanisms for these earthquakes are unavailable, so it is not possible to assess whether these possibly roughly aligned epicenters occurred on the Las Villas fault or on another fault or faults. Cotilla-Rodriguez et al. (Reference 494) suggest that the largest recorded earthquake associated with the Las Villas fault is the Ms 5.6 event on August 15, 1939 (listed in the Phase 2 earthquake as M_w 5.84). Based on the fault mapping of Pardo (Reference 439) and the location of this earthquake from the Phase 2 earthquake catalog, however, this earthquake is located approximately 20 miles (32 km) northeast of this southwest-dipping fault (Figure 2.5.1-368 Sheet 2), suggesting a fault other than the Las Villas ruptured during this event.

Review of geologic mapping (References 480, 848, and 846) reveals that no units of Quaternary age are faulted, but the coarse scale of mapping (1:250,000 to 1:2,500,000) does not preclude recent activity. Because they do not label faults by name, it is not clear whether the Las Villas fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Las Villas fault (Figure 2.5.1-369).

The Las Villas fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Reference 944, plate III.2.4-8) shows an unnamed fault in the vicinity of the Las Villas fault. Likewise, the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) depicts and labels the Las Villas fault as an approximately 120-mile-long (190-km-long), northwest-trending feature.

Nipe Fault

The Nipe fault is a northeast-striking fault in southern Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 3) that separates the mountainous Sierra Maestra province on the east from the Camaguey terrane on the west. At its nearest point, the Nipe fault is approximately 420 miles (675 km) from the Turkey Point Units 6 & 7 site. Other names for this fault include the Cauto, Cauto-Nipe, Guacanayabo, and Nipe-Guacanayabo fault.

Leroy et al. (Reference 499) and Rojas-Agramonte et al. (Reference 445) interpret the Nipe fault as the southern transform limb of the early Cayman spreading center. In their models, the Nipe fault was abandoned by the early Oligocene (approximately 20 Ma) as the plate boundary shifted south to its present location at the Oriente fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Nipe fault as active based on possible association of seismicity with the fault and gross geomorphic expression. Cotilla-Rodriguez et al. (Reference 494, p. 516) describe the Nipe fault as "a fault system with transcurrence to the left" whose "outline is labeled by several epicenters" including "some epicentral swarms" near its northeastern end. The Phase 2 earthquake catalog shows sparse seismicity associated with the Nipe fault (Figure 2.5.1-368 Sheet 3). The largest earthquakes in the vicinity of the fault include

the August 3, 1926 M_w 5.3 and July 19, 1962 M_w 5.36 earthquakes (Figure 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Unnamed faults in the vicinity of the Nipe fault are shown on Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map of Cuba. Because they do not label faults by name, it is not clear whether the Nipe fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the mapped position of the Nipe fault (Figure 2.5.1-369). Unnamed faults in the vicinity of the Nipe fault also are shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba depicts and labels the Nipe fault as the "Cauto-Nipe" fault.

The Nipe fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Reference 944, plate III.2.4-8), however, shows two sub-parallel, unnamed faults in the vicinity of the Nipe fault. The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) labels two faults as "Cauto I" and "Cauto II" in the vicinity of the Nipe fault. On this map, Cauto I strikes northeast and extends from Cuba's southern to its northern coast. Cauto II is more northerly striking and is truncated by Cauto I.

Nortecubana Fault

The Nortecubana fault system is the main structure within the Cuban fold-and-thrust belt offshore of, and near-shore to, northern Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). The Nortecubana fault system dips south with a dip angle that varies along strike. At its nearest point, the Nortecubana fault system is approximately 150 miles (240 km) from the Turkey Point Units 6 & 7 site.

The role of the Nortecubana thrust in the evolution of the Caribbean-North America plate boundary has been interpreted in different ways. The Nortecubana fault system may represent the ancestral subduction zone that was abandoned as the plate boundary shifted southward towards its current location south of Cuba. Alternatively, the Nortecubana thrust fault has been interpreted to represent the frontal decollement of an accretionary wedge associated with the collision of the Greater Antilles Arc and the North America plate south of Cuba (References 786 and 439). Regardless of its ancestral origins, the Nortecubana fault system underlies the preponderance of folding and deformation within and just north of Cuba, which is collectively referred to as the Cuban fold-and-thrust belt. Wells drilled directly offshore of northeastern Cuba have encountered faults and repeated stratigraphy indicating Eocene thrusting (Reference 439), and seismic reflection data have imaged northward thrusting of basin deposits (Reference 307). Seismic lines typically indicate that the offshore north-vergent thrusts are draped by unfaulted late Tertiary to Quaternary sediments (Figures 2.5.1-279, 2.5.1-280, 2.5.1-282, 2.5.1-287, and 2.5.1-288).

Cotilla-Rodríguez et al. (Reference 494) characterize the Nortecubana fault as active based on its possible association with seismicity. They note that the preponderance

of this seismic activity is associated with eastern portions of the fault nearest the modern plate boundary. In the Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 COL, seismicity along the west and central portions of the Nortecubana fault is sparse (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2), relative to the easternmost portion of the fault (Figure 2.5.1-368 Sheet 3). The Phase 2 earthquake catalog includes a M_w 6.29 earthquake that occurred on February 28, 1914 off the north coast of southeastern Cuba (Figure 2.5.1-368 Sheet 3). Cotilla-Rodríguez et al. (Reference 494) suggest this earthquake occurred on the Nortecubana fault. Due to the absence of a permanent seismic monitoring network in Cuba, however, this epicenter is poorly located. The given location, at approximately 4 miles (6 km) north-northeast of the south-dipping Nortecubana fault (and approximately 400 miles (640 km) from the Turkey Point Units 6 & 7 site), suggests that this earthquake could have occurred on another fault. Due to uncertainties in the locations of the 1914 earthquake as well as the fault, this does not preclude the 1914 earthquake from having occurred on the Nortecubana fault. No focal mechanism or depth determination for this earthquake is available with which to help identify the causative fault. It is unlikely that an earthquake of this magnitude would have ruptured to surface of the ocean floor but, even if it had, bathymetric data are insufficient to assess the presence of a submarine fault scarp and no detailed submarine paleoseismic studies are available for the region. Thus, it is not possible to definitively state whether the 1914 earthquake occurred on the Nortecubana or another fault.

The submarine Nortecubana fault typically does not appear on regional surface geologic maps. For example, the Nortecubana fault is not shown on Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map, Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). This fault, however, is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (Reference 847) 1:500,000 scale tectonic map of Cuba shows the Nortecubana fault as an unnamed, discontinuous, dashed line north of Cuba. The 1:2,000,000 scale neotectonic and lineament maps from the Nuevo Atlas Nacional de Cuba (Reference 944, plates III.2.4-8 and III.3.1-11) show but do not label the Nortecubana fault as solid and dashed lines, respectively. Because they do not label faults by name, it is not clear whether the Nortecubana fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Nortecubana fault (Figure 2.5.1-369).

Oriente Fault Zone

The most seismically active region of Cuba today is the Oriente fault zone, located offshore south of eastern Cuba (Figures 2.5.1-229, 2.5.1-247, 2.5.1-251, and 2.5.1-368 Sheet 3). This left-lateral fault system is part of the active North America-Caribbean Plate boundary and connects the Cayman Trough spreading center to the Septentrional fault (Figure 2.5.1-202). Geodetic data indicate that between 8 and 13 millimeters/year of slip are accommodated on this structure; hence it is classified as

a capable tectonic source. For further discussion, see Subsections 2.5.1.1.2.3.1.2, 2.5.2.4.4.3.2.2, and 2.5.2.4.4.3.2.3.

Pinar Fault

The Pinar fault is a northeast-striking, steeply southeast-dipping fault in western Cuba (Figures 2.5.1-247, 2.5.1-251, 2.5.1-289, and 2.5.1-368 Sheet 1). As mapped by Tait (Reference 448) and shown on Figure 2.5.1-368 Sheet 1, the Pinar fault is located, at its nearest point, approximately 205 miles (330 km) from the Turkey Point Units 6 & 7 site. As mapped by Garcia et al. (Reference 489), the Pinar fault is approximately 200 miles (320 km) southwest of the site at its nearest point. As mapped by Cotilla-Rodríguez et al. (Reference 494), the Pinar fault is approximately 225 miles (360 km) southwest of the site at its nearest point. Rosencrantz (Reference 529) maps a series of offshore faults along the eastern Yucatan Platform and tentatively indicates they could be the offshore southwestern extension of the Pinar fault.

The Sierra del Rosario in western Cuba displays a prominent and fairly linear southeast-facing mountain front, suggesting the possibility of recent or ongoing uplift associated with the Pinar fault. There are, however, conflicting opinions in the literature regarding whether the Pinar fault is active. Garcia et al. (Reference 489, p. 2,571) note the Pinar fault is grossly expressed as a prominent escarpment and suggest the Pinar fault "was reactivated in the Neogene-Quaternary" and may have produced the January 23, 1880 M_w 6.13 earthquake (Figure 2.5.1-368 Sheet 1). Cotilla-Rodríguez et al. (Reference 494, p. 516) describe the Pinar fault as having "very nice relief expression" but conclude it is "inactive." Cotilla-Rodríguez et al. (Reference 494) provide no evidence in support of their assessment but suggest that the 1880 earthquake instead occurred on the subsurface Guane fault, which is subparallel to the Pinar fault and is located within the Los Palacios basin to the southeast (Figure 2.5.1-368 Sheet 1). Cotilla-Rodriguez and Cordoba-Barba (Reference 943) cite historical accounts of the severity and distribution of earthquake-related damage as evidence that the January 23, 1880 earthquake occurred on the Guane fault instead of the Pinar fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 943, p. 514) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Gordon et al. (Reference 697) describe multiple phases of deformation in western Cuba in general and on the Pinar fault in particular. Gordon et al. (Reference 697, p. 10,078-10,079) are unable to constrain the upper bound of the age of most-recent deformation on the Pinar fault "because lower Miocene rocks were the youngest rocks from which observations were made."

The Phase 2 earthquake catalog indicates that a M_w 6.13 earthquake occurred on January 23, 1880 in western Cuba in the vicinity of the Pinar and Guane faults (Figure 2.5.1-368 Sheet 1). The epicenter of this poorly located, pre-instrumental earthquake is approximately 7 miles (11 km) south of the trace of the steeply southeast-dipping Pinar fault and approximately 5 miles (8 km) north of the Guane fault. As Garcia et al. (Reference 489) suggest, however, locational uncertainties for historical earthquakes in Cuba could be on the order of 15 to 20 kilometers or more. Based on available information, it is not possible to definitively state whether the

1880 earthquake occurred on the Guane fault, the Pinar fault, or another fault in the region. No focal mechanism or depth determination for the 1880 earthquake is available with which to help identify the causative fault. Moreover, no paleoseismic trench studies or detailed tectonic geomorphic assessments are available for the Pinar fault, Guane fault, or other faults in the region. The Phase 2 earthquake catalog indicates generally sparse seismicity in the vicinity of the Pinar fault (Figure 2.5.1-368 Sheet 1). There does not appear to be an alignment of epicenters along the Pinar fault, but rather sparse earthquakes appear distributed throughout western Cuba both north and south of the fault in the Sierra del Rosario mountains and the Palacios Basin. The Phase 2 earthquake catalog indicates that additional minor- to moderate-magnitude (M_w 4 to 5.1) earthquakes occurred in western Cuba near the Pinar and Guane faults in 1896, 1937, 1944, and 1957 (Figure 2.5.1-368 Sheet 1).

The Pinar fault is depicted on many regional scale maps of Cuba, including numerous maps in the Nuevo Atlas Nacional de Cuba (Reference 944) and Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba. Available geologic mapping at scales between 1:250,000 and 1:1,000,000 is consistent with an active Pinar fault. These data do not, however, require that the Pinar fault is active. Generally, there is a lack of young deposits mapped along the Pinar fault with which to assess the age of its most-recent slip. Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic mapping shows an unnamed fault in the vicinity of the Pinar fault that, along most of its length, juxtaposes Jurassic-age limestones of the Arroyo Cangre and San Cayetano formations on the northwest against Paleogene-age deposits on the southeast. This map shows the southernmost 3 miles (5 km) of the fault as a dashed line that juxtaposes Jurassic limestone on the northwest against upper Pliocene to lower Pleistocene undifferentiated alluvial and marine deposits, which may constitute evidence for activity. Along strike immediately to the south near Playa de Galafre on Cuba's southern coast, however, the fault is covered by the same upper Pliocene to lower Pleistocene unit with no apparent deformation (Reference 846). Along the central portion of the fault near Pinar del Rio, Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic mapping shows an approximately 4-mile-long (6-km-long) section where weakly cemented upper Pliocene-lower Pleistocene undifferentiated alluvial and marine deposits on the southeast are fault-juxtaposed against middle Jurassic Arroyo Cangre formation on the northwest. This map relationship may indicate that the Plio-Pleistocene deposits are faulted. Alternatively, the Plio-Pleistocene deposits may have been deposited against pre-existing topography along the fault, and therefore possibly post-date the age of most-recent faulting. Based on the crude scale of mapping, it is unclear which of these alternative interpretations is correct.

Perez-Othon and Yarmoliuk (Reference 848) present geologic mapping of Cuba at a scale of 1:500,000. Their map does not include fault names, but shows a fault in the vicinity of the Pinar fault that generally juxtaposes Jurassic-age rocks on the northwest against Eocene to Miocene rocks on the southeast. Near Pinar del Rio, they map a small patch of Pliocene- to Pleistocene-age conglomerates that apparently are correlative with Pushcharovskiy et al.'s (Reference 846) upper Pliocene to lower Pleistocene undifferentiated alluvial and marine deposits in the

same area and described above. According to Perez-Othon and Yarmoliuk's (Reference 848) mapping, and unlike Pushcharovskiy et al.'s (Reference 846) mapping, these Plio-Pleistocene deposits extend very close to, but are not in contact with, the fault. Instead, Perez-Othon and Yarmoliuk (Reference 848) show Jurassic-age limestone in fault contact with Eocene-age rocks in this area. Farther to the northeast near Los Palacios, Perez-Othon and Yarmoliuk (Reference 848) show an approximately 1- to 2-mile-long (2- to 4-km-long) stretch along the central section of the fault where Quaternary alluvial deposits are juxtaposed against Jurassic carbonate rocks. The resolution of Perez-Othon and Yarmoliuk's (1985) (Reference 848) mapping is insufficient to determine whether these Quaternary alluvial deposits are faulted or if they were deposited against pre-existing topography along the fault, and therefore possibly post-date the age of most-recent faulting. As an inset to their geologic map, Perez-Othon and Yarmoliuk (Reference 848) provide an additional map that shows their estimates of fault ages in Cuba. On their inset map of fault ages in Cuba, Perez-Othon and Yarmoliuk (Reference 848) assign a Neogene-Quaternary age to a northeast-striking fault that is presumed to be the Pinar fault (the inset map does not include fault names). Despite this Neogene-Quaternary age on the inset map, their 1:500,000 scale geologic map shows unnamed northwest-striking faults, to which they assign a Paleogene age on their inset map, as offsetting the younger Pinar fault.

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Reference 944, plate III.1.2-3). No fault names appear on this map, but a fault in the vicinity of the Pinar fault is shown as juxtaposing Jurassic carbonate rocks on the northwest against Miocene and older rocks on the southeast. Due to the crude scale at which this map is presented, however, it is not possible to constrain with certainty the age of faulting. This atlas also includes a 1:2,000,000 scale neotectonic map of Cuba (Reference 944, plate III.2.4-8) that defines "zones of maximum neotectonic gradient" and classifies them as "moderate", "intense", or "very intense". Only the modern plate boundary offshore southern Cuba is classified as "very intense" in this scheme. No fault names appear on this map, but a fault in the vicinity of the Pinar fault is shown within an "intense" zone.

Surcubana Fault

At its nearest distance, the Surcubana fault as mapped by Cotilla-Rodriguez et al. (Reference 494) is located approximately 230 miles (370 km) from the site (Figures 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) do not include the Surcubana fault in their list of twelve "seismoactive" faults in Cuba and this fault generally is not described by other studies of faulting in Cuba (e.g.,References 489, 786, and 439).

In the Phase 2 earthquake catalog, seismicity is sparse along and near the Surcubana fault, with only a dozen or so earthquakes located within approximately 20 miles (30 km) of the more than 500-mile-long (800-km-long) trace (Figures 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). Of these earthquakes, all are low to moderate magnitude and most are located at the southeastern end of the fault near the active plate boundary and may instead be associated with the Oriente fault. The closest earthquakes to the central and western sections of the Surcubana fault

from the Phase 2 earthquake catalog are located at approximately 81° west longitude (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). The first of these is located approximately 5 miles (8 km) north of the trace and occurred on March 27, 1964 with M_w 3.7. The second is located approximately 3 miles (5 km) south of the trace and occurred on October 22, 2005 with M_w 3.8. Because they do not label faults by name, it is not clear whether the Surcubana fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Surcubana fault (Figure 2.5.1-369).

Like the Nortecubana fault, the submarine Surcubana fault typically does not appear on regional surface geologic maps. For example, the Surcubana fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). This fault is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (Reference 847) 1:500,000 scale tectonic map of Cuba shows the Surcubana fault as an unnamed, discontinuous, dashed line south of Cuba. The 1:2,000,000 scale neotectonic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.2.4-8) shows, but does not label, the Surcubana fault as a solid line. The lineament map from the same atlas (Reference 944, plate III.3.1-11) shows but does not label the Surcubana fault as discontinuous and dashed lines.

~~Oriente Fault Zone~~

~~The most seismically active region of Cuba today is the Oriente fault zone, located offshore south of eastern Cuba (Figures 2.5.1-229, 2.5.1-247, and 2.5.1-251). This left-lateral fault system is part of the active North America-Caribbean Plate boundary and connects the Cayman Trough spreading center to the Septentrional fault (Figure 2.5.1-202). Geodetic data indicate that between 8 and 13 millimeters/year of slip are accommodated on this structure; hence it is classified as a capable tectonic source. For further discussion, see Subsections 2.5.1.1.2.3.1.2, 2.5.2.4.4.3.2.2, and 2.5.2.4.4.3.2.3.~~

Other Cuban Structures

Numerous other tectonic structures exist on the island of Cuba. Some of these are limited in extent, unstudied, or unnamed. These include the Punta ~~Allegre~~**Alegre** fault, folds along the northern edge of Cuba, and many short, unnamed northeast- and northwest-striking faults. The Punta ~~Allegre~~**Alegre** fault was discovered by logging repeated strata in oil wells just offshore north-central Cuba (Figure**s 2.5.1-247 and** 2.5.1-290). This fault is not imaged with seismic data, but postulated from well data. It is depicted with a vertical dip, but its orientation and extent are unknown (Reference 501).

Eocene and older strata along the northern edge of Cuba are deformed in a series of anticlines and synclines typically associated with underlying thrust faults (Figures 2.5.1-252 and 2.5.1-282). Because these folds are covered by undeformed Miocene and younger strata, they are pre-Miocene in age, and probably formed during the Eocene collision of the Greater Antilles Arc with the Bahama Platform.

Many short (<10 kilometers [<6.2 miles] in length) northeast- and northwest-striking faults, with undetermined sense of slip, do cut strata as young as middle Miocene throughout the island of Cuba. Where younger units (such as Plio-Pleistocene) overlie these same structures, they are consistently unfaulted. This suggests that these short faults are pre-Quaternary in age. Many of these faults do not intersect units younger than Miocene. These structures may be correlated with post-early Miocene normal faults and cross-cutting strike-slip faults described in outcrops in western Cuba (Reference 697).

In summary, many faults have been mapped on the island of Cuba. Aside from the Oriente fault, most of these faults were active during the Cretaceous to Eocene, associated with subduction of the Bahama Platform beneath the Greater Antilles Arc of Cuba and the subsequent southward migration of the plate boundary to its present position south of Cuba (Figure 2.5.1-250). However, only a few detailed studies of the most recent timing of faulting are available, and conflicting age assessments exist for many of the regional structures (Table 2.5.1-204). ~~Nonetheless, available geologic mapping (at 1:250,000 and 1:500,000 scales; References 846, 847, and 848) provides some information regarding the timing of activity for some of the regional structures and largely indicates that the Pleistocene and younger strata are undeformed throughout the island. This is consistent with geodetic data that indicate that less than 3 millimeters/year of deformation is occurring within Cuba relative to North America (References 502 and 503).~~ The available data indicate that the Oriente fault system, located offshore ~~just~~ **directly** south of Cuba, should be characterized as a capable tectonic source. Aside from the Oriente fault, no clear evidence for Pleistocene or younger faulting is available for any of the other regional tectonic structures on Cuba, and none of these faults are adequately characterized with late Quaternary slip rate or recurrence of large earthquakes. The scales of available geologic mapping (1:250,000 and 1:500,000; References 846, 847, and 848) do not provide sufficient detail to adequately assess whether or not individual faults in Cuba can be classified as capable tectonic structures.

The following new references will be included in a future revision of the FSAR:

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ASSOCIATED ENCLOSURES:

Enclosure A: SSHAC Level 2 Questionnaire in Support of Cuba Hazard Sensitivity Calculations