Enclosure A

SSHAC Level 2 Questionnaire in Support of Cuba Hazard Sensitivity Calculations

Questionnaire for Seismic Source Characterization of Cuba

As part of a seismic hazard sensitivity study for a proposed power plant at Florida Power & Light Company's (FPL) Turkey Point site in southern Florida, we are soliciting expert opinions regarding seismic source modeling options for the Cuba region. We hope that you will be able to take a few minutes to provide your thoughts on any or all of the six questions below. Thanks in advance for your assistance.

Southeastern Cuba lies directly north of the modern left-lateral strike-slip North American-Caribbean plate boundary (Figure 1). Individual fault sources along this plate boundary are capable of Mw 8+ earthquakes and exhibit slip rates on the order of 10 mm/yr. These distant plate boundary fault sources are included in our seismic source model and their closest distance from the site is approximately 680 km (bold red lines in Figure 1). The questions we pose to you are related to the appropriateness of modeling fault sources within intraplate Cuba away from the modern plate boundary and the background zone model options for the Cuba region (north of the modern plate boundary).

<u>Cuba Faults as Seismic Sources</u>

Cotilla-Rodriguez et al. (2007) identify about a dozen faults in Cuba as active structures on the basis that most exhibit a spatial association with seismicity (Figure 2). At their closest approaches, these faults range in distance from approximately 240 to 800 km from the Turkey Point site. The historical seismicity within Cuba includes events as large as ~Mw 6.2 and since most are based on felt intensity, epicentral locations generally are poor. Epicentral uncertainties on instrumentally located seismicity in Figures 1 and 3 are unknown. No surface fault ruptures are known to have occurred in Cuba and no slip rate information has been published for any faults. In addition, GPS deformation models, which could be used to help constrain slip rates, are not available for Cuba.

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?**

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?**

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?**

<u>Cuba Areal Seismic Source(s)</u>

In comparison to the Straits of Florida, Bahamas, and offshore areas to the north, Cuba exhibits characteristics that justify differentiating it as a separate seismic source(s). For example, Cuba lies closer to a plate boundary, exhibits a higher rate of seismicity, different tectonic history and geology, and greater crustal thickness than surrounding regions. We have modeled Cuba in two different areal (or

background) zone configurations. The first is a single areal zone with a uniform seismicity rate (bold black polygon on Figure 3) and the second is a six-zone model with uniform seismicity rates designed to isolate areas of higher and lower rates of seismicity (dashed black polygons in Figure 3). For the Turkey Point site, the single zone model results in a greater hazard than the six-zone model.

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?**

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?**

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?**

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Table 1. Assumed slip rate distributions for possible Cuba fault sources.

Fault Source	Assigned Slip Rate (mm/yr) [and weight]
Baconao NW	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Baconao SE	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Camaguey	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cochinos	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cubitas	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Guane	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Habana-Cienfuegos	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Hicacos	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
La Trocha	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Las Villas	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nipe	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Nortecubana Central	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nortecubana E	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Nortecubana W	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Pinar	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]

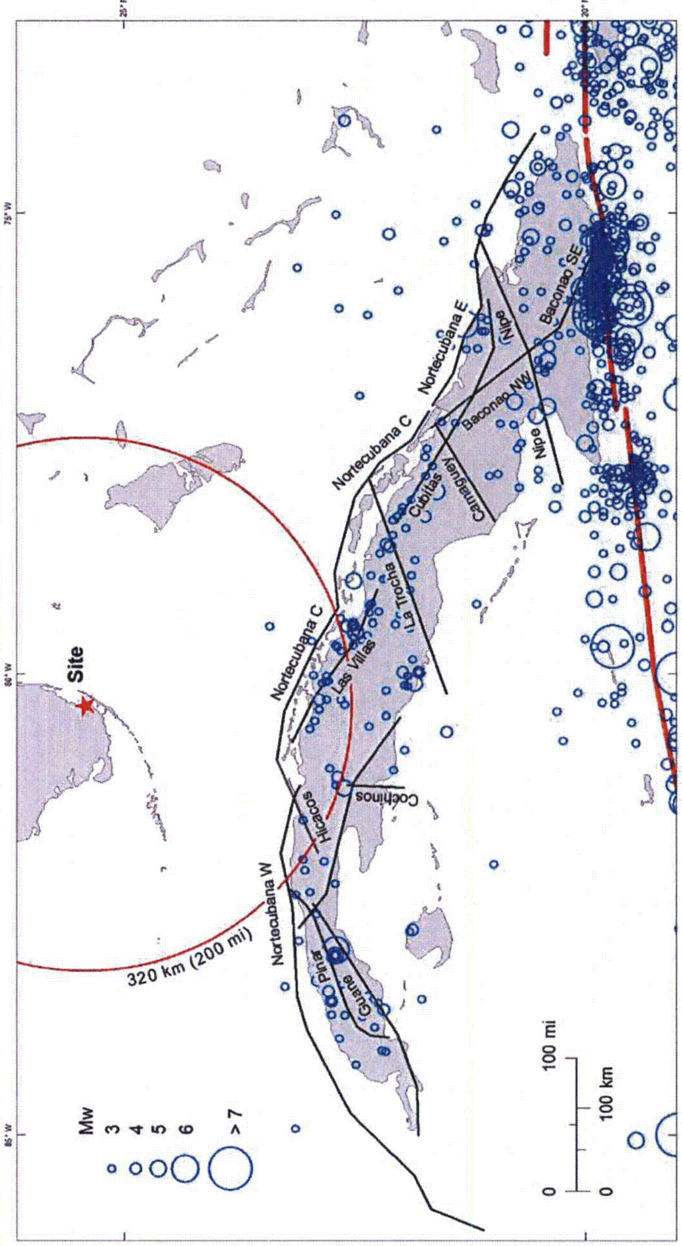

Figure 1. Possible Cuba fault sources (black lines), based on mapping by French and Schenk (1997), Kerr et al. (1999), Hall (2004), Cotilla-Rodriguez et al. (2007), Tait et al. (2009), and Pardo (2009). Seismicity (blue circles) is based on the earthquake catalog developed for the Turkey Point project.

Proposed Turkey Point Units 6 and 7
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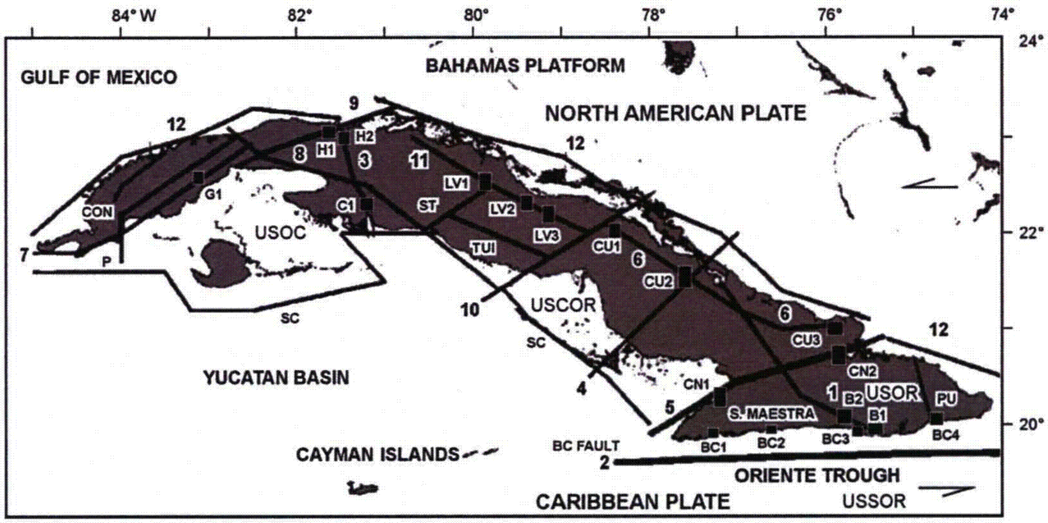

Fig. 5. Simplified seismotectonic map of Cuba (Cotilla et al. (1991a). Active faults: 1 — Baconao, 2 — Bartlett-Caiman, 3 — Cochinos, 4 — Camaguey, 5 — Cauto-Nipe, 6 — Cubitas, 7 — Guane, 8 — Habana-Cienfuegos, 9 — Hicacos, 10 — La Trocha, 11 — Las Villas, 12 — Nortecubana. Other faults: CON — Consolacion del Norte, P — Pinar, PU — Purial, SC — Surcubana, ST — Santa Clara, TUI — Tuinicii. See Tables 1 and 2. Black squares are sites for which microtectonic measurements are made (see Fig. 10).

Figure 2. Map of active faults in Cuba, taken from Cotilla-Rodriguez et al. (2007).

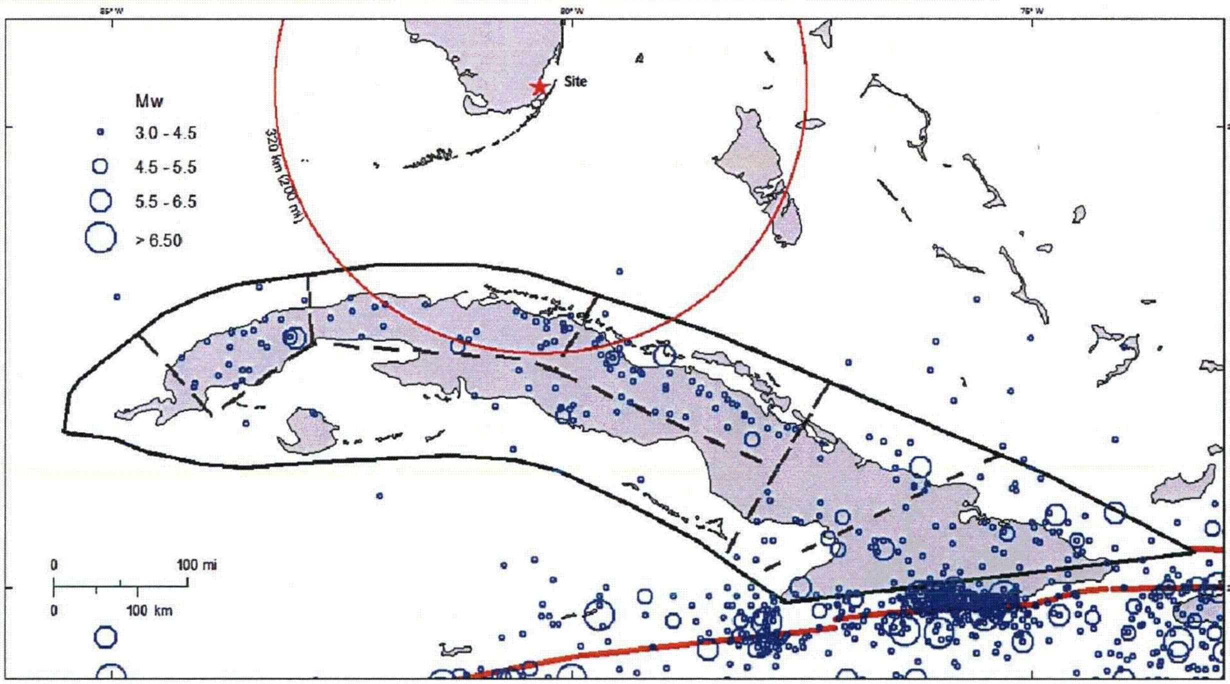

Figure 3. Possible Cuba areal seismic sources (black lines). Seismicity (blue circles) is based on the earthquake catalog developed for the Turkey Point project.

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: 02.05.01-22 (eRAI 6024)

FSAR Section 2.5.1.1.1.2.3, the "Stratigraphy of Cuba" passage, states that "Late Miocene to Pliocene deposits are poorly developed and Pleistocene rocks include shelf and coastal carbonates that in places have been uplifted into terraces (Reference 383)". The staff notes that this implies Pleistocene tectonic uplift. The staff further notes that Agassiz (1894)[1] described the extensive marine terraces along the northern coast of Cuba and very young elevated patch reef corals in growth position, forming the lowest terraces. In addition, a suite of Quaternary terraces along the northern edge of Cuba is clearly depicted in available 1:500,000 scale geologic maps of the region.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Explain the tectonic context of these uplifted terraces in light of continued seismicity along the northern coast of Cuba.
b) Discuss the ages, lateral extents, morphologies, and origins of the terraces.
c) Discuss the implications of these terraces for assessments of active faulting in the Site Region.

[1]Agassiz, A., 1894, A reconnaissance of the Bahamas and elevated reefs of Cuba: Bulletin of the Museum of Comparative Zoology, v. 26, 203 p.

FPL RESPONSE:

The components of the response to RAI 02.05.01-22 (eRAI 6024) are not presented in the same sequential order as the RAI question components. FPL has addressed the RAI question to respond to parts b, a, then c in order to first discuss the geology (stratigraphy), geomorphology, and the origin of the marine terraces followed by a discussion of the marine terraces in the context of seismicity and active faulting in the site region. FPL believes that by answering the questions in this manner, it will provide the NRC staff the context needed for staff to assess the tectonic and structural features within the site region.

b) Discuss the ages, lateral extents, morphologies, and origins of the terraces.

Along Cuba's north coast within the site region, the marine terraces that dip gently seaward (to the north) consist primarily of Miocene through Pleistocene age limestones (Reference 12 and Reference 13) and extend laterally along the north coast (FSAR 2.5.1 Reference 848) except where rivers have eroded gaps in the terraces (Reference 15). The terraces are wide with gentle slopes (as compared to those in southeastern Cuba), the karst processes (i.e., the formation of caves and caverns and sinkholes) are more pronounced, and notches (cuts along the base of a sea cliff near the high water mark that form by undercutting the sea cliff due to wave erosion and/or chemical solution) are pronounced (Reference 10). The Miocene rocks on which the marine terrace deposits formed are divided into the Cojimar Formation marls and the Güines Formation carbonates (chalks, argillaceous bioclastic limestones, and reef limestones) that outcrop from Havana to

Matanzas. The Cojimar Formation marls represent a middle Miocene deep open shelf that is overlain unconformably by the Güines Formation. The Güines Formation represents a carbonate platform that covered almost the entire Greater Antilles from the second half of the middle Miocene up to the late Miocene. Late Miocene-Pliocene deposits are only locally developed at the Morro Castle of Havana (the Morro limestones) and near Matanzas City at El Abra de Yumurí (El Abra Formation). The El Abra Formation is a fluvio-marine unit. Pleistocene carbonates of the Jaimanitas Formation (coral reef limestones and calcarenites) are exposed along the coastal plain of Havana and Matanzas (FSAR 2.5.1 Reference 383 and Reference 8) and along much of the north coast of Cuba (Reference 14).

Terraces in Cuba near Matanzas are classified as erosional, depositional/cumulative, and constructional (References 9 and 12). Erosional terraces on Cuba's northern coastline are located east of Boca de Juruco, province of Havana and in the vicinity of the Bay of Matanzas (Reference 12). Cumulative terraces are described as: (1) having a sandy beach with an inner edge of 3.3 to 4.9 feet (1 to 1.5 meters) above sea level and (2) storm bank with heights of 6.6 to 9.8 feet (2 to 3 meters) above sea level. Cumulative terraces occur on the northern coastline of Cuba, east of Havana. Constructional coral reef terraces are located on the north coast west of Havana to Mariel and the suburbs of Havana and Santa Fe Jaimanitas (References 9 and 12).

Four marine terraces near Havana occur at elevations 200, 100, 10-15 and 4-5 feet (61, 31, 3.1-4.6 and 1.2-1.5 meters) above mean sea level (FSAR 2.5.1 Reference 383; References 6, 7 and 15). Near Matanzas, six terraces have been observed at elevations 400, 300, 200, 140, 30, and 5-6 feet (122, 91, 61, 43, 9, and 1.5-1.8 meters) above sea level (References 6, 7 and 15). At Matanzas Bay, Ducloz (Reference 4), Shanzar et al., (Reference 12) and Penalver Hernandez et al., (Reference 10) observed four terraces at the following approximate elevations 82 – 167 feet (25 – 51 meters) (Ryonera), 49 – 108 feet (15 – 33 meters) (Yucayo), approximately 52 feet (approximately 16 meters) (Puerto) and 13 – 33 feet (4 to 10 meters) (Terraza de Seboruco) (Table 1).

The Rayonera terrace is strongly karstic. The presence of sinkholes and caves indicate that the outer edge of the terrace has a height of 128 feet (39 meters) whereas the inner edge is around 167 feet (51 meters) giving this surface a topographic slope of about 3 to 4 degrees towards the coast. The rocks of this terrace are Pliocene-Pleistocene in age. As noted by its name, the Yucayo terrace is "narrow". It has an average height of 98 feet (30 meters) near the Bay of Matanzas. The terrace is cut off from the sea by a vertical cliff that is approximately 20 to 46 feet (6 to 14 meters) in height. Sea caves are present and are indicative of coastal erosion. The Pliocene-Pleistocene rocks of this terrace are algal conchiferas with hard, massive, and recrystallized limestone reefs. The Pliocene-Pleistocene Puerto terrace is similar to the Yucayo and Rayonera terraces. All three are characterized by the development of karst, sinkholes and a very sharp weathering surface known "diente de perros" (dog's teeth) (References 4 and 10).

The Terraza de Seboruco, the youngest of these terraces is located west of Matanzas Bay. It rises 2 to 3 meters (6.6 to 9.8 feet) above mean sea level with paleolagoonal facies extending inland 1 or more kilometers. Near Havana and Matanzas, the elevation of the Terraza de Seboruco ranges from 2 to 3 meters (6.6 to 9.8 feet) above mean sea level to 4

to 5 meters (13 to 16 feet) above mean sea level respectively. The terrace is described as porous or cavernous fossilized limestone from the Pleistocene Jaimanitas Formation with a weathering surface of diente de perros (References 4 and 14).

The terraces and sea cliffs form a stair-step sequence, which suggests that reef deposition was followed by high sea level stands that cut the bench-like features in the sea cliffs (Reference 1). Several alternate processes can explain or partially explain the stair-step morphology and bench-like features that were described by Agassiz (Reference 1), Spencer (Reference 13) and Ducloz (Reference 4). The alternate hypotheses for what might have contributed to terrace formation as discussed in FSAR Subsections are eustatic changes in sea level (FSAR Subsection 2.5.1.1.1.1.1.1), changes in ocean circulation pattern (FSAR Subsection 2.5.1.1), rise and fall in sea level as a direct result of melting and formation of the continental glaciers (FSAR Subsection 2.5.1.1.1.1.1.1), and tectonic activity (FSAR Subsections 2.5.1 and 2.5.1.3.3).

U-Th dates were obtained on corals (two very large *Montastrea* sp. and one *Acropora* palmate) from the Terraza de Seboruco at the Cantera Playa Baracoa quarry and in the Santa Cruz del Norte canal. When corrected from the initial Uranium age dates, the ages of the samples correspond to the Marine Isotope Stage 5e sea level high stand at approximately 120–130 ka (Reference 14). Toscano et al. (Reference 14) observe that similar age terraces throughout stable portions of the Caribbean area are at similar elevations, which is evidence for the absence of active uplift near Matanzas in the past 120–130 ka. Therefore, based on the U-Th dates, the Terraza de Seboruco is correlative to the Cockburntown reef (Bahamas) (Reference 3), Barbados III (Barbados) (Reference 5), and Key Largo Limestone (Florida) (References 2 and 11).

a) Explain the tectonic context of these uplifted terraces in light of continued seismicity along the northern coast of Cuba.

Elevated marine terraces were identified along the northern coast of Cuba as early as the late 19th century (Reference 1). Recent studies of the marine terraces along the north coast of Cuba, especially for the stretch between Matanzas and Havana, are summarized below. As noted above, Ducloz (Reference 4) provides a description of the Quaternary deposits and surfaces in the Matanzas region, including the Pleistocene-age Terraza de Seboruco surface west of Matanzas Bay. Ducloz (Reference 4) suggests that the elevated marine terraces along Cuba's north coast likely formed as the result of both fluctuations in sea level and epeirogenic uplift (Table 1). Ducloz (Reference 4) suggests that reactivation of a regional scale anticline may be partly responsible for formation of the terrace surfaces near Matanzas.

Similarly, Shanzer et al. (Reference 12) identify three Pleistocene-age marine terraces in the Matanzas-Havana region. Shanzer et al (Reference 12) correlate to segments of the Pleistocene-age Terraza de Seboruco between Matanzas and Havana and suggest that this terrace is approximately 1.5 to 3 meters (4.9 to 9.8 feet) lower at Havana than at Matanzas. Shanzer et al (Reference 12) do not consider erosion of the terrace surface to explain the difference in elevation between Havana and Matanzas. Shanzer et al. (Reference 12) postulate that this difference in elevation may be the result of differential tectonic uplift, but they do not suggest what structure or structures may be responsible for this postulated tectonic uplift.

Toscano et al. (Reference 12) also observe that the Terraza de Seboruco (ages discussed above) 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 14) conclude, "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba."

Pedoja et al. (Reference 9) investigate late Quaternary coastlines worldwide and observe minor uplift relative to sea level of approximately 0.2 millimeters per year, even along passive margins, outpacing eustatic sea level decreases by a factor of four. Pedoja et al. (Reference 9) suggest that the decreasing number of subduction zones since the Late Cretaceous, coupled with relatively constant ridge length, has resulted in an increase in the average magnitude of compressive stress in the lithosphere. They argue that this average increase in compressive stress has produced low rates of uplift, even along passive margins as observed in their widespread measurements of uplifted continental margins. The measurements specific to Cuba suggest that the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco) has been uplifted at an average rate that ranges from approximately 0.00 to 0.04 millimeter per year over the last approximately 122 ka (Reference 9).

The Turkey Point Units 6 & 7 phase 2 earthquake catalog indicates sparse minor- to light-magnitude seismicity along Cuba's north coast between Havana and Matanzas (Figures 1A and 1B in FPL's revised response to RAI 02.05.01-21). It is possible that these earthquakes occurred on faults partially responsible for uplift of the marine terraces along Cuba's north coast in the site region. However, the association of the uplift of these terraces and earthquakes with individual faults in northern Cuba is uncertain. Based on the Turkey Point Units 6 & 7 phase 2 earthquake catalog, earthquakes do not appear to be aligned along faults in the Matanzas-Havana region. In addition, there are no known focal mechanisms available for these earthquakes that would help to constrain the causative fault or faults nor is there sufficient data to correlate uplift of marine terraces with these individual faults in northern Cuba.

c) Discuss the implications of these terraces for assessments of active faulting in the Site Region.

It is possible that the elevations above modern sea level of marine terraces along Cuba's north coast in the site region are partially the result of tectonic uplift (References 4 and 12). Based on extensive literature review performed for this project, to FPL's knowledge, the Terraza de Seboruco is the only terrace in northern Cuba for which radiometric age control is available. There is not sufficient data on this or other marine terraces in northern Cuba to assess the implications for active faulting. As described in this response (parts a and b), Toscano et al.'s (Reference 14) U-Th analyses of corals collected from the Terraza de Seboruco indicates that tectonic uplift is not required to explain the present elevation of this Substage 5e terrace. Instead, they conclude that the elevation of this terrace surface is consistent with other Substage 5e terraces in other tectonically stable regions of the Caribbean and that global fluctuations in sea level, not tectonic uplift, are responsible for the Terraza de Seboruco's present elevation above modern sea level. Likewise, Pedoja et al.'s (Reference 9) global study suggests that the elevation of the Terraza de Seboruco is

consistent with the elevations of other Substage 5e terraces in tectonically stable regions worldwide.

Based on recent studies by Toscano et al. (Reference 14) and Pedoja et al. (Reference 9), active faulting is not required to explain the elevation of the Terraza de Seboruco along Cuba's north coast in the site region. However, observations of the Terraza de Seboruco cannot necessarily be used to preclude possible strike-slip faulting in the site region. As shown by the Turkey Point Units 6 & 7 phase 2 earthquake catalog, only sparse minor- to light-magnitude seismicity is observed along Cuba's northern coast between Havana and Matanzas. It is possible that at least some of these earthquakes occurred on the faults mapped in the region. However, in the absence of well-located hypocenters and focal mechanisms, these earthquakes cannot be definitively attributed to a particular fault or faults.

Table 1 Marine Terraces in the Matanzas Area of Northern Cuba

Marine Terrace (Reference 4)	Elevation of Marine Terrace (Reference 4)	Geologic Stratum (References 4 and 10)	Depositional Environment (Reference 4)	Possible Geologic Age (Reference 4)	Possible Geologic Age (Reference 10)
			Start of emergence	Start of the Upper Miocene	
			Erosion Cycle (No. 1)	Upper Miocene	
			Uplift and buckling (env. 60 m)	Pliocene (?)	
			Erosion Cycle (No. 2)		
			Uplift (env. 80 m)	Pliocene	
			Erosion Cycle (No. 3)		
			Uplift and folding (10 and 45 m)		
La Rayonera	25 and 51 m		Erosion Cycle (No. 4)		Pliocene-Pleistocene
			Uplift and folding (15 and 25 m)		
Yucayo	15 and 33 m		Erosion epicycle (No. 1)	Pliocene (?)	Pliocene-Pleistocene
			Drop in sea level: uplift, very light folding (10 m)	Pliocene (?)	
Puerto	16 m		Erosion epicycle (No. 2)	Start of the Illinoian Glaciation	
			Drop in sea level (11 and 13 m)		
submarine terrace	No. 1 (-1 m)		Erosion epicycle (No. 3)		
			Drop in sea level (1 m)		
submarine terrace	No. 2 (-2 and -6 m)		Erosion epicycle (No. 4)		
			Drop in sea level (env. 130 m)	Illinoian Glaciation Maximum	
Continental Shelf terrace			Erosion epicycle (No. 5)		
			Rise in eustatic sea level (+11 m)	Sangamon Interglacial	
		Jaimanitas Formation (Terraza de Seboruco). Rosario Terrace (continental alluvial terrace)	Formation of fringing reefs on uplifted alluvium deposits		Pleistocene
Limits of the Terraza de Seboruco	+/- 8 m		Drop in sea level (env. 12 m)	Start of the Wisconsinan Glaciation	
submarine terrace	No. 3 (-10 and -17 m)		Erosion epicycle (No. 6)		
			Drop in sea level (env. 10 m)		
submarine terrace	No. 4 (-20 and -55 m)		Erosion epicycle(No. 7)		
			Drop in sea level (env. 110 m)	Wisconsinan Glaciation Maximum	
Limit of the Restart of the Continental Plate			Erosion epicycle (No. 8)		
			Eustatic rise to present sea level	FlandrianTransgression	
		Recent alluvium	Induation of river valleys		

Source: Reference 4 and Reference 10

This response is PLANT SPECIFIC.

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ASSOCIATED COLA REVISIONS:

The following text in FSAR Subsection 2.5.1.1.1.2.3, Stratigraphy of Cuba, will be revised in a future revision of the COLA.

After the last paragraph of this subsection:

flysch. The Eocene-Oligocene contact is at a depth of approximately 4500 feet (1370 meters). The Oligocene unit consists of up to 600 feet (183 meters) of deep-water chalk and limestone that grades laterally into an arenaceous and shaly limestone deposited in marine water of intermediate depth. This is overlain by 400 to 1000 feet (120 to 300 meters) of Miocene sediments consisting of deep-water marl, siltstone, and shaly limestone that grade into arenaceous and calcareous sediments with intercalated, fossiliferous sandy limestone deposited in a neritic environment (Reference 382). Late Tertiary deposits occur in the northern coastal area and dip gently toward the north. ~~Miocene rocks are divided into marl and carbonate units. Miocene and younger deposits are described as horizontal or only slightly tilted (Reference 440). Late Miocene to Pliocene deposits are poorly developed and Pleistocene rocks include shelf and coastal carbonates that in places have been uplifted into terraces (Reference 383).~~

Along Cuba's north coast within the site region, the marine terraces that dip gently seaward (to the north) consist primarily of Miocene through Pleistocene age limestones (References 924 and 923) and extend laterally along the north coast (Reference 848) except where rivers have eroded gaps in the terraces (Reference 926). The terraces are wide, with gentle slopes, the karst processes are more pronounced (i.e., the formation of caves and caverns and sinkholes), and notches (a cut along the base of a sea cliff near the high water mark that forms by undercutting the sea cliff due to wave erosion and/or chemical solution) are pronounced (Reference 921). The Miocene rocks that the marine terrace deposits formed are divided into the Cojimar Formation marls and the Güines Formation carbonates (chalks, argillaceous bioclastic limestones, and reef limestones) that outcrop from Havana to Matanzas. The Cojimar Formation marls represent a middle Miocene deep open shelf that is overlain unconformably by the Güines Formation. The Güines Formation represents a carbonate platform that covered almost the entire Greater Antilles from the second half of the middle Miocene up to the late Miocene. Late Miocene-Pliocene deposits are only locally developed at the Morro Castle of Havana (the Morro limestones) and near Matanzas City at El Abra de Yumurí (El Abra Formation). The El Abra Formation is a fluvio-marine unit. Pleistocene carbonates of the Jaimanitas Formation (coral reef limestones and calcarenites) are exposed along

the coastal plain of Havana and Matanzas (References 383 and 919) and along much of the north coast of Cuba (Reference 925).

Terraces in Cuba near Matanzas are classified as erosional, depositional/cumulative and constructional (References 923 and 920). Erosional terraces on Cuba's northern coastline are located east of Boca de Juruco, province of Havana and in the vicinity of the Bay of Matanzas (Reference 923). Cumulative terraces are described as: (a) having a sandy beach with an inner edge of 3.3 to 4.9 feet (1 to 1.5 meters) above sea level, and (b) storm bank with heights of 6.6 to 9.8 feet (2 to 3 meters) above sea level. Cumulative terraces occur on the northern coastline of Cuba, east of Havana. Constructional coral reef terraces are located on the north coast west of Havana to Mariel and the suburbs of Havana and Santa Fe Jaimanitas (References 923 and 920).

Four marine terraces near Havana occur at elevations 200, 100, 10-15 and 4-5 feet (61, 31, 3.1-4.6 and 1.2-1.5 meters) above mean sea level (References 383, 918, 917, and 926). Near Matanzas six terraces have been observed at elevations 400, 300, 200, 140, 30, and 5-6 feet (122, 91, 61, 43, 9, and 1.5-1.8 meters) above sea level (References 918, 917, and 926). At Matanzas Bay, Ducloz (Reference 4), Shanzar et al., (Reference 12) and Penalver Hernandez et al., (Reference 10) observed four terraces at the following approximate elevations 82 – 167 feet (25 – 51 meters) (Ryonera), 49 – 108 feet (15 – 33 meters) (Yucayo), approximately 52 feet (approximately 16 meters) (Puerto) and 13 – 33 feet (4 to 10 meters) (Terraza de Seboruco) (Table 2.5.1-208). The Rayonera terrace is strongly karstic. The presence of sinkholes and caves indicate that the outer edge of the terrace has a height of 128 feet (39 meters) whereas the inner edge is around 167 feet (51 meters) giving this surface a topographic slope of about 3 to 4 degrees towards the coast. The rocks of this terrace are Pliocene-Pleistocene in age. As noted by its name, the Yucayo terrace is "narrow". It has an average height of 98 feet (30 meters) near the Bay of Matanzas. The terrace is cut off from the sea by a vertical cliff that is approximately 20 to 46 feet (6 to 14 meters) in height. Sea caves are present and are indicative of coastal erosion. The Pliocene-Pleistocene rocks of this terrace are algal conchiferas, with hard, massive, and recrystallized limestone reefs. The Pliocene-Pleistocene Puerto terrace is similar to the Yucayo and Rayonera terraces. All three are characterized by the development of karst, sinkholes and a very sharp weathering surface known "diente de perros" (dog's teeth) (References 915 and 921). The Terraza de Seboruco , the youngest of these terraces is located west of Matanzas Bay. It rises just a few meters (2 to 3 meters) (6.6 to 9.8 feet) above mean sea level with paleo-lagoonal facies extending inland one or more kilometers. Near Havana and Matanzas, the elevation of the Terraza de Seboruco ranges from 2 to 3 meters (6.6 to 9.8 feet) above mean sea level to 4 to 5 meters (13 to 16 feet) above mean sea level respectively. The terrace is described as porous or cavernous fossilized limestone from the Pleistocene Jaimanitas Formation with a weathering surface of "diente de perros" (References 915 and 925).

The terraces and sea cliffs form a stair-step sequence, which suggests that reef deposition was followed by high sea level stands that cut the bench-like features in the sea cliffs (Reference 912). Several alternate processes can explain or partially

explain the stair-step morphology and bench-like features that were described by Agassiz (Reference 912), Spencer (Reference 924) and Ducloz (Reference 915). The alternate hypotheses for what might have contributed to terrace formation as discussed in FSAR Subsections are eustatic changes in sea level (FSAR Subsection 2.5.1.1.1.1.1.1), changes in ocean circulation pattern (FSAR Subsection 2.5.1.1), rise and fall in sea level as a direct result of melting and formation of the continental glaciers (FSAR Subsection 2.5.1.1.1.1.1.1), and tectonic activity (FSAR Subsections 2.5.1 and 2.5.1.3.3).

U-Th dates were obtained on corals (two very large *Montastrea* sp. and one *Acropora* palmate) from the Terraza de Seboruco at the Cantera Playa Baracoa quarry and in the Santa Cruz del Norte canal. When corrected from the initial Uranium age dates, the ages of the samples correspond to the Marine Isotope Stage 5e sea level high stand at approximately 120–130 ka (Reference 925). Toscano et al. (Reference 925) observe that similar age terraces throughout "stable" portions of the Caribbean area are at similar elevations, which is evidence for the absence of active uplift near Matanzas in the past 120-130 ka. Therefore, based on the U-Th dates, the Terraza de Seboruco is correlative to the Cockburntown reef (Bahamas) (Reference 914), Barbados III (Barbados) (Reference 916), and Key Largo Limestone (Florida) (References 913 and 922).

The following text in FSAR Subsection 2.5.1.1.1.3.2.4, Cuba, will be revised in a future revision of the COLA.

After the last paragraph of Structures of Cuba in this subsection:

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 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.

Additionally, elevated marine terraces were identified along the northern coast of Cuba as early as the late 19th century (Reference 912). Recent studies of the marine terraces along the north coast of Cuba, especially for the stretch between Matanzas and Havana, are summarized below. Subsection 2.5.1.1.1.2.3 provides a description of the Quaternary deposits and surfaces in the Matanzas region, including the Pleistocene-age Terraza de Seboruco surface west of Matanzas Bay. Ducloz (Reference 915) suggests that the elevated marine terraces along Cuba's north coast likely formed as the result of both fluctuations in sea level and epeirogenic uplift (Table 2.5.1-208). Ducloz (Reference 915) suggests that reactivation of a regional

scale anticline may be partly responsible for formation of the terrace surfaces near Matanzas.

Similarly, Shanzer et al. (Reference 923) identify three Pleistocene-age marine terraces in the Matanzas-Havana region. Shanzer et al. (Reference 923) correlate segments of the Pleistocene-age Terraza de Seboruco between Matanzas and Havana and suggest that this terrace is approximately 1.5 to 3 meters (4.9 to 9.8 feet) lower at Havana than at Matanzas. Shanzer et al. (Reference 923) do not consider erosion of the terrace surface to explain the difference in elevation between Havana and Matanzas. Shanzer et al. (Reference 923) postulate that this difference in elevation may be the result of differential tectonic uplift, but they do not suggest what structure or structures may be responsible for this postulated tectonic uplift.

Toscano et al. (Reference 925) also observe that the Terraza de Seboruco 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 925) conclude, "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba."

Pedoja et al. (Reference 920) investigate late Quaternary coastlines worldwide and observe minor uplift relative to sea level of approximately 0.2 millimeter per year, even along passive margins, outpacing eustatic sea level decreases by a factor of four. Pedoja et al. (Reference 920) suggest that the decreasing number of subduction zones since the Late Cretaceous, coupled with relatively constant ridge length, has resulted in an increase in the average magnitude of compressive stress in the lithosphere. They argue that this average increase in compressive stress has produced low rates of uplift even along passive margins, as observed in their widespread measurements of uplifted continental margins. The measurements specific to Cuba suggest that the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco) has been uplifted at an average rate that ranges from approximately 0.00 to 0.04 millimeter per year over the last approximately 122 ka (Reference 920).

Seismicity of Cuba

Maps of instrumental and pre-instrumental epicenters for Cuba show that seismicity can be separated into two zones: (a) the very active plate boundary region, including the east Oriente fault zone along Cuba's southern coast, and (b) the remainder of the island away from the active plate boundary region, which exhibits low to moderate levels of seismic activity (Figures 2.5.1-267, 2.5.2-220, and 2.5.2-221). **Regarding (b) above, along the north coast of Cuba between Havana and Matanzas, the Turkey Point Units 6 & 7 Phase 2 earthquake catalog indicates sparse minor- to light-magnitude seismicity. It is possible that these earthquakes occurred on faults partially responsible for uplift of the marine terraces along Cuba's north coast in the site region. However, the association of the uplift of these terraces and earthquakes with individual faults in northern Cuba is uncertain. Based on the Phase 2 earthquake catalog, earthquakes do not appear to be aligned along faults in the Matanzas-Havana region. In addition,**

there are no known focal mechanisms available for these earthquakes that would help to constrain the causative fault or faults nor is there sufficient data to correlate uplift of marine terraces with these individual faults in northern Cuba.

It is possible that the elevations above modern sea level of marine terraces along Cuba's north coast in the site region are partially the result of tectonic uplift (References 915 and 923). The Terraza de Seboruco is the only terrace in northern Cuba for which radiometric age control is available. There is not sufficient data on this or other marine terraces in northern Cuba to assess the implications for active faulting. As discussed in Subsection 2.5.1.1.1.2.3, Toscano et al.'s (Reference 925) U-Th analysis of corals collected from the Terraza de Seboruco indicates that tectonic uplift is not required to explain the present elevation of this Substage 5e terrace. Instead, they conclude that the elevation of this terrace surface is consistent with other Substage 5e terraces in other tectonically stable regions of the Caribbean and that global fluctuations in sea level, not tectonic uplift, are responsible for the Terraza de Seboruco's present elevation above modern sea level. Likewise, Pedoja et al.'s (Reference 920) global study suggests that the elevation of the Terraza de Seboruco is consistent with the elevations of other Substage 5e terraces in tectonically stable regions worldwide.

Based on studies by Toscano et al. (Reference 925) and Pedoja et al. (Reference 920), active faulting is not required to explain the elevation of the Terraza de Seboruco along Cuba's north coast in the site region. However, observations of the Terraza de Seboruco cannot necessarily be used to preclude possible strike-slip faulting in the site region. As shown by the Phase 2 earthquake catalog, only sparse minor- to light-magnitude seismicity is observed along Cuba's northern coast between Havana and Matanzas. It is possible that at least some of these earthquakes occurred on the faults mapped in the region. However, in the absence of well-located hypocenters and focal mechanisms, these earthquakes cannot be definitively attributed to a particular fault or faults.

The east Oriente fault zone is an active plate boundary, with seismic activity concentrated on the Cabo Cruz Basin and the Santiago deformed belt. Focal mechanisms from the Cabo Cruz area show consistent east-northeast to west-southwest oriented normal faulting, indicative of an active pull-apart basin. In the Cabo Cruz Basin, all hypocenters are less then 30 kilometers (19 miles) deep. The Santiago deformed belt mechanisms show a combination of northwest-directed underthrusting and east-west left-lateral strike-slip, consistent with a bi-modal transpressive regime (Reference 504). In the Santiago deformed belt, thrust mechanisms occur between depths of 30 and 60 kilometers (19 and 37 miles), while the strike-slip mechanisms are shallower.

The following text in FSAR Subsection 2.5.1.3, References, will be revised in a future revision of the COLA.

912. Agassiz, A., A reconnaissance of the Bahamas and elevated reefs of Cuba: Bulletin of the Museum of Comparative Zoology, v. 26, p. 203, 1894.

913. Broecker, W.S. and Thurber, D. L., Uranium-series dating of coral and oolites from Bahaman and Florida Key limestones: Science, vol. 149, pp. 58-60, 1965.

914. Chen, J. H., Curran, H. A., White, B., Wasserburg, G. J., Precise chronology of the last interglacial period: 234U-230 Th data from fossil coral reefs in the Bahamas: Geological Society of America Bulletin, vol., 103, pp. 82-97, 1991.

915. Ducloz, C., Etude geomorphologique de la region de Matanzas, Cuba avec une contribution a l'etude des depots quaternaires de la zone Habana-Matanzas, Archives des Sciences, Societe de Physique et d'Histoire Naturelle de Geneve, Imprimerie Kundig, 402 pp, 1963.

916. Gallup, C. D., Edwards, R. L., and Johnson, R. G., The timing of high sea levels over the past 200,000 years: Science, vol. 263, pp. 796-800, 1994.

917. Hayes, C.W., Vaughan, T.W., and Spencer, A.C., A Geological Reconnoissance [sic] of Cuba, pp. 18-20, 1901.

918. Hill, R.T., Notes on the Geology of the Island of Cuba, Based Upon a Reconnoissance [sic] Made for Alexander Agassiz, Bulletin of the Museum of Comparative Zoology, v. XVI, no. 15, pp. 264-274, 1895.

919. Iturralde-Vinent, M.A., Linked Earth Systems Field Guide Sedimentary Geology of Western Cuba, The 1st SEPM Congress on Sedimentary Geology [sp] of Cuba, pp. 18-20, 1901.

920. Pedoja, K., Husson, L., Regard, V., Cobbold, P.R., Ostanciaux, E., Johnson, M.E., Kershaw, S., Saillard, M., Martinod, J., Furgerot, L., Weill, P., and Delcaullau, B., Relative sea-level fall since the last interglacial state: Are coasts uplifting worldwide?, Earth Science Reviews, v. 108, p. 1-15, 2011.

921. Penalver Hernandez, L, L., Castellanos Abella, E., Perez Aragon, R. O., and Rivada Suarez, R., Las Terrazas Marinas de Cuba y Su Correlacion Con Algunas Del Area Circumcaribe, Memorias Geomin, V Congreso de Geologia y Mineria, 24-28 De Marzo, La Habana, pp. 10, 2003.

922. Osmond, J. K., Carpenter, J.R., and Windom, H.L., 230 Th/234 U age of Pleistocene corals and oolites of Florida: Journal of Geophysical Research, vol. 70, pp. 1843-1847, 1965.

923. **Shanzer, E.V., Petrov, O.M., and Franco, G., Sobre las formaciones costeras del Holoceno en Cuba, las terrazas Pleistocenicas de la region Habana-Matanzas y los sedimentos vinculados a ellas, Serie Geologica no. 21, Acadamia de Ciencias de Cuba, Instituto de Geologia y Paleontologia, p. 1-26, 1975.**

924. **Spencer, J.W., Geographical Evolution of Cuba, Bulletin of the Geological Society of America, v. 7, pp. 67-94, 1895.**

925. **Toscano, M.A., Rodriguez, E., and Lundberg, J., Geologic investigation of the late Pleistocene Jaimanitas formation: science and society in Castro's Cuba, Proceedings of the 9th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Bahamian Field Station, Ltd., San Salvador, Bahamas. p. 125-142, 1999.**

926. **Vaughan, T.W., and Spencer, A., The Geography of Cuba, Bulletin of the American Geographical Society, v. 34, no. 2, pp. 105-116, 1902.**

The following table in FSAR Subsection 2.5.1 will be added in a future revision of the COLA.

Table 2.5.1-208 Marine Terraces in the Matanzas Area of Northern Cuba

Marine Terrace (Reference 915)	Elevation of Marine Terrace (Reference 915)	Geologic Stratum (References 915 and 921)	Depositional Environment (Reference 915)	Possible Geologic Age (Reference 915)	Possible Geologic Age (Reference 921)
			Start of emergence	Start of the Upper Miocene	
			Erosion Cycle (No. 1)	Upper Miocene	
			Uplift and buckling (env. 60 m)	Pliocene (?)	
			Erosion Cycle (No. 2)		
			Uplift (env. 80 m)	Pliocene	
			Erosion Cycle (No. 3)		
			Uplift and folding (10 and 45 m)		
La Rayonera	25 and 51 m		Erosion Cycle (No. 4)		Pliocene-Pleistocene
			Uplift and folding (15 and 25 m)		
Yucayo	15 and 33 m		Erosion epicycle (No. 1)	Pliocene (?)	Pliocene-Pleistocene
			Drop in sea level: uplift, very light folding (10 m)	Pliocene (?)	
Puerto	16 m		Erosion epicycle (No. 2)	Start of the Illinoian Glaciation	
			Drop in sea level (11 and 13 m)		
submarine terrace	No. 1 (-1 m)		Erosion epicycle (No. 3)		
			Drop in sea level (1 m)		
submarine terrace	No. 2 (-2 and -6 m)		Erosion epicycle (No. 4)		
			Drop in sea level (env. 130 m)	Illinoian Glaciation Maximum	
Continental Shelf terrace			Erosion epicycle (No. 5)		
			Rise in eustatic sea level (+11 m)	Sangamon Interglacial	
		Jaimanitas Formation (Terraza de Seboruco), Rosario Terrace (continental alluvial terrace)	Formation of fringing reefs on uplifted alluvium deposits		Pleistocene
Limits of the Terraza de Seboruco	+/- 8 m		Drop in sea level (env. 12 m)	Start of the Wisconsinan Glaciation	
submarine terrace	No. 3 (-10 and -17 m)		Erosion epicycle (No. 6)		
			Drop in sea level (env. 10 m)		
submarine terrace	No. 4 (-20 and -55 m)		Erosion epicycle(No. 7)		
			Drop in sea level (env. 110 m)	Wisconsinan Glaciation Maximum	
Limit of the Restart of the Continental Plate			Erosion epicycle (No. 8)		
			Eustatic rise to present sea level	FlandrianTransgression	
		Recent alluvium	Induation of river valleys		

Source: References 915 and 921

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: 02.05.01-23 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2, under the Cuban Fold-and-Thrust Belt passage states: "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) (FSAR Figure 2.5.1-282), these faults are concluded to be Tertiary in age and not capable tectonic structures." However, FSAR Figure 2.5.1-279 (S-SE end of seismic profile) shows mapped basement faults of the Cuban Fold and Thrust belt with overlying and laterally continuous reflectors that appear to be deformed and folded up to and including the seafloor. Additionally, the unfaulted, but uplifted, Pleistocene and younger marine terraces along the northern edge of Cuba may actually demonstrate a capable tectonic structure. Lastly, FSAR Figure 2.5.1-282 shows Tertiary, post-tectonic deposits (Unit 6) as faulted. The uppermost Tertiary deposits appear to lap-onto, rather than drape, an underlying fold on the same FSAR Figure 2.5.1-282. Both relations are consistent with deformation that continues to present day.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23 please address the following:

a) Discuss the tectonic implications of the seismic reflection features above the mapped faults for Plio-Pleistocene activity in the Cuban Fold and thrust belt.
b) Clarify how the unfaulted and uplifted Pleistocene marine terraces demonstrate a lack of capable tectonic feature.
c) Discuss the suitability of using the schematic diagram (FSAR Figure 2.5.1-282) to conclude that faults of the Cuban Fold-and-Thrust Belt are Tertiary in age and not capable tectonic structures.

FPL RESPONSE:

a) Discuss the tectonic implications of the seismic reflection features above the mapped faults for Plio-Pleistocene activity in the Cuban fold and thrust belt.

FSAR Figure 2.5.1-279 is modified slightly after Saura et al.'s (2008) (FSAR Reference 485) Figure 8, which shows: (a) an annotated seismic reflection profile from the Straits of Florida offshore north of Cuba and (b) a geologic cross section interpreted from this seismic reflection profile. According to Saura et al. (2008) (FSAR Reference 485, p. 12), the dashed lines shown in their panel (a) (and reproduced in the upper panel of FSAR Figure 2.5.1-279) represent "approximate boundaries between the main domains." In this upper panel, reflectors within the Cuban thrust belt domain appear as faulted and deformed. This deformation continues upward into the Cenozoic basin domain. Visible irregularities in the Oligocene and Pleistocene reflectors in the seismic profile are discussed by Saura et al. (2008) (FSAR Reference 485, p. 12) as "bright, irregular, internally chaotic reflections above the front of the Cuban thrust belt," which are typical of the Cenozoic section in this area (seismic unit G in Saura et al.'s [2008] [FSAR Reference 485] Figure 8a). Saura et al.

(2008) (FSAR Reference 485, p. 12) interpret the irregular reflectors to correspond to "olistostromic sediments, on the basis of their seismic character and published borehole and seismic data.

Saura et al.'s (2008) (FSAR Reference 485) panel (b) (reproduced in the lower panel of FSAR Figure 2.5.1-279) shows their interpreted geologic cross section and provides more detailed age information for the sediments. This lower panel shows that deformation and faulting associated with the Cuban thrust belt extends upward into Late Cretaceous to Eocene reflectors (dark gray) but does not appear to deform overlying Oligocene to Pleistocene reflectors (light gray). This is consistent with Saura et al.'s (2008) (FSAR Reference 485, p. 13) statement that "[the Cuban thrust belt] was a long-lived structure, which could be active at least up to late Eocene times. However, the main growth stage corresponds to the lowermost part of the sequence, which from borehole data is known to be pre-Middle Eocene." Seismic reflection lines depicted in FSAR Figures 2.5.1-280, -287, and -288 also show evidence for unfaulted late Tertiary to Quaternary sediments draping thrusts of the Nortecubana fault system, as mentioned in FSAR Subsection 2.5.1.1.1.3.2.4 (p. 2.5.1-104).

FSAR Figure 2.5.1-282 consists of a set of panels schematically depicting the evolution of the northern edge of Cuba. In the top-most and youngest panel, panel E, which represents a late Tertiary or Quaternary time, an undeformed younger layer of Tertiary post-tectonic strata has been deposited, and no faults are shown as active (all faults are shown as black). A topographic high in the lower Tertiary post-tectonic strata is shown, and it is not completely covered by the later Tertiary post-tectonic strata. No indications of faulting or folding in the later Tertiary post-tectonic strata are depicted. However, this relationship only indicates that the topographic high still existed during the beginning of the deposition of later Tertiary post-tectonic strata and does not necessarily indicate deformation that continues to present day. Although Moretti et al. (2003) (FSAR Reference 484, p. 678) do not specifically address Quaternary activity, the conclusions above are supported by their statement that "thrusting ceased in the Eocene, whereas infilling of the basin continued to the Quaternary because of sediment influx...Few minor reactivations occurred during the Tertiary." The minor reactivation of early Tertiary thrusts and Jurassic normal faults, and subsequent deposition of undeformed Tertiary sediments, are respectively depicted in FSAR Figure 2.5.1-282, parts D and E.

b) Clarify how the unfaulted and uplifted Pleistocene marine terraces demonstrate a lack of capable tectonic feature.

Recent studies of the marine Substage 5e terrace that formed approximately 122 ka preserved on Cuba's north coast between Matanzas and Havana are consistent with the lack of ongoing or recent tectonic uplift (References 1 and 2). However, these terraces do not preclude the possibility of tectonic activity in the region. The only terrace for which radiometric age dating exists is the Terraza de Seboruco, which is discussed in detail below.

References 3 and 4 provide descriptions of three Pleistocene marine terraces in the Matanzas-Havana region. The first (youngest) of these Pleistocene terraces is the Terraza de Seboruco terrace west of Matanzas Bay. Reference 4 documents heights of between 3 and 5 m above sea level for this terrace. The second terrace is the Terraza de Yucayo

(Reference 3), found at 8–10 m above sea level near Havana and from 15–25 m above sea level in the northwest portion of Matanzas (Reference 4). The third terrace, the Terraza de Rayonera, is found at 20–25 m above sea level near Havana and at no less than 23–25 m above sea level in the northwest portion of Matanzas (Reference 3). Reference 4 notes a minimum height of 35–40 m above sea level for this third terrace near Matanzas.

Both Reference 3 and 4 speculate that the elevated marine terraces along Cuba's north coast may have formed as the result of both fluctuations in sea level and epeirogenic uplift. Reference 3 speculates that reactivation of a regional scale anticline may be partly responsible for formation of the terrace surfaces near Matanzas. Reference 4 postulates that the lower elevation of all terraces near Havana could be due to differential tectonic uplift although no causative faults are identified by the authors. Alternatively, these differences in elevation could be the result of erosion or miscorrelation of surfaces (Reference 1).

Reference 1 describes the same Terraza de Seboruco terrace surface in the vicinity of Matanzas Bay. The U-Th radiometric dating of corals indicates an age of approximately 120–142 ka for this constructive surface. Based on these ages, Reference 1 associates the Terraza de Seboruco terrace with the global Substage 5e sea level high-stand at approximately 122 ka. Reference 1 also observes 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. Reference 1 concludes that "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba."

Reference 2 investigates 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. Reference 2 suggests that the decreasing number of subduction zones worldwide since the Late Cretaceous, coupled with relatively constant ridge length, has resulted in an increase in the average magnitude of compressive stress in the lithosphere. Reference 2 argues that this average increase in compressive stress has produced low rates of uplift even along passive margins, as observed in their widespread measurements of uplifted continental margins. Data specific to Cuba provided online as an electronic supplement to their manuscript suggest that the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco) has been uplifted at an average rate that, when accounting for eustatic changes in sea level, ranges from approximately 0.00–0.04 mm/yr over the last approximately 122 ka. If the effects of eustasy are ignored, Reference 2's data allow for an uplift rate at Matanzas of approximately 0.06 mm/yr over the last approximately 122 ka, following this "conservative" (Reference 2, p. 5) approach.

It is possible that the elevations above modern sea level of Pleistocene-age marine terraces along Cuba's north coast in the site region are partially the result of tectonic uplift (e.g., References 3 and 4). However, Reference 1's radiometric age dating of the Terraza de Seboruco indicates that tectonic uplift is not required to explain the present elevation of this Substage 5e terrace. Instead, Reference 1 concludes that the elevation of this terrace surface is consistent with other 5e terraces in other tectonically stable regions of the Caribbean and that global fluctuations in sea level, not tectonic uplift, are responsible for the Terraza de Seboruco's present elevation above modern sea level. Likewise, Reference

2's global study suggests that the elevation of the Terraza de Seboruco is consistent with the elevations of other Substage 5e terraces in tectonically stable regions worldwide.

Based on the most recent studies, active faulting is not required to explain the elevation of the Terraza de Seboruco along Cuba's north coast in the site region. If there is ongoing uplift of terraces in northern Cuba, the rate of this uplift is very low and approaching the limit of detection by recent studies. However, observations of the Terraza de Seboruco cannot necessarily be used to preclude possible strike-slip faulting in the site region. As shown by the Phase 2 earthquake catalog, only sparse minor-to light-magnitude seismicity is observed along Cuba's northern coast between Havana and Matanzas. It is possible that at least some of these earthquakes occurred on the faults mapped in the region. However, in the absence of well-located hypocenters and focal mechanisms, these earthquakes cannot be definitively attributed to a particular fault or faults.

c) Discuss the suitability of using the schematic diagram (FSAR Figure 2.5.1-282) to conclude that faults of the Cuban Fold-and-Thrust Belt are Tertiary in age and not capable tectonic structures.

FSAR Figure 2.5.1-282 is a schematic diagram that is intended to depict the evolution of the Cuba fold-and-thrust belt, rather than provide documentation for ages of individual structures. This figure is modified after Moretti et al.'s (2003) (FSAR Reference 484) Figure 4. This figure serves as a simplified illustration of the tectonic evolution of the northwest offshore area of Cuba, which is presented in more detail in the text of Moretti et al. (2003) (FSAR Reference 484). Specifically, this figure shows the end of the Cuban orogen in the early Eocene, with slight compressive reactivation on some faults in the Neogene. Moretti et al. (2003) (FSAR Reference 484, p. 678) describe this figure as illustration that "the [Cuba fold-and-thrust belt] thrusting ceased in the Eocene, whereas infilling of the basin continued to the Quaternary because of sediment influx resulting from the mountain belt erosion. Few minor reactivations occurred during the Tertiary."

The FSAR relies on Moretti et al.'s (2003) (FSAR Reference 484) more detailed text descriptions along with data and summaries provided in other publications, such as Lewis and Draper (1990) (FSAR Reference 217), Iturralde-Vinent (1994) (FSAR Reference 440), Bralower and Inturralde-Vinent (1997) (FSAR Reference 220), Saura et al. (2008) (FSAR Reference 485), and Pardo (2009) (FSAR Reference 439) to conclude that the Cuban fold-and-thrust belt structures are not capable tectonic sources. For example, this conclusion is supported by Saura et al. (2008) (FSAR Reference 485), who, as described in part (a) of this response, conclude that the main growth stage of the Cuban thrust belt was pre-Middle Eocene. Pardo (2009) (FSAR Reference 439, p. 35) also characterizes the early-to-middle Eocene as a period of intense activity, with "very little tectonic activity" from the late Eocene to present. Moretti et al.'s (2003) (FSAR Reference 484) schematic Figure 4 only provides a useful illustration that reflects the conclusions of a number of regional studies regarding the evolution of the Cuban fold-and-thrust belt structures.

This response is PLANT SPECIFIC.

References:

1. Toscano, M.A., Rodriguez, E., and Lundberg, J., 1999. Geologic investigation of the late Pleistocene Jaimanitas Formation: Science and society in Castro's Cuba, *Proceedings of the 9th Symposium on the Geology of the Bahamas and other Carbonate Regions*, Curran, H.A., and Mylroie, J.E. (eds), San Salvador, Bahamian Field Station, pp. 125–142.
2. Pedoja, K., Husson, L., Regard, V., Cobbold, P.R., Ostanciaux, E., Johnson, M.E., Kershaw, S., Saillard, M., Martinod, J., Furgerot, L., Weill, P., and Delcaullau, B., 2011. Relative sea-level fall since the last interglacial state: Are coasts uplifting worldwide?, *Earth Science Reviews*, Vol. 108, pp. 1–15.
3. Ducloz, C., 1963. Etude geomorphologique de la region de Matanzas, Cuba avec une contribution a l'etude des depots quaternaires de la zone Habana-Matanzas, *Archives des Sciences*, Societe de Physique et d'Histoire Naturelle de Geneve, Imprimerie Kundig, 402 pp.
4. Shanzer, E.V., Petrov, O.M., and Franco, G., 1975. *Sobre las formaciones costeras del Holoceno en Cuba, las terrazas Pleistocenicas de la region Habana-Matanzas y los sedimentos vinculados a ellas*, Serie Geologica no. 21, Acadamia de Ciencias de Cuba, Instituto de Geologia y Paleontologia, pp. 1–26.

ASSOCIATED COLA REVISIONS:

The Cuban Fold-and-Thrust Belt section of FSAR Subsection 2.5.1.1.1.3.2.2 will be revised as shown in a future revision of the COLA:

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). 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. 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 **(References 220, 485, and 439) and** published structural interpretations indicating unfaulted Quaternary strata above these structures offshore **(References 484 and 485)**, ~~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. **This age determination is also in agreement with published summaries of the tectonic evolution of Cuba (References 217 and 440). Moreover, recent studies of the marine Substage 5e terrace that formed approximately 122 ka preserved on Cuba's north coast between Matanzas and Havana are consistent with the lack of ongoing or recent tectonic uplift (References 912 and 913).**

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

920. Toscano, M.A., Rodriguez, E., Lundberg, J., "Geologic investigation of the late Pleistocene Jaimanitas Formation: Science and society in Castro's Cuba," *Proceedings of the 9th Symposium on the Geology of the Bahamas and other Carbonate Regions*, Curran, H.A., and Mylroie, J.E. (eds), San Salvador, Bahamian Field Station, pp. 125-142, 1999.

925. Pedoja, K., Husson, L., Regard, V., Cobbold, P.R., Ostanciaux, E., Johnson, M.E., Kershaw, S., Saillard, M., Martinod, J., Furgerot, L., Weill, P., and Delcaullau, B., 2011. Relative sea-level fall since the last interglacial state: Are coasts uplifting worldwide?, Earth Science Reviews, Vol. 108, pp. 1–15.

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: 02.05.01-24 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4, discusses Structures of Cuba; however, the staff needs more information regarding the various fault systems within the Cuba areal source.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Identify the Nortecubana fault or faults on seismic reflection sections and provide a map showing the surface trace or projection of the Nortecubana fault or faults with respect to topography and bathymetry.
b) Clarify the relationship between the Nortecubana fault system and the Cuban Fold and Thrust Belt.
c) The FSAR states "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." Please clarify what processes give rise to a bathymetric expression of an inactive fault in a sedimentary basin.
d) Discuss the February 1914 (Mw 6.2) earthquake offshore northeastern Cuba near the Nortecubana fault in light of the FSAR Section 2.5.1.1.1.3.2.4 that states that "there is no direct evidence that these earthquakes occurred on the Pinar and Nortecubana Faults". Please clarify what direct evidence is required to establish a connection between the earthquake and the faults.
e) Discuss the location of the Nortecubana fault as depicted in the reflection profiles (i.e., dip, depth).

FPL RESPONSE:

a) Identify the Nortecubana fault or faults on seismic reflection sections and provide a map showing the surface trace or projection of the Nortecubana fault or faults with respect to topography and bathymetry.

Figures 1A, 1B, and 1C show the surface projection of the Nortecubana fault as mapped by French and Schenk (2008) (FSAR Subsection 2.5.1, Reference 492) on a shaded-relief map. Additionally, FSAR Figures 2.5.1-202 and 2.5.1-229 plot the approximate location of the Nortecubana fault on shaded-relief maps.

The surface projection of the Nortecubana fault system is located roughly at the continental slope off northern Cuba. Here, the Nortecubana fault system splays updip into a broad zone of thrust faults collectively referred to as the Cuban thrust belt or Cuban fold-and-thrust belt, as mapped on FSAR Figure 2.5.1-251 and shown on seismic reflection sections in FSAR Figures 2.5.1-279, -280, -287 and -288. In addition, the Nortecubana fault system is schematically represented in FSAR Figure 2.5.1-282.

b) Clarify the relationship between the Nortecubana fault system and the Cuban Fold and Thrust Belt.

The Nortecubana fault is the main structure within the Cuban fold-and-thrust belt offshore of, and nearshore to, northern Cuba. The role of the Nortecubana thrust in the evolution of the Caribbean-North America plate boundary has been interpreted in different ways. As described in FSAR Subsection 2.5.1.1.1.3.2.4, it has been suggested that the Nortecubana thrust represents the ancestral subduction zone that was abandoned as the plate boundary shifted southward toward its current location south of Cuba (FSAR Subsection 2'.5.1, Reference 318). 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 North America south of Cuba (Iturralde-Vinent et al. 2008, Pardo 2009) (FSAR Subsection 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 offshore of northern Cuba, which is collectively referred to as the Cuban fold-and-thrust belt.

c) The FSAR states "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." Please clarify what processes give rise to a bathymetric expression of an inactive fault in a sedimentary basin.

Along much of its length, the surface projection of the Nortecubana fault is roughly associated with the continental slope off northern Cuba and, as such, is approximately spatially associated with this gross feature in the bathymetry. A continental slope is a bathymetric feature common to many nearshore areas and is not typically produced by faulting. In their Table 2, Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494, p. 515) indicate that the Nortecubana fault is "expressed" in the "sea" as opposed to the "land." This terminology, however, does not necessarily indicate bathymetric expression of the Nortecubana fault. Instead, this is Cotilla-Rodriguez et al.'s (2007) (FSAR Subsection 2.5.1, Reference 494) way of expressing whether a Cuban fault is either located onshore or offshore, as opposed to its degree of geomorphic expression. For example, the Guane fault also is listed in their Table 2 as expressed in the land. However, the Guane fault is a subsurface structure that Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494, p. 516) describe as "totally covered by young sediments of the Palacios Basin" and therefore not expressed at the surface. Thus, Cotilla-Rodriguez et al.'s (2007) (FSAR Subsection 2.5.1, Reference 494) description of the Guane fault as expressed in the land indicates that this fault is mapped onshore and does not indicate that it is expressed topographically. Similarly, Cotilla-Rodriguez et al.'s (2007) (FSAR Subsection 2.5.1, Reference 494) description of the Nortecubana fault as expressed in the sea is their indication that this fault is located offshore, as opposed to onshore. To be consistent with the text of Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494), the FSAR will be revised to remove the statement about Cotilla-Rodriguez et al.'s (2007) (FSAR Subsection 2.5.1, Reference 494) contention that the Nortecubana fault is expressed in the bathymetry north of Cuba.

Other studies suggest the possibility that the Nortecubana fault may be expressed in the bathymetry, but these studies do not provide detailed descriptions of the nature of this possible bathymetric expression. Malloy and Hurley's (1970) depiction of the offshore Las Villas fault extends for approximately 120 miles (200 kilometers) roughly from Matanzas Bay westward to Havana (Figure 2) and is nearly coincident with more recent depictions of the Nortecubana fault in that region (e.g., Cotilla-Rodriguez et al. (2007) [FSAR Subsection 2.5.1, Reference 494], French and Schenk 2008 [FSAR Subsection 2.5.1, Reference 492]) (Figure 1A). Due to this spatial coincidence, it is assumed that Malloy and Hurley's (1970) offshore Las Villas fault is the same structure as that portion of the Nortecubana fault as depicted in more recent literature (e.g., Cotilla-Rodriguez et al. [2007] [FSAR Subsection 2.5.1, Reference 494], French and Schenk 2008 [FSAR Subsection 2.5.1, Reference 492]). Malloy and Hurley (1970, p. 1962) provide only a very limited description of the offshore Las Villas fault and state that it "appears to be reflected in the bathymetry as a scarp" and that this bathymetric expression is "due presumably to faulting." Malloy and Hurley (1970) do not provide any description of scarp dimensions, including length, height, and continuity, and therefore, it is not clear whether their use of the term "scarp" refers to gross features in the bathymetry like the slope break north of Cuba or more localized features. Moreover, they do not explore alternate explanations that include possible submarine slumping along the continental slope and submarine erosion associated with currents and low sea level stands, as has been proposed for other bathymetric features within the Straits of Florida (e.g., Mullins and Newman 1979).

d) Discuss the February 1914 (Mw 6.2) earthquake offshore northeastern Cuba near the Nortecubana fault in light of the FSAR Section 2.5.1.1.1.3.2.4 that states that "there is no direct evidence that these earthquakes occurred on the Pinar and Nortecubana Faults." Please clarify what direct evidence is required to establish a connection between the earthquake and the faults.

According to the Phase 2 earthquake catalog, a M_w 6.29 earthquake occurred on February 28, 1914, off the northeastern coast of Cuba (Figure 1C). The direct evidence required to establish a connection between an earthquake and a given fault would include at least one of the following:

- A well-located hypocenter and focal mechanism for the earthquake consistent with the orientation of the causative fault
- Numerous aftershocks defining a rupture plane
- Observations of surface rupture or other coseismic surface deformation features
- Paleoseismic trench evidence, including well-constrained age data

In this case, the direct evidence for a connection between the February 1914 earthquake and the Nortecubana fault is lacking. Due to the absence of a permanent seismic monitoring network in Cuba, this epicenter is poorly located (data are insufficient for an estimate of the location error) at approximately 4 miles (6 kilometers) north-northeast of the south-dipping Nortecubana fault, approximately 400 miles (645 kilometers) from the site as the fault is mapped by French and Schenk (2008) (FSAR Subsection 2.5.1, Reference 492). No focal mechanism or depth determination for this earthquake is available with which to help identify the causative fault. An aftershock sequence defining a rupture plane has not been identified. No detailed submarine paleoseismic studies are available for the

region, and the available coarse bathymetric data do not suggest the presence of a submarine fault scarp.

However, uncertainties in the locations of the 1914 earthquake as well as the fault do not preclude the 1914 earthquake from having occurred on the Nortecubana fault. Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) suggest this earthquake may have occurred on the Nortecubana fault but state that the positional accuracy of epicentral locations is limited by the lack of a permanent seismic network in Cuba. Given its magnitude, it is unlikely that significant surface rupture was produced by the 1914 earthquake. Thus, it is not possible to definitively state whether the 1914 earthquake occurred on the Nortecubana fault or another fault.

e) Discuss the location of the Nortecubana fault as depicted in the reflection profiles (i.e., dip, depth).

As imaged in seismic reflection profiles, the Nortecubana fault underlies the Cuban fold-and thrust-belt of offshore and nearshore northern Cuba, dipping to the south. For example, Saura et al. (2008) (FSAR Subsection 2.5.1, Reference 485) present a cross section from offshore northern Cuba near Bahia Honda in western Cuba. They convert their seismic profile from two-way travel time to kilometers and produce a 1:1 interpreted cross section of the Cuban thrust belt (FSAR Figure 2.5.1-279). In this cross section, the Nortecubana fault basal thrust is imaged at depths of approximately 3 to 5.5 miles (approximately 5 to 9 kilometers), with an apparent average dip of approximately 10 degrees to the south. However, shallower splays within the Nortecubana fault system have apparent dips of up to approximately 35 degrees. As interpreted in this figure, the basal thrust of the Nortecubana fault appears to flatten southward. Similar dip angles and depths are also seen in FSAR Figure 2.5.1-248. Although not identified, the Nortecubana fault may be part of the North Cuban thrust belt faults dipping to the south, seen in FSAR Figures 2.5.1-280, -287, and -288. The vertical axes on these sections are shown in units of two-way travel time in seconds, not depth, so depth and dip determinations for the faults are not straightforward.

This response is PLANT SPECIFIC.

References:

Khudoley, K.M., 1967. Principal features of Cuban geology, *American Association of Petroleum Geologists Bulletin*, Vol. 51, No. 5, pp. 668-677.

Malloy, R.J. and Hurley, R.J., 1970. Geomorphology and geologic structure: Straits of Florida, *Geological Society of America Bulletin*, Vol. 81, pp. 1947–1972.

Mullins, H. T., and Neuman, A. C., 1979. Geology of the Miami Terrace and its paleo-oceanographic implications, *Marine Geology*, Vol. 30, pp. 205–232

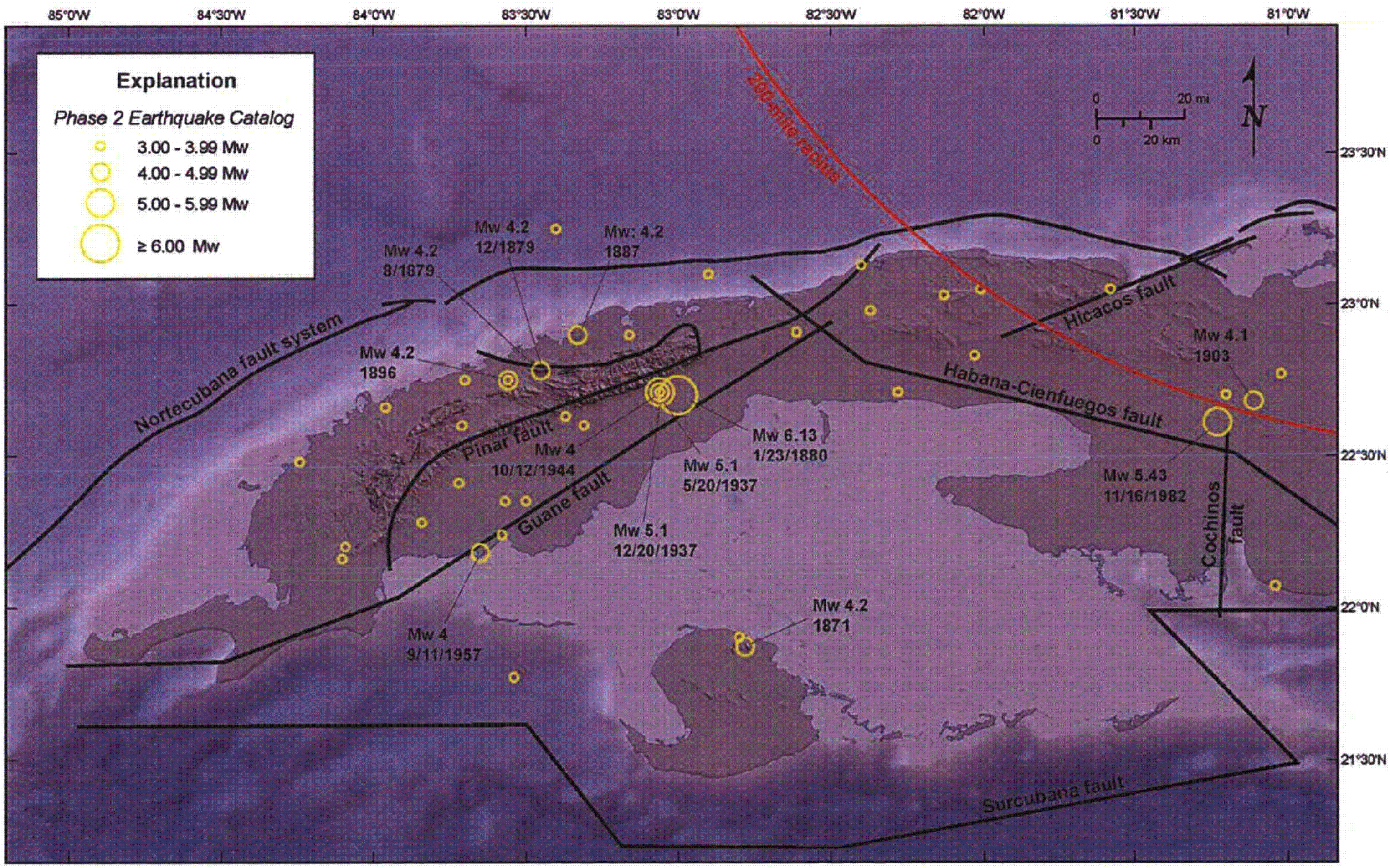


Figure 1A The Phase 2 Earthquake Catalog and Faults of Western Cuba

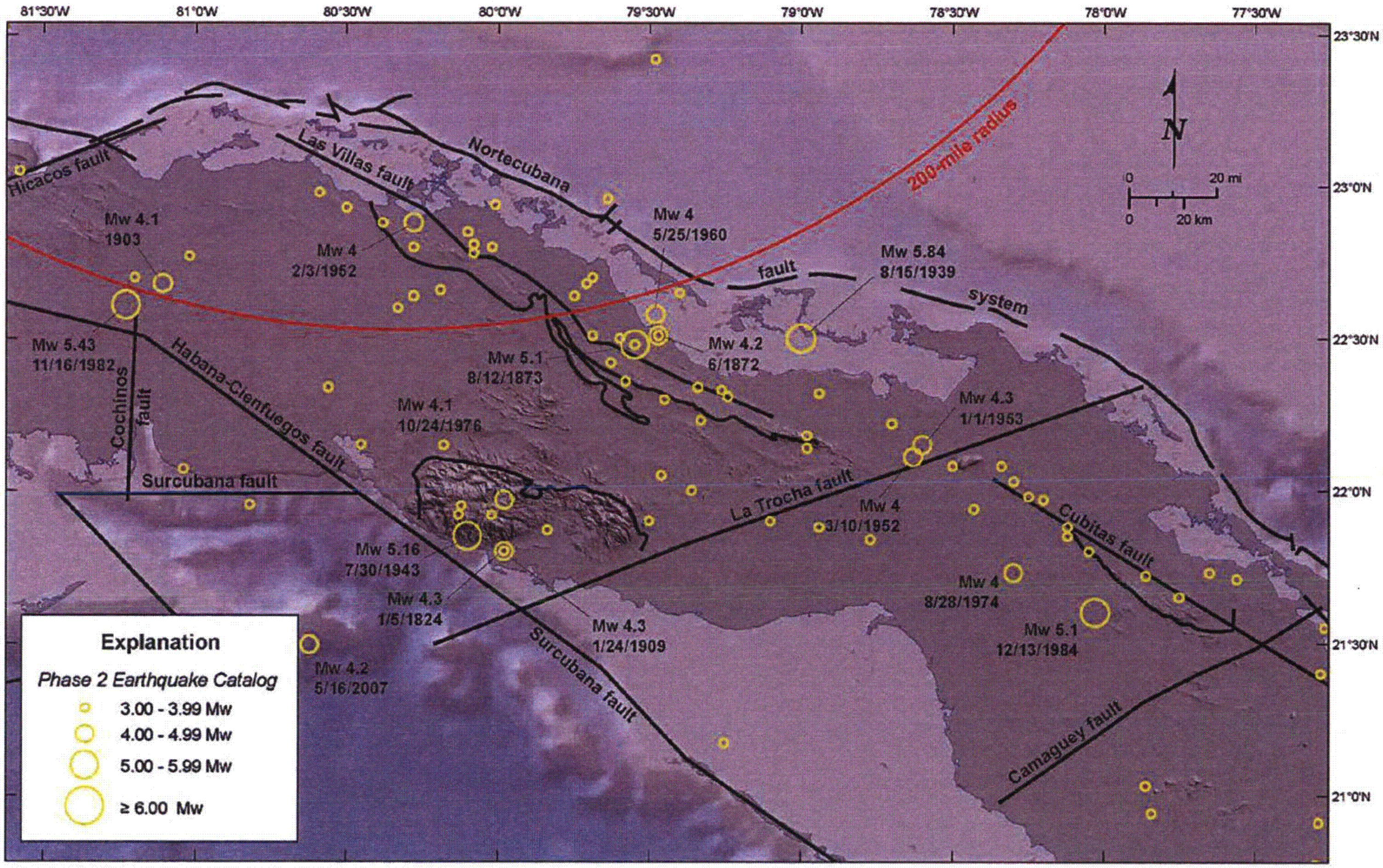


Figure 1B The Phase 2 Earthquake Catalog and Faults of Central Cuba

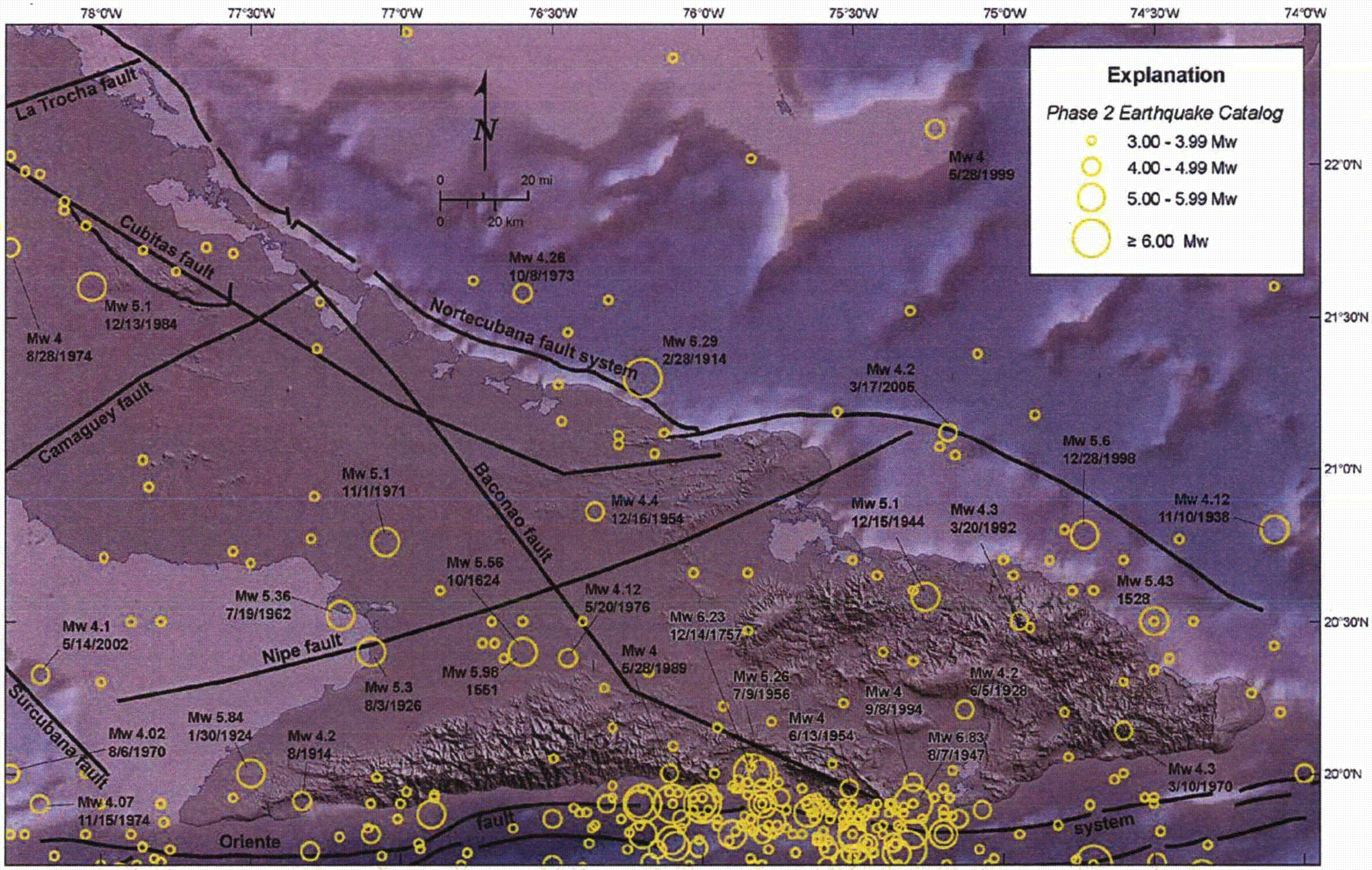


Figure 1C The Phase 2 Earthquake Catalog and Faults of Eastern Cuba

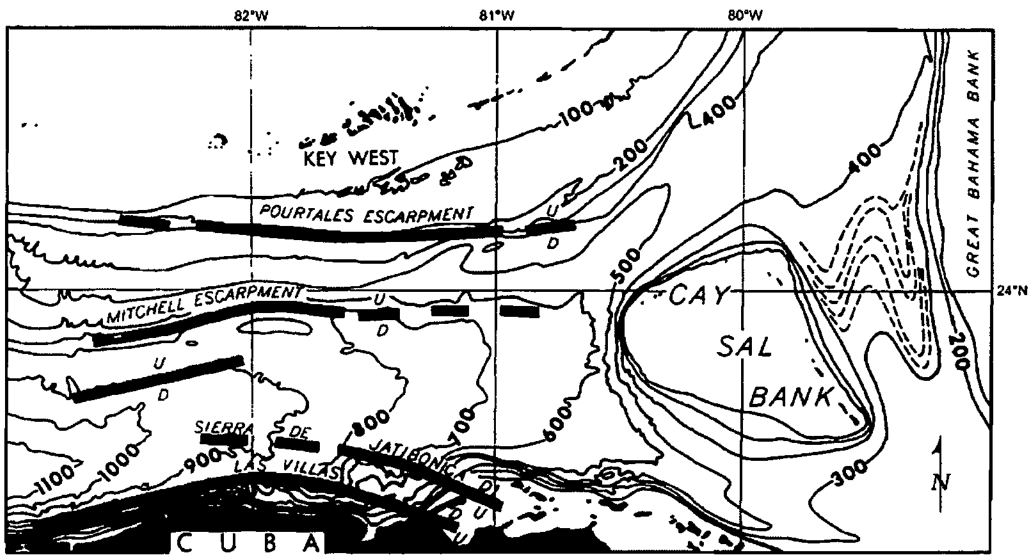


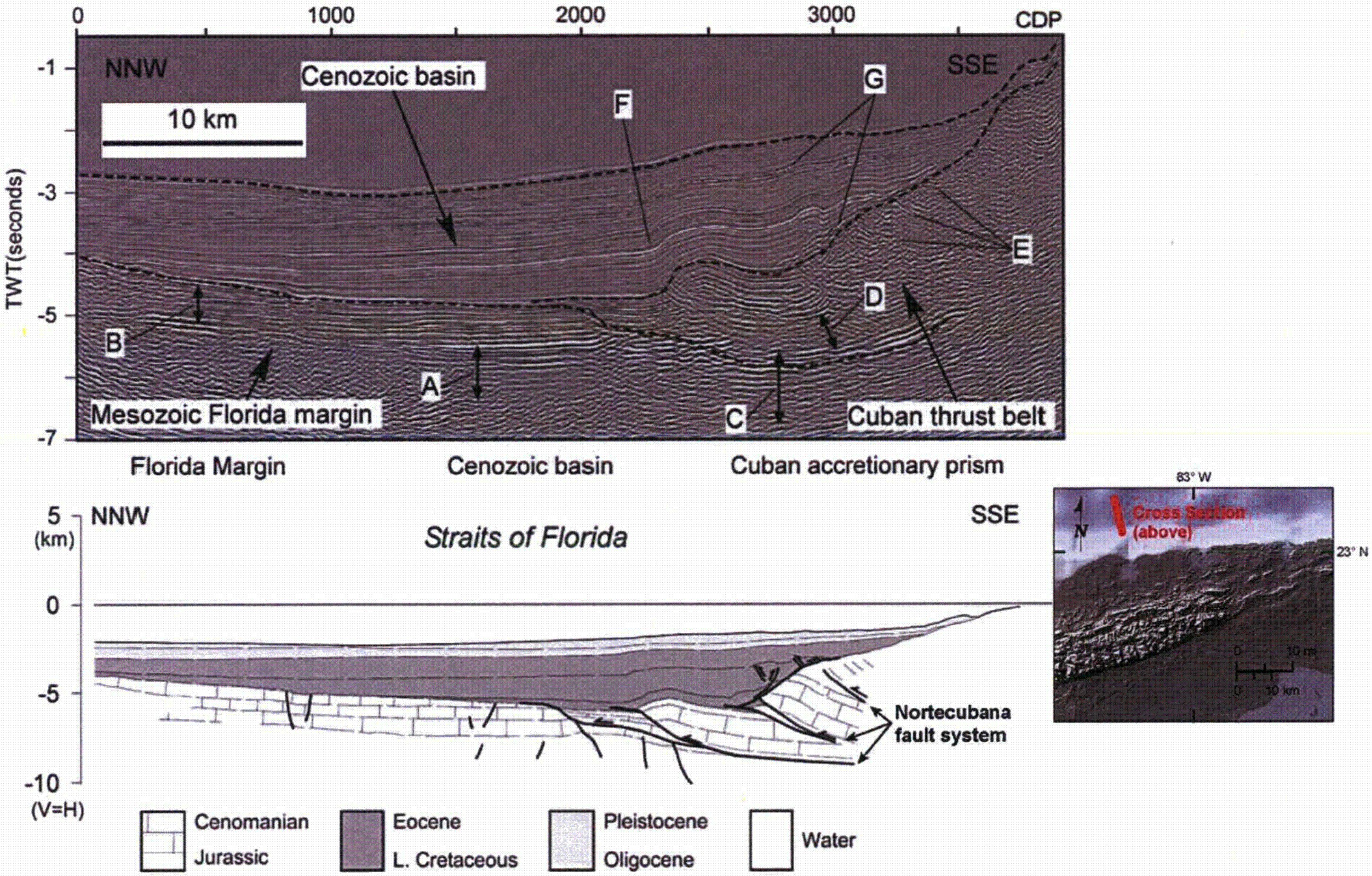
Figure 2 Escarpments and Postulated Faults in the Southern Straits of Florida from Malloy and Hurley (1970)

ASSOCIATED COLA REVISIONS:

The COLA will be revised to include information provided in this response pertaining to the Nortecubana fault. These COLA revisions are provided as part of the response to RAI 02.05.01-21.

FSAR Figure 2.5.1-279 will be replaced with the revised figure shown below in a future revision of the FSAR.

Figure 2.5.1-279 Offshore Cross Section across the Cuban Fold-and-Thrust Belt, Western Cuba



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: 02.05.01-25 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4 discusses the Hicacos, Surcubana, Habana-Cienfuegos, La Trocha and the Sierra Maestra faults; however the staff notes that more information is needed to assess the potential activity of these faults.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Provide a map of the Hicacos fault and seismicity, including earthquake location errors, and discuss the relationship of the Hicacos fault to nearby seismicity.
b) Provide a map and discussion of the activity of the Surcubana fault zone.
c) Provide a map of the surface trace of the Habana-Cienfuegos fault (including the undersea extension proposed in Cotilla-Rodriguez et al. Reference 494), including seismicity with location uncertainties. In addition, Discuss other nearby active faults that might have been the source of the "associated earthquake epicenters" referred to by Cotilla-Rodriguez.
d) Provide a map of the La Trocha fault trace and nearby seismicity, including location uncertainties and discuss potential sources of the observed seismicity.
e) Provide map and discussion of the faults associated with the Sierra Maestra. Consider for example Taber (1931) 1 which describes a scarp associated with the Sierra Maestra as "so fresh that its age must be measured in hundreds of years rather than tens of thousands." In addition discuss the relationship of these faults to nearby seismicity.

[1]Taber, S., 1931, The structure of the Sierra Maestra near Santiago De Cuba: The Journal of Geology. v. 39, n. 6, 532-557

FPL RESPONSE:

a) Provide a map of the Hicacos fault and seismicity, including earthquake location errors, and discuss the relationship of the Hicacos fault to nearby seismicity.

Figure 1A shows epicenters from the Phase 2 earthquake catalog and faults in western Cuba, including the Hicacos fault. The Phase 2 catalog is declustered and includes earthquakes of M_w 3 and above. 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 Cuban 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 Figure 1A because the data with which to estimate these errors for each earthquake are not available. According to Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494, p.518), 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) (FSAR 2.5.1 Reference 489, p. 2,569) 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."

Figure 1A indicates only sparse, minor-magnitude seismicity from the Phase 2 catalog near the northeast-striking Hicacos fault, described as a normal left-lateral transcurrent fault by Cotilla-Rodriquez et al. (2007) (FSAR 2.5.1 Reference 494). 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 Medvedev-Sponheuer-Karnik (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.

b) Provide a map and discussion of the activity of the Surcubana fault zone.

At its nearest distance, the segmented Surcubana fault as mapped by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) is located approximately 230 miles (370 kilometers) from the site (Figures 1A, 1B, and 1C). Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) do not include the Surcubana fault in their list of 12 "seismoactive" faults in Cuba, nor is the Surcubana fault described or depicted in many other studies of faulting in Cuba (e.g., Pushcharovskiy et al. 1988 [FSAR 2.5.1 Reference 846], Inturralde-Vinent 1994 [FSAR 2.5.1 Reference 440], Gordon et al. 1997 [FSAR 2.5.1 Reference 697], Iturralde-Vinent et al. 2008 [FSAR 2.5.1 Reference 786], Pardo 2009 [FSAR 2.5.1 Reference 439]).

Seismicity is sparse near the Surcubana fault along its entire length, with only a dozen or so earthquakes located within approximately 20 miles (30 kilometers) of the more than 500-

milelong (800-kilometer-long) mapped trace (Figures 1A, 1B, and 1C). Of these dozen earthquakes, all are low to moderate magnitude, and many 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 kilometers) north of the trace and occurred on March 27, 1964, with M_w 3.7. The second is located approximately 3 miles (5 kilometers) south of the trace and occurred on October 22, 2005, with M_w 3.8. However, as described in part a), the association of these earthquakes with the Surcubana 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.

c) Provide a map of the surface trace of the Habana-Cienfuegos fault (including the undersea extension proposed in Cotilla-Rodriguez et al. Reference 494), including seismicity with location uncertainties. In addition, discuss other nearby active faults that might have been the source of the "associated earthquake epicenters" referred to by Cotilla-Rodriguez.

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). Figures 1A and 1B indicate only sparse seismicity from the Phase 2 earthquake catalog near the Habana-Cienfuegos fault as mapped by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494). As described in part a) above, earthquake location errors are not shown on Figures 1A and 1B because the data with which to estimate these errors for each earthquake are not available.

Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494, p. 516) identify "associated earthquake epicenters" 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. This association is based presumably on proximity alone; however, no rationale is specified. Cotilla-Rodriguez et al. (2007, pp. 516–517) (FSAR 2.5.1 Reference 494) indicate that recent earthquakes are associated with "two knots (intersections) of faults" where the Habana-Cienfuegos crosses the Cochinos and Guane faults.

The largest associated earthquake epicenter identified by Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) is the December 16, 1982, M_s 5.0 earthquake (listed in the Phase 2 earthquake catalog as the November 16, 1982, M_w 5.4 earthquake). According to the Phase 2 earthquake catalog, this earthquake is located approximately 7 miles (11 kilometers) north of the Habana-Cienfuegos fault trace. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) also suggest that this earthquake may have occurred on the nearby Cochinos fault instead. They also associate a M_s 2.5 earthquake and nine MSK intensity III to V earthquakes (approximately MMI III to V) with the Habana-Cienfuegos fault. Cotilla-Rodriquez et al. (2007) (FSAR 2.5.1 Reference 494) suggest that the March 9,

1995, M_s 2.5 earthquake could have occurred on the Habana-Cienfuegos fault or on the nearby Guane fault. However, as described in part a), the association of these earthquakes with the Habana-Cienfuegos 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. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

d) Provide a map of the La Trocha fault trace and nearby seismicity, including location uncertainties and discuss potential sources of the observed seismicity.

The La Trocha fault is mapped as a northeast-striking fault in central Cuba and described as a normal fault "transcurrent to the left" by Cotilla-Rodriguez et al. (2007, p. 517) (FSAR 2.5.1 Reference 494) (Figure 1B). The La Trocha fault is not shown on Pushcharovskiy et al.'s (1988) 1:250,000 scale geologic map of Cuba (FSAR 2.5.1 Reference 846). 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 strata and could be pre-middle Miocene in age.

Figure 1B indicates only sparse seismicity from the Phase 2 earthquake catalog near the La Trocha fault. Only four earthquakes from the Phase 2 catalog are located within 6 miles (10 kilometers) of the fault trace, the largest of which is the January 1, 1953 M_w 4.3 earthquake. As described in part a) above, earthquake location errors are not shown on Figure 1B because the data with which to estimate these errors for each earthquake are not available. Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494) suggest a possible association between three earthquakes of less than or equal to MSK intensity V (approximately MMI V) and the La Trocha fault. Some of the seismicity near this structure occurs near its projected intersection with the Cubitas fault (Figure 1B). However, as described in part a), the association of these earthquakes with the La Trocha fault or another mapped or unmapped fault is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba.

e) Provide map and discussion of the faults associated with the Sierra Maestra. Consider for example Taber (1931) which describes a scarp associated with the Sierra Maestra as "so fresh that its age must be measured in hundreds of years rather than tens of thousands." In addition discuss the relationship of these faults to nearby seismicity.

The Sierra Maestra is an east–west-trending mountain range in southernmost Cuba, located approximately 450 miles (725 kilometers) from the site and adjacent to the offshore Oriente fault. Figure 2 shows a simplified depiction of faults in the Sierra Maestra, based on mapping by Rojas-Agramonte et al. (2005). The Oriente fault and near-shore portion of the Sierra Maestra are an area of abundant ongoing seismicity (Figure 1C) and neotectonic faulting (Oliva Gutierrez 1989, plate IV.3.2-3; Rojas-Agramonte et al. 2005). Taber's (1931, p. 532) observation from the near-shore Sierra Maestra at Puerto Pelado ridge near Santiago de Cuba of a "scarp so fresh its age must be measured in hundreds of years" is consistent with this active tectonic setting.

The scarps in the Sierra Maestra may be related to some of the seismicity in southeastern Cuba. Given the proximity to the modern plate boundary, as well as the abundant moderate- to strong-magnitude seismicity (Figure 1C), there almost certainly are active faults in this region. However, as described in part a), the confident association of specific earthquakes with a given Sierra Maestra fault is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba. For the purposes of characterizing ground-motion hazard at the site, the entire plate boundary rate is modeled on the offshore Oriente fault source and is not represented as a more complex series of diffuse faults along the plate boundary. A thin strip of the near-shore portion of the Sierra Maestra is excluded from the Cuba areal seismic source zone (revised FSAR Figure 2.5.2-217). The seismic moment release from this thin near-shore portion of the Sierra Maestra is assumed to be related to deformation associated with the Oriente fault system and therefore is included in the seismic source model as part of the Orient fault-East seismic source. The remainder of the Sierra Maestra is included in the seismic source characterization as part of the Cuba areal source, and the seismicity observed from this portion of the Sierra Maestra is included in the assessment of seismicity recurrence rate for the entire areal source.

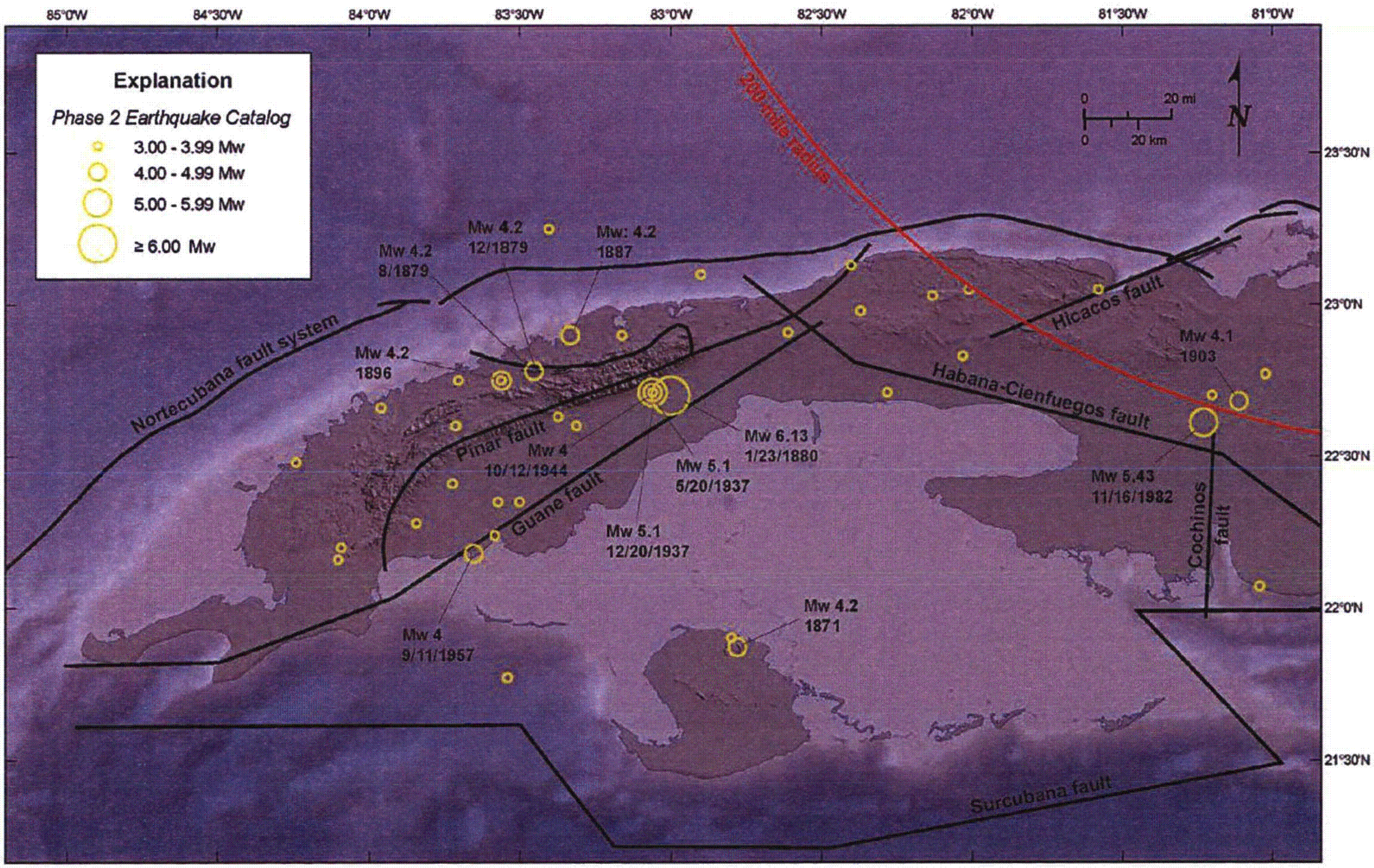


Figure 1A The Phase 2 Earthquake Catalog and Faults of Western Cuba

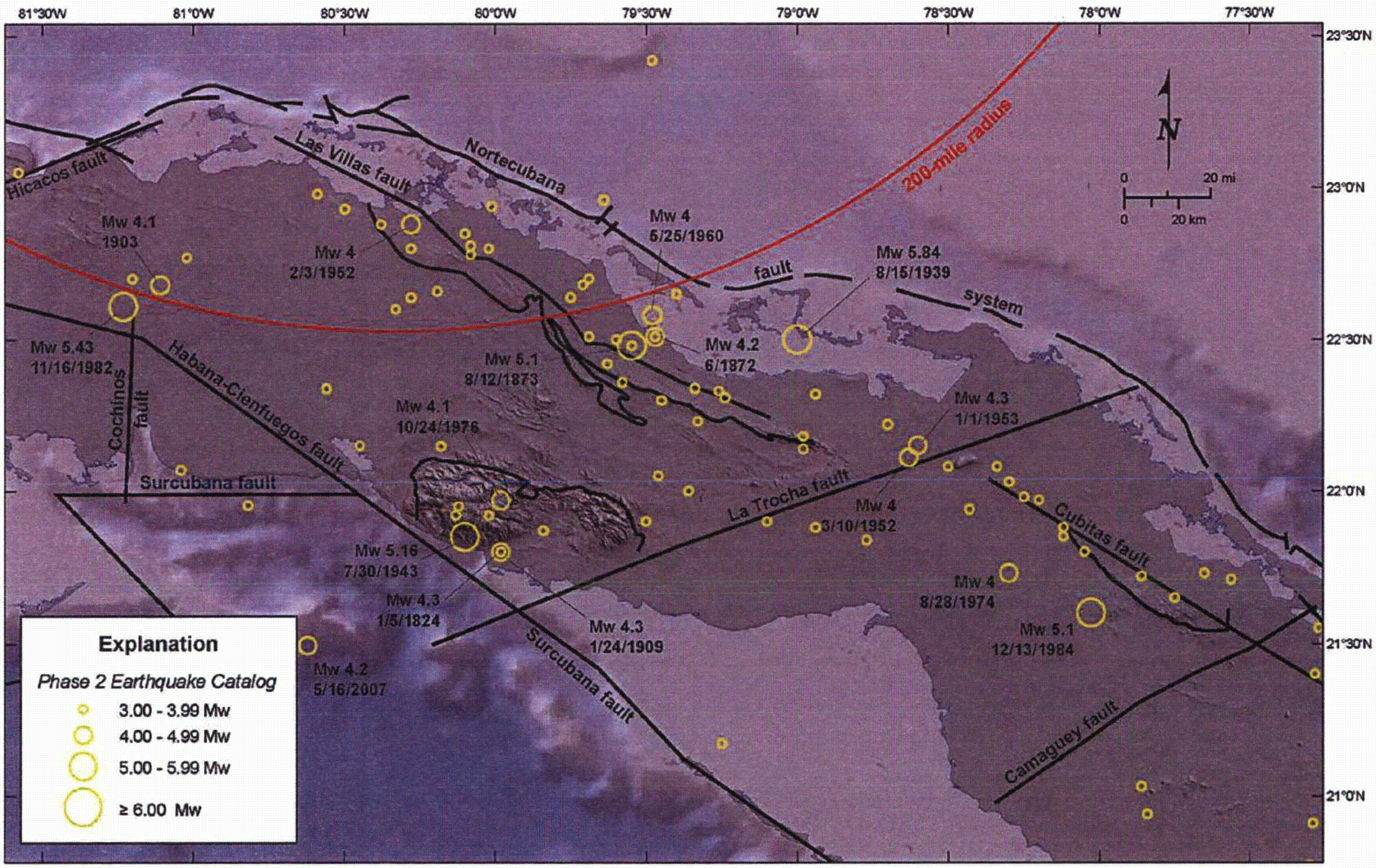
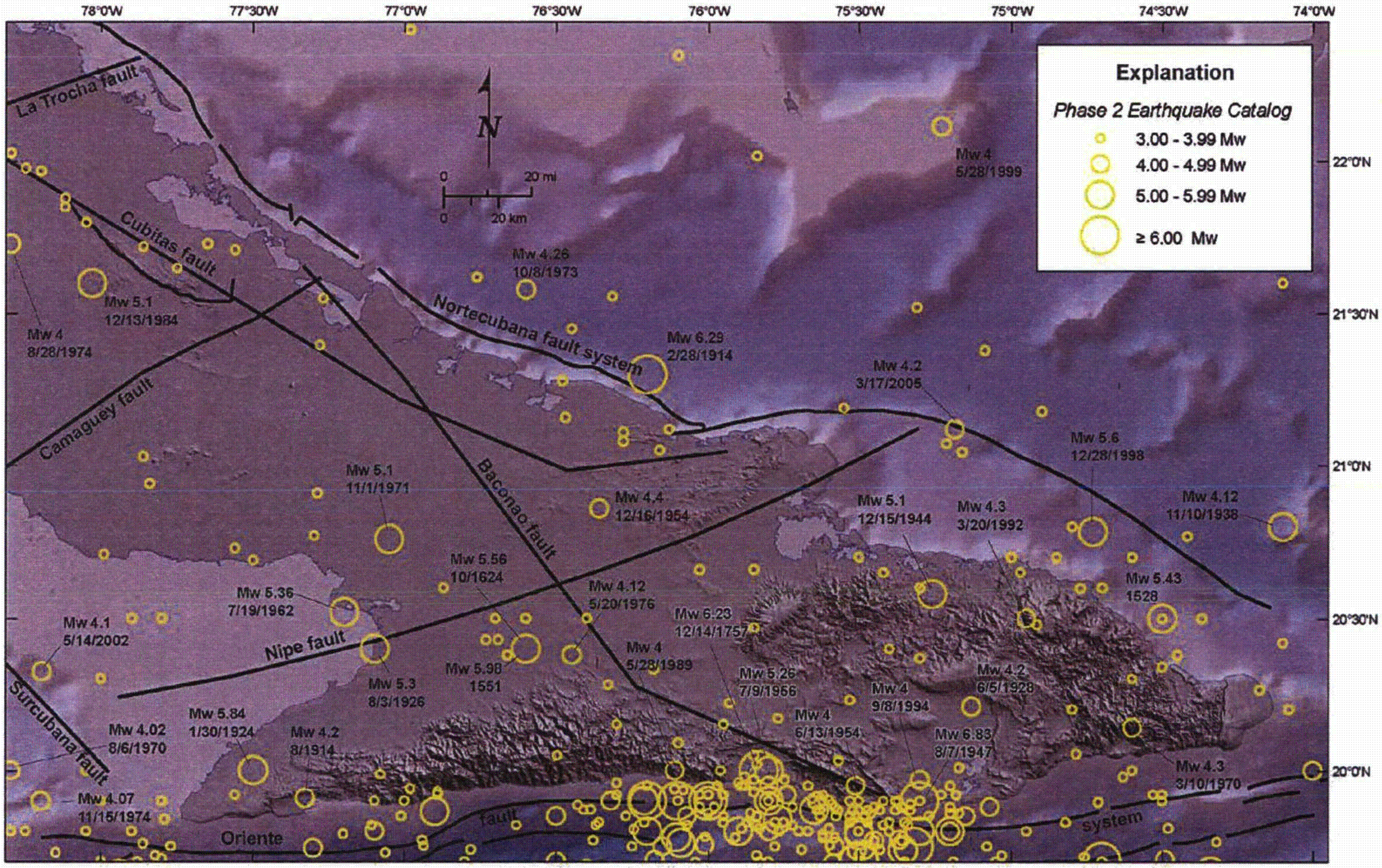


Figure 1B The Phase 2 Earthquake Catalog and Faults of Central Cuba



Note: All of the area depicted is outside the 200-mile site region.

Figure 1C The Phase 2 Earthquake Catalog and Faults of Eastern Cuba

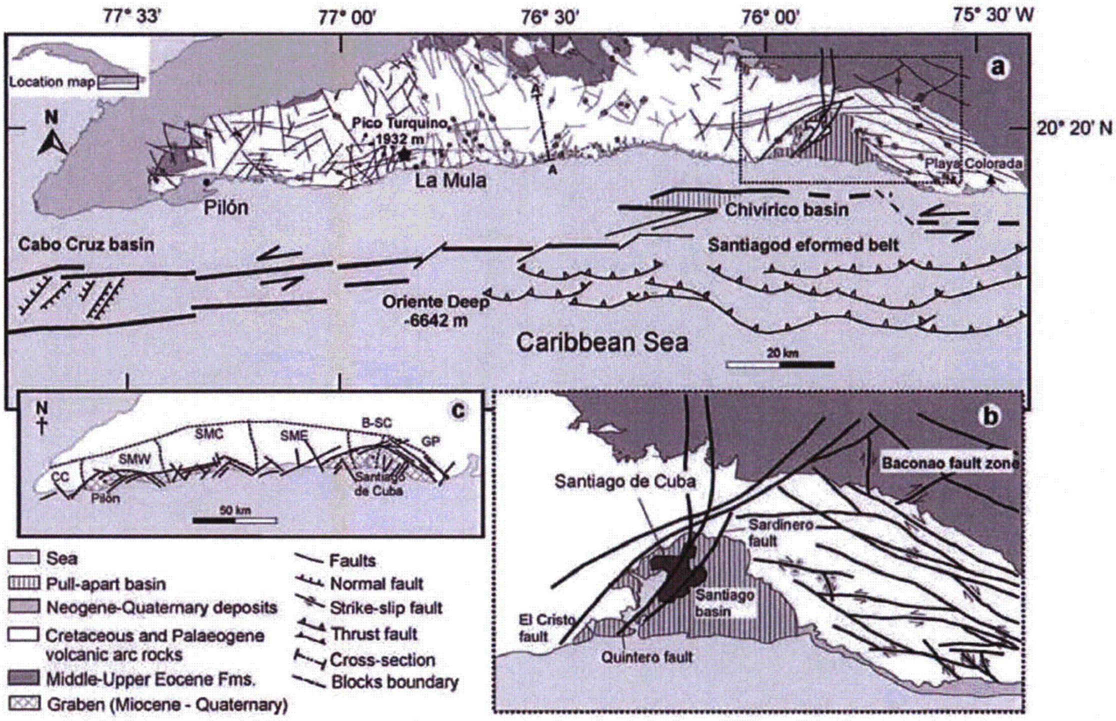


Figure 2 Geologic Maps of Sierra Maestra Region of Cuba (Rojas-Agramonte et al. 2005)

This response is PLANT SPECIFIC.

References:

Oliva Gutierrez, G., Sanchez Herrero, E.A. (directors), 1989. *Nuevo Atlas Nacional de Cuba*, Instituto de Geografía de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesia y Cartografía, and the Instituto Geográfico Nacional de España, 220 pp.

Rojas-Agramonte, Y., Neubauer, F., Handler, R., Garcia-Delgado, D.E., Friedl, G., Delgado-Damas, R., 2005. Variations of paleostress patterns along the Oriente transform wrench corridor, Cuba: significance for Neogene-Quaternary tectonics of the Caribbean realm, *Tectonophysics*, Vol. 396, pp. 161–180.

Taber, S.T., 1931. The structure of the Sierra Maestra near Santiago de Cuba, *Journal of Geology*, Vol. 39, No. 6, pp. 532–557.

ASSOCIATED COLA REVISIONS:

COLA revisions as a result of this response are included in the response to RAI 02.05.01-21.

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: 02.05.01-26 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4 states, in the "Cochinos Fault" passage, that Cotilla Rodriguez et al. (2007) provided no geologic evidence for activity in this fault and described it as covered by young sediments. The FSAR also indicates that the Cochinos fault appears to be geographically associated with sparse instrumental seismicity, but that these earthquakes are poorly located and no focal mechanisms are available.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Provide a map of the Cochinos fault with respect to topography and bathymetry, and discuss if the association of the Cochinos fault with bathymetric relief provides geologic evidence for activity.

b) Map seismicity with respect to the Cochinos fault trace, showing location uncertainties, and discuss the relationship of the fault to seismicity.

FPL RESPONSE:

a) Provide a map of the Cochinos fault with respect to topography and bathymetry, and discuss if the association of the Cochinos fault with bathymetric relief provides geologic evidence for activity.

The Cochinos fault is a north- (e.g., Hall et al. 2004; Cotilla-Rodriguez et al. 2007) (FSAR References 770 and 494) to north-northwest-striking (e.g., Mann et al. 1990) (FSAR Reference 493) fault in south-central Cuba. Cotilla-Rodriguez et al. (2007) (FSAR Reference 494) describe the Cochinos fault as a "normal fault with a few inverse type sectors which demonstrates transcurrence to the left" (p. 514) and "normal and reverse type with left strike-slip" (p. 515). Figures 1A, 1B, and 2 show the location of the Cochinos fault with respect to topography and bathymetry. On these figures, shaded relief topography is based on Shuttle Radar Topography Mission (SRTM) 3-arcsecond (90 meter) data and shaded relief bathymetry is based on General Bathymetric Chart of the Oceans (GEBCO) 500 m data.

Various researchers present different locations and extents for the Cochinos fault. For example, Figures 1A and 1B show the location of the Cochinos fault after Hall et al. (2004) (FSAR Reference 770), who indicate the fault at its nearest point is approximately 205 miles (330 kilometers) from the Turkey Point Units 6 & 7 site. Cotilla-Rodriguez et al. (2007) (FSAR Reference 494) suggest this fault may extend northward to within 175 miles (280 kilometers) of the site, whereas mapping by Mann et al. (1990) (FSAR Reference 493) indicates a closest distance of approximately 210 miles (340 kilometers).

The Cochinos fault is depicted differently on various maps from the *Nuevo Atlas Nacional de Cuba* (Reference 1). 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-kilometer-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 (Figure 2). The southernmost 18 miles (30 kilometers) of this fault are shown by a dashed line (Figure 2). At its nearest point, this fault is approximately 185 miles (300 kilometers) from the site. 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-kilometer-long) unnamed fault in the vicinity of the Cochinos fault, the southernmost 30 miles (50 kilometers) 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). On this map, the Cochinos lineament is shown as an approximately 90-mile-long (140-km-long) feature, the southern 25 miles (40 km) of which is located off the southern shore of Cuba and labeled as "supuestos" (assumed or postulated). 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-kilometer-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 meters or 5 – 7 meters above sea level. They do not provide an explanation for the lack of specificity in elevation of the platform nor do they provide a precise age for the Quaternary abrasion platform.

The southern Cochinos fault is grossly expressed in the topography and bathymetry in the Bahia de Cochinos (Figure 2). The Cochinos fault is the only onshore feature in intraplate Cuba identified as "neotectonic" by Mann et al. (1990) (FSAR 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-Rodríguez et al. (2007) (FSAR Reference 494) classify the Cochinos fault as active based on the possible association of seismicity with the fault. Cotilla-Rodríguez et al. (2007) (FSAR 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 (Pushcharovskiy et al. 1988) (FSAR Reference 846). It is not clear whether the Cochinos fault is depicted on Perez-Othon and Yarmoliuk's (1985) (FSAR Reference 848) inset map of fault ages in Cuba, but they seemingly indicate a Paleogene age for a northern extension of this fault. Pushcharovskiy's (1989) (FSAR Reference 847) 1:500,000 scale tectonic map of Cuba shows and labels the approximately 60-mile-long (100-kilometer-long) Cochinos fault. This fault does not extend as far north as the Hicacos fault, and the southern approximately 50 miles (80 kilometers) are shown as a dashed line. Garcia et al. (2003) (FSAR Reference 489) provide no discussion of the Cochinos fault.

b) Map seismicity with respect to the Cochinos fault trace, showing location uncertainties, and discuss the relationship of the fault to seismicity.

Seismicity in the vicinity of the Cochinos fault is sparse. Cotilla-Rodríguez et al. (2007) (FSAR Reference 494) list six earthquakes that they suggest may have occurred on the Cochinos fault. The largest of these is the December 16, 1982 M_s 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 site 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) (FSAR 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 kilometers) northwest of the Cochinos fault trace (Figures 1A and 1B). Cotilla-Rodriguez et al. (2007) (FSAR Reference 494) suggest that the 1982 earthquake may instead have occurred on the Habana-Cienfuegos fault (Figures 1A and 1B). In addition to the 1982 earthquake, the Phase 2 earthquake catalog shows only four other earthquakes within 20 miles (32 kilometers) of the Cochinos fault, the largest of which is assigned M_w 4.1 (Figures 1A and 1B). Cotilla-Rodriguez et al. (2007) (FSAR Reference 494) indicate there are no focal mechanisms associated with earthquakes in the vicinity of the Cochinos fault.

Earthquake location errors are not shown on Figures 1A and 1B because the data with which to estimate these errors for each earthquake are not available. According to Cotilla-Rodriguez et al. (2007) (FSAR 2.5.1 Reference 494, p.518), 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." Regarding the locations of pre-instrumental earthquakes in Cuba, Garcia et al. (2003) (FSAR 2.5.1 Reference 489, p. 2,569) 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." Therefore, the association of this sparse seismicity with the Cochinos fault or another mapped or unmapped fault in the vicinity is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba.

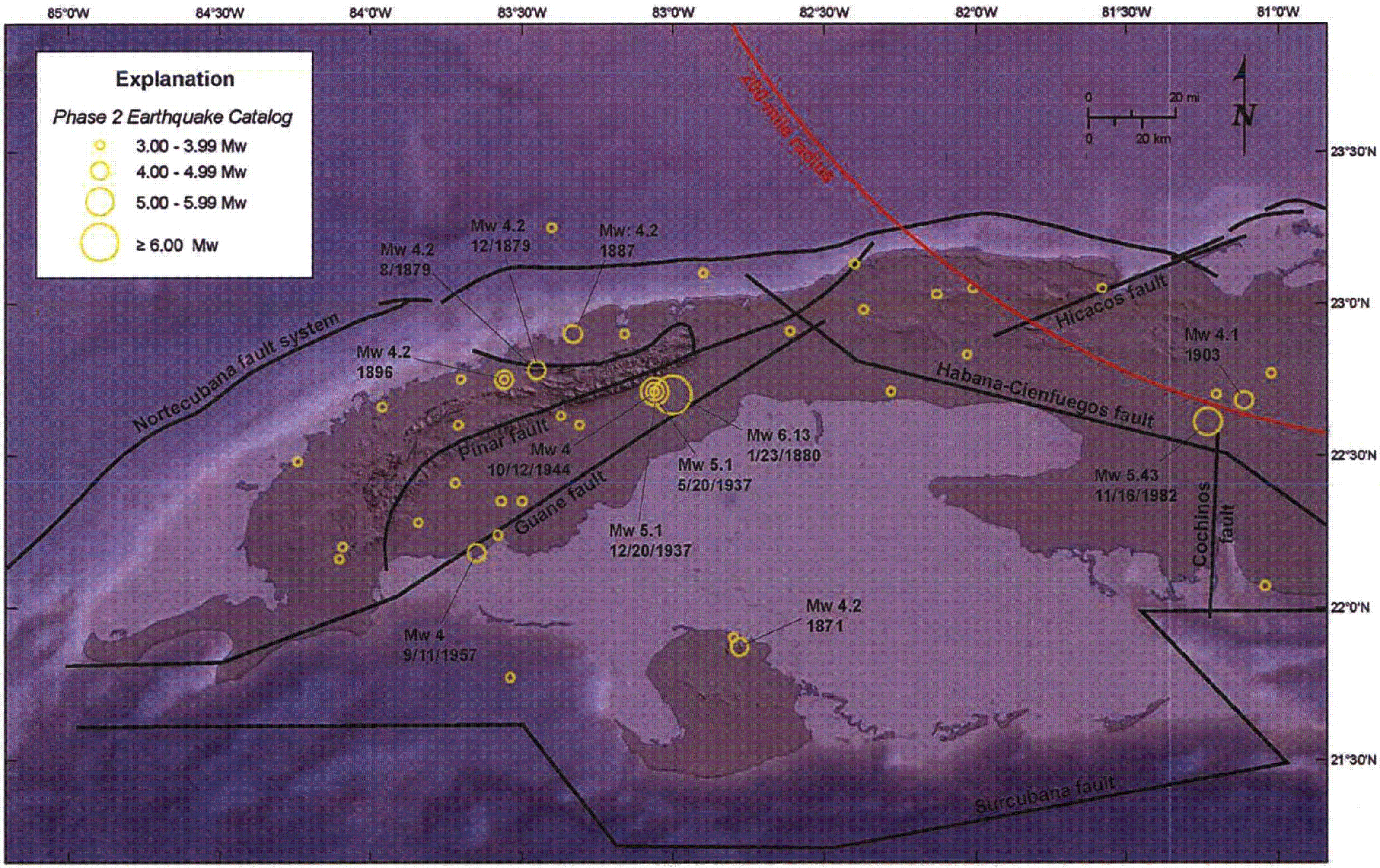


Figure 1A Fault Map of Western Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog.

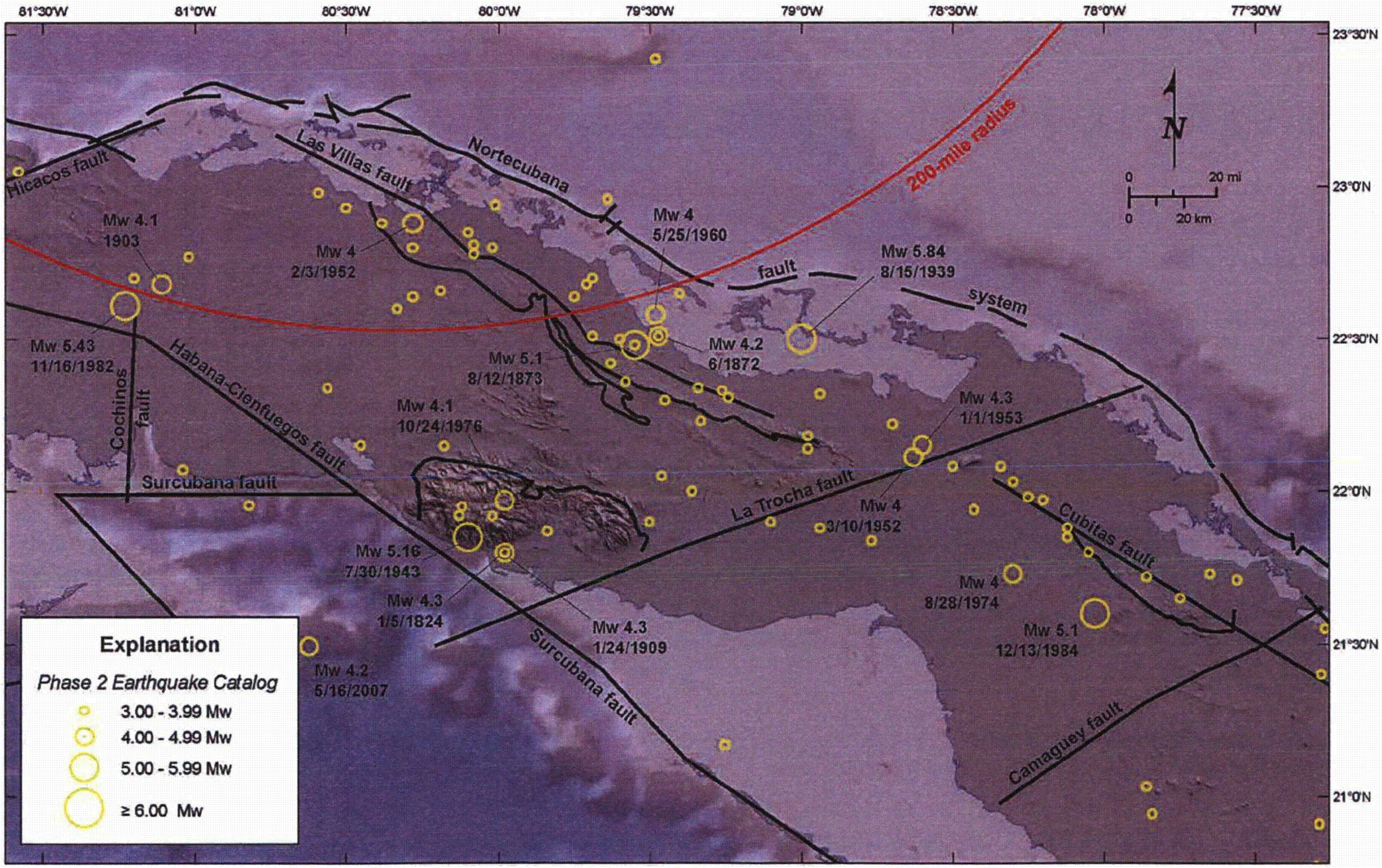


Figure 1B Fault Map of Central Cuba Showing Earthquakes from the Phase 2 Earthquake Catalo

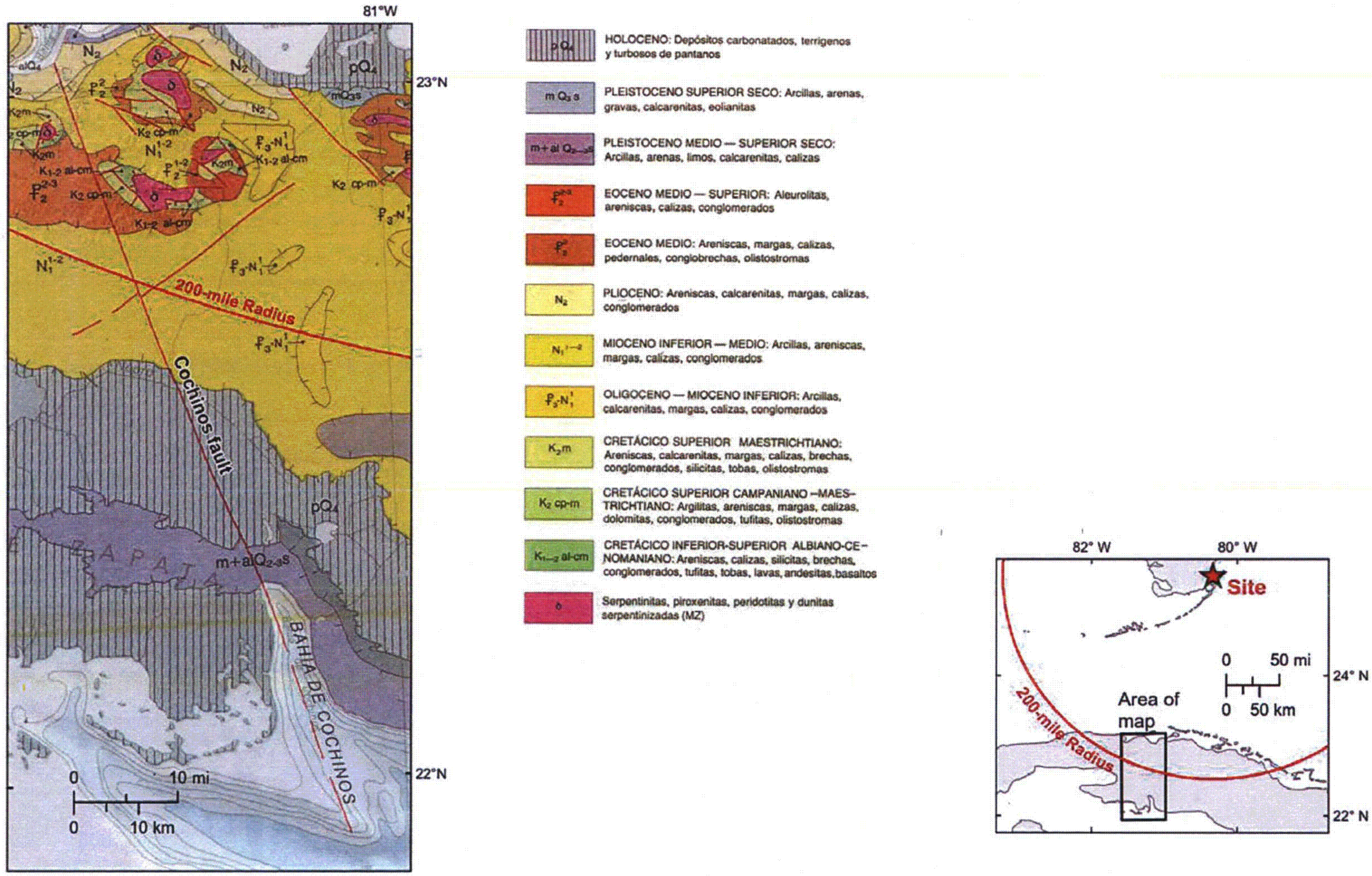


Figure 2 Geologic Map of Central Cuba Showing the Cochinos Fault (modified after Oliva Gutierrez 1989 plate III.1.2-3

This response is PLANT SPECIFIC.

References:

1. Oliva Gutierrez, G. and Sanchez Herrero, E.A. (directors), 1989. Nuevo Atlas Nacional de Cuba, Instituto de Geografía de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesia y Cartografía, and the Instituto Geográfico Nacional de España, 220 pp.

ASSOCIATED COLA REVISIONS:

The COLA will be revised to include information provided in this response pertaining to the Cochinos fault. These COLA revisions are provided as part of the response to RAI 02.05.01-21.

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: 02.05.01-27 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4, "Las Villas Fault" passage, states that according to Cotilla-Rodríguez et al. (2007), the Las Villas fault has 'young eroded scarps', 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. The FSAR also described, quoting Cotilla Rodriguez et al. (2007), "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". The staff notes however, that Cotilla-Rodriguez et al. (1997) states in the same paragraph as the above quoted statement, that the Las Villas fault "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".

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Provide more detail from the Cotilla-Rodríguez et al. (2007) paper regarding the young eroded scarps of the Las Villas fault and specifically address Cotilla's conclusion that the fault is Pliocene-Quaternary in age.

b) In the context of the chronology of geomorphic surfaces on Cuba, clarify the distinction between erosional processes that may have recently created "young" fault-line scarps along the Las Villas fault and Quaternary tectonic fault scarps.

c) Discuss bathymetric evidence for the offshore location and recency of faulting along the Las Villas fault.

d) Address the alignment of epicenters shown on Figure 2.5.1-267 along the Las Villas fault with respect to its tectonic activity. Please plot the uncertainties in event locations and include this information in the discussion.

FPL RESPONSE:

a) Provide more detail from the Cotilla-Rodríguez et al. (2007) paper regarding the young eroded scarps of the Las Villas fault and specifically address Cotilla's conclusion that the fault is Pliocene-Quaternary in age.

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

> *[The Las Villas] 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 (M_s = 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. (FSAR Subsection 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 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. Based on the information provided in Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494), it is not possible to distinguish between these alternatives. Based on literature review performed for this project, we know of no paleoseismic trench studies or detailed geomorphic assessments of the Las Villas fault with which to assess recent earthquake activity on this fault.

In their description of scarps along the Baconao fault in southeastern Cuba, Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 513) state "there are vast, continuous and abrupt escarpments and many distorted and broken fluvial terraces of the Quaternary and Pleistocene." This statement clearly indicates tectonic scarps forming in deposits of Pleistocene to Quaternary age. In contrast, Cotilla-Rodríguez et al.'s (FSAR Subsection 2.5.1, Reference 494) brief description of scarps along the Las Villas fault implies erosion and does not indicate the age of the rocks or deposits in which the scarps have formed. Thus, there is uncertainty regarding what Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 517) imply by "young eroded scarps."

Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494) state that the Las Villas fault is Pliocene-Quaternary in age and indicate it is associated with seismicity and has "young eroded scarps" (FSAR Subsection 2.5.1, Reference 494, p. 517). We assume that the association with seismicity and young eroded scarps are the basis for their assessment that the fault is "of Pliocene-Quaternary age" (FSAR Subsection 2.5.1, Reference 494, p. 517). However, if the association with seismicity were definitive, then the Las Villas fault would be considered Quaternary in age, instead of Pliocene-Quaternary in age. Furthermore, Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 507-508) state that their "seismoactive" faults in Cuba satisfy one or more of the following criteria:

> *a) direct observation of faulting in connection with at least one earthquake; b) occurrence of well-located earthquake or microearthquake activity close to a known fault. In addition, a well-constrained fault-plane solution with one nodal plane showing the same orientation and sense of displacement as the fault is required; c) close correspondence of orientation of nodal planes and senses of displacement of well-constrained fault-plane solutions to the type and orientation of young faults or fault zones observed in the epicentral region; d) mapping of hypocenters by high-precision location of individual events of local clusters of earthquakes displaying almost identical signal forms, controlled by well-constrained fault-plane solution(s).*

It is questionable whether the Las Villas fault meets the above criteria, given the poorly located earthquakes in Cuba and paucity of available focal mechanisms.

b) In the context of the chronology of geomorphic surfaces on Cuba, clarify the distinction between erosional processes that may have recently created "young" fault-line scarps along the Las Villas fault and Quaternary tectonic fault scarps.

The chronology of geomorphic surfaces in northern Cuba is not well established. Some regional studies have investigated marine terraces along the north coast of Cuba near Matanzas Bay (e.g., Reference 4, Reference 5), approximately 30 miles (50 kilometers) west of the Las Villas fault. Reference 4 identifies three Pleistocene-age marine terraces in the Matanzas-Havana region. They postulate that the elevations above sea level of these terraces may be the result of tectonic uplift, but they do not suggest what structure or structures may be responsible. More recent studies, however, conclude that ongoing tectonic uplift is not required to explain the elevation of marine terraces in northern Cuba. For example, based on their analysis of elevations and ages of marine terraces near Matanzas, Reference 5 concludes that "no obvious tectonic uplift is indicated for this time frame [i.e., since Marine Isotope Stage 5e at approximately 120–130 ka] along the northern margin of Cuba." Reference 5 does not provide definitive evidence precluding possible Pleistocene or younger deformation associated with the Las Villas fault because the location, extent, and continuity of Pleistocene marine terraces east of Matanzas near the westernmost portion of the Las Villas fault is not well documented. Moreover, Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494) do not provide information regarding the specific location or extent of the scarps along the Las Villas fault. They do not describe whether these scarps are located in bedrock, marine terraces, or other rocks or deposits. Thus, it is not possible to assess the possible association of these scarps with the 5e marine terrace or other geomorphic surfaces.

According to Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 517), the Las Villas fault has "young eroded scarps", but it is not clear from this limited description if these are fault scarps that formed directly by recent slip on the Las Villas fault. Alternatively, these "young eroded scarps" could be fault-line scarps formed by recent local or differential erosion. Based on the scant information provided in Cotilla-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494), it is not possible to distinguish between these alternatives. Pardo (FSAR Subsection 2.5.1, Reference 439, p. 316) indicates that along much of its length the Las Villas fault "places the Sagua conglomerate of the Las Villas belt on Vega Formation of the Yaguajay belt" and that there is a "striking difference between the facies north and south of the fault." Pardo (FSAR Subsection 2.5.1, Reference 439, p. 316) indicates that the Eocene Sagua conglomerate is a carbonate breccia and that the "Vega formation is found all along the fault front, as if this formation had acted as the incompetent material on which the displacement occurred." This juxtaposition of dissimilar rock types across the Las Villas fault along much of its length is consistent with the possibility that the "young eroded scarps" are the result of differential erosion. There are no paleoseismic trench studies on the Las Villas fault and there are no detailed geomorphic assessments of the "young eroded scarps" of the Las Villas fault with which to assess recent earthquake activity on this fault.

c) Discuss bathymetric evidence for the offshore location and recency of faulting along the Las Villas fault.

The Las Villas fault is mapped differently by different researchers. Some early depictions of the Las Villas fault (e.g., Reference 1 and Reference 2) show significant offshore extent and possible bathymetric expression. More recent depictions of the Las Villas fault show a more limited offshore extent (e.g., Pardo (FSAR Subsection 2.5.1, Reference 439)) or no offshore extent (e.g., Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494)). Comparisons between the various depictions of the Las Villas fault suggest that the name "Las Villas fault" may have been applied to different geologic structures by different researchers over time. This subsection provides clarification regarding the various depictions of the Las Villas fault and whether these potentially are expressed in the bathymetry.

Reference 1 identifies the Las Villas fault as a "deep" fault of Cuba "whose length is approximately 800 kilometers, generally paralleling the island." Despite this, the map in Reference 1 shows the Las Villas fault as approximately 220 miles (350 kilometers) long (Figure 1). As mapped in Reference 1, the Las Villas fault extends along the northern coast of Cuba from approximately 80°W to 83°W, transitioning from an onshore to an offshore structure near Carahatas, Cuba (Figure 1). The total offshore length of Khudoley's Las Villas fault is approximately 120 miles (200 kilometers). Reference 1 does not describe the data that constrain the location and extent of the offshore portions of the Las Villas fault, but this is presumably based on bathymetric data because these are the primary data presented by the author.

Reference 2 presents compiled bathymetric and seismic reflection data for the Straits of Florida. They identify escarpments in the Straits of Florida and postulate the existence of faults, including the offshore Las Villas fault (Figure 2). Reference 2 indicates that "since traverses could not be made within 12 [nautical miles] of Cuba, no seismic reflection profiles were obtained of these steep and complex slopes." As such, they base their offshore mapping of the Las Villas fault on Khudoley's previous mapping and on their compiled bathymetric data. The depiction in Reference 2 of the offshore Las Villas fault extends for approximately 120 miles (200 kilometers) from roughly Matanzas Bay westward to Havana. Reference 2 states that "the Las Villas fault appears to be reflected in the bathymetry as a scarp", but they do not provide any description of scarp dimensions, including length, height, and continuity.

More recent depictions of the Las Villas fault indicate that this structure is located mostly or entirely onshore in central Cuba. For example, the depiction of the Las Villas fault on Figure 3 from Pardo (FSAR Subsection 2.5.1, Reference 439) extends offshore near Carahatas, Cuba and continues offshore to the northwest roughly parallel and close to the coast for only about 40 miles (65 kilometers) (Figure 3). Pardo (FSAR Subsection 2.5.1, Reference 439) does not describe bathymetric expression of this fault. Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494) show the Las Villas fault as entirely onshore, and therefore it is not expressed in the bathymetry. Similarly, the 1:2,000,000 scale lineament map of Cuba from the *Nuevo Atlas Nacional de Cuba* (Reference 3, plate III.3.1-11) depicts and labels the Las Villas fault as an approximately 120-mile-long (190-kilometers-long), northwest-trending feature that is located entirely onshore. The 1:2,000,000 scale

neotectonic map of Cuba from the same atlas (Reference 3, plate III.2.4-8) shows an unnamed fault in the vicinity of the Las Villas fault that is located entirely onshore. Based on its location, we assume that this unnamed fault is the Las Villas fault. Perez-Othon and Yarmoliuk (FSAR Subsection 2.5.1, Reference 848) show an unnamed fault on their 1:500,000 scale geologic map of Cuba in the vicinity of the Las Villas fault and this unnamed fault is located entirely onshore. Pushcharovskiy's (FSAR Subsection 2.5.1, Reference 847) 1:500,000 scale tectonic map of Cuba depicts and labels the Las Villas fault as a thrust fault located entirely onshore.

Figure 4 is a map of faults in Cuba compiled for this project from various sources. This map shows Pardo's (FSAR Subsection 2.5.1, Reference 439) depiction of the Las Villas fault and Case and Holcombe's (FSAR Subsection 2.5.1, Reference 480) depiction of the Nortecubana fault as black lines. Additionally, this map shows Malloy and Hurley's (Reference 2) depictions of the postulated offshore Las Villas and Sierra de Jatibonico faults as red and white lines. As shown on Figure 4, Malloy and Hurley's (Reference 2) offshore Las Villas fault is roughly coincident with Case and Holcombe's (FSAR Subsection 2.5.1, Reference 480) Nortecubana fault between roughly Matanzas Bay and Havana. For this reason, it is assumed that Malloy and Hurley's (Reference 2) offshore Las Villas fault is a portion of what Case and Holcombe (FSAR Subsection 2.5.1, Reference 480) later mapped as the Nortecubana fault and that Malloy and Hurley's (Reference 2) offshore Las Villas fault is not the same structure as the Las Villas fault mapped by Pardo (FSAR Subsection 2.5.1, Reference 439), Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494), Perez-Othon and Yarmoliuk (FSAR Subsection 2.5.1, Reference 848), Pushcharovskiy (FSAR Subsection 2.5.1, Reference 847), and others. As such, Reference 2 observations of possible bathymetric expression of the offshore Las Villas fault are assumed to be irrelevant for assessing the recency of movement on the mostly onshore Las Villas fault as defined by Pardo (FSAR Subsection 2.5.1, Reference 439) and others, but may be relevant for the Nortecubana fault.

d) Address the alignment of epicenters shown on Figure 2.5.1-267 along the Las Villas fault with respect to its tectonic activity. Please plot the uncertainties in event locations and include this information in the discussion.

At a larger scale, Figure 3 shows moderately sparse seismicity from the Phase 2 earthquake catalog (shown on FSAR Figure 2.5.1-267) that may be roughly aligned with Pardo et al.'s (FSAR Subsection 2.5.1, Reference 439) depiction of the Las Villas fault. The Phase 2 catalog is declustered and includes earthquakes of M_w 3 and above. 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 Cuban 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 because the data with which to estimate these errors for each earthquake are not available. According to Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494, p.518), 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 authors appear to be acknowledging the difficulty in associating seismicity with faults due to the limitations in the data. Regarding the locations of pre-instrumental earthquakes in Cuba, Garcia et al. (FSAR Subsection 2.5.1, Reference 489, p. 2,569) 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."

A total of 33 earthquakes from the Phase 2 earthquake catalog are located within approximately 6 miles (10 kilometers) 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 kilometers) northeast of the fault (Figure 3). Cotilla-Rodriguez et al. (FSAR Subsection 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. (FSAR Subsection 2.5.1, Reference 494) suggest that the largest recorded earthquake associated with the Las Villas fault is the M_s 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 (FSAR Subsection 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 kilometers) northeast of this southwest-dipping fault (Figure 3), suggesting a fault other than the Las Villas ruptured during this event. Historical accounts suggest four other earthquakes of less than or equal to MSK intensity V (approximately MMI V) occurred in the vicinity of the Las Villas fault (Cotilla-Rodriguez et al. 2007) (FSAR Subsection 2.5.1, Reference 494). However, the association of these earthquakes with the Las Villas 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.

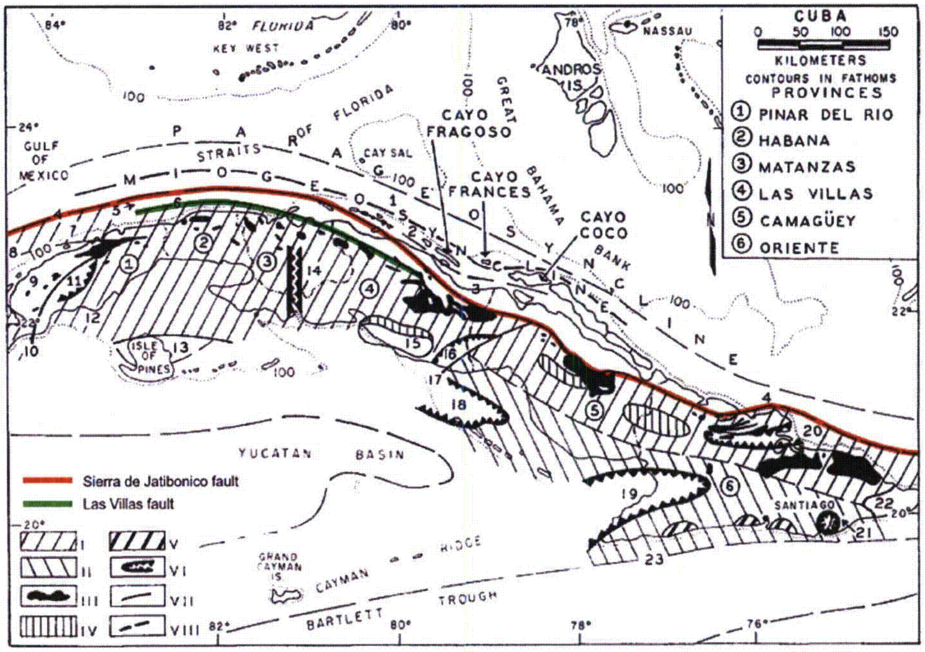


FIG. 1.—Tectonic sketch of Cuba. I–Cretaceous magmatic area (Zaza tectonic unit); II–Tertiary magmatic area (Cauto tectonic unit); III–Upper Cretaceous basic and ultrabasic intrusives; IV–Cretaceous granitoids; V–Tertiary granitoids; VI–Tertiary depressions; VII–deep fault; VIII–boundary between facies-structural zones (tectonic units).

Principal structures (north-south): *paragecosyncline; miogeosyncline:* 1–Old Bahamas Channel depression; 2–Cayo Coco tectonic unit; 3–Remedios tectonic unit; 4 Sierra de Jatibonico deep fault; 5–Las Villas tectonic zone or marginal elevation; *eugeosyncline and intrageanticlines of Zaza tectonic unit:* 6–Las Villas deep fault; 7–Bahia Honda tectonic unit; 8–Consolación del Norte deep fault; 9–Pinar del Rio tectonic unit; 10–Pinar del Río deep fault; 11–Palacios depression; 12–San Diego de los Baños tectonic unit; 13–Isla de Pinos tectonic unit; 14–Cochinos depression; 15–Trinidad tectonic unit; 16–Central basin depression; 17–La Trocha deep fault; 18–Ana María depression; 19–Cauto depression; 20–Nipe depression; 21–Guantánamo depression; 22–Oriente tectonic unit; 23–North Bartlett deep fault.

Figure 1 Tectonic Sketch Map of Cuba, Modified after Reference 1

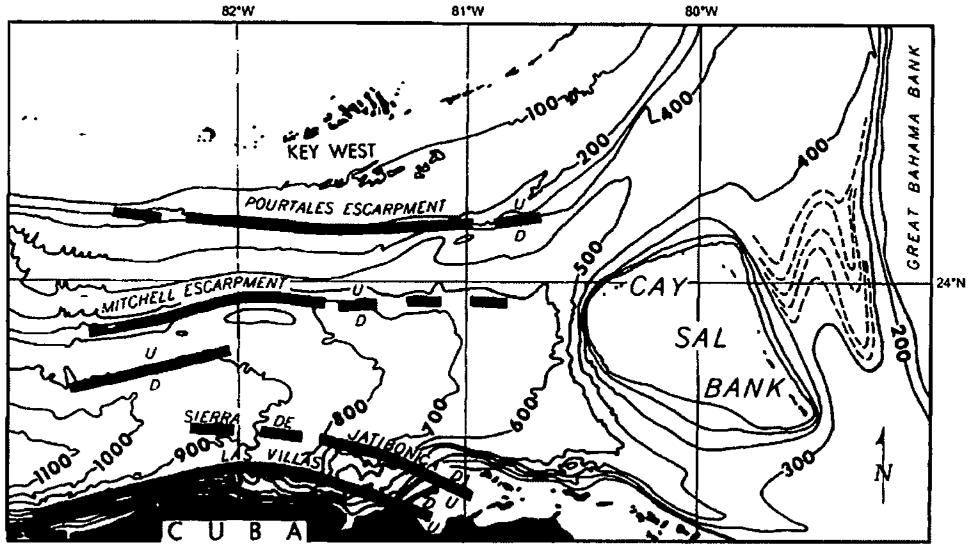


Figure 2 Escarpments and Postulated Faults in the Southern Straits of Florida from Reference 2

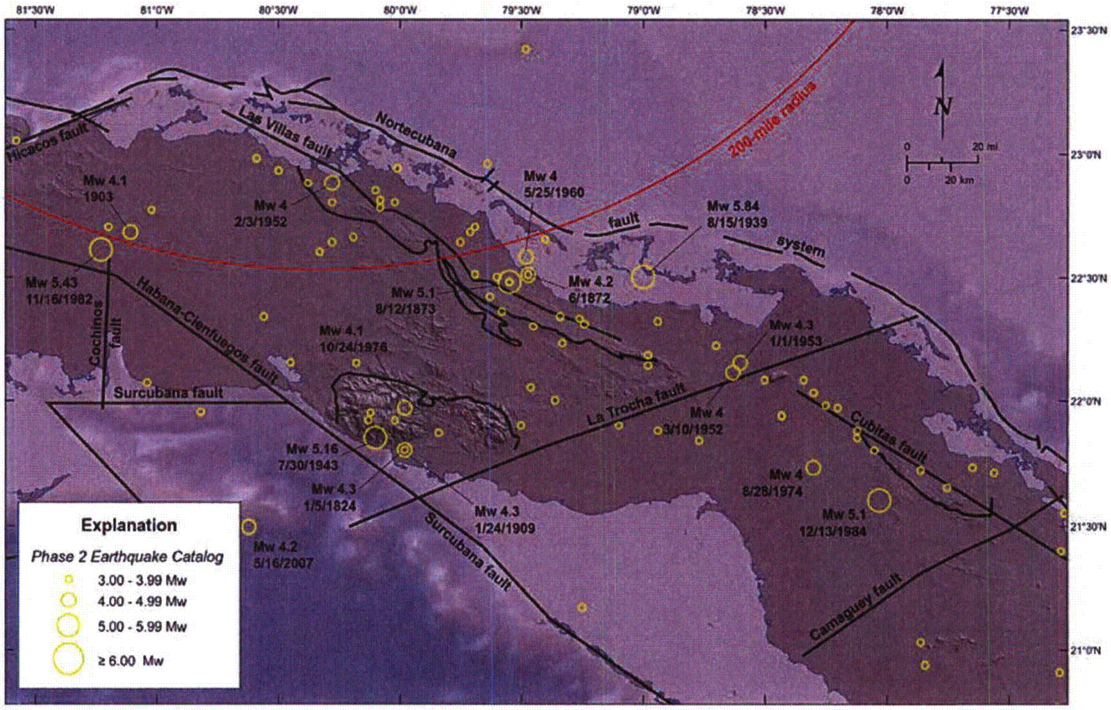
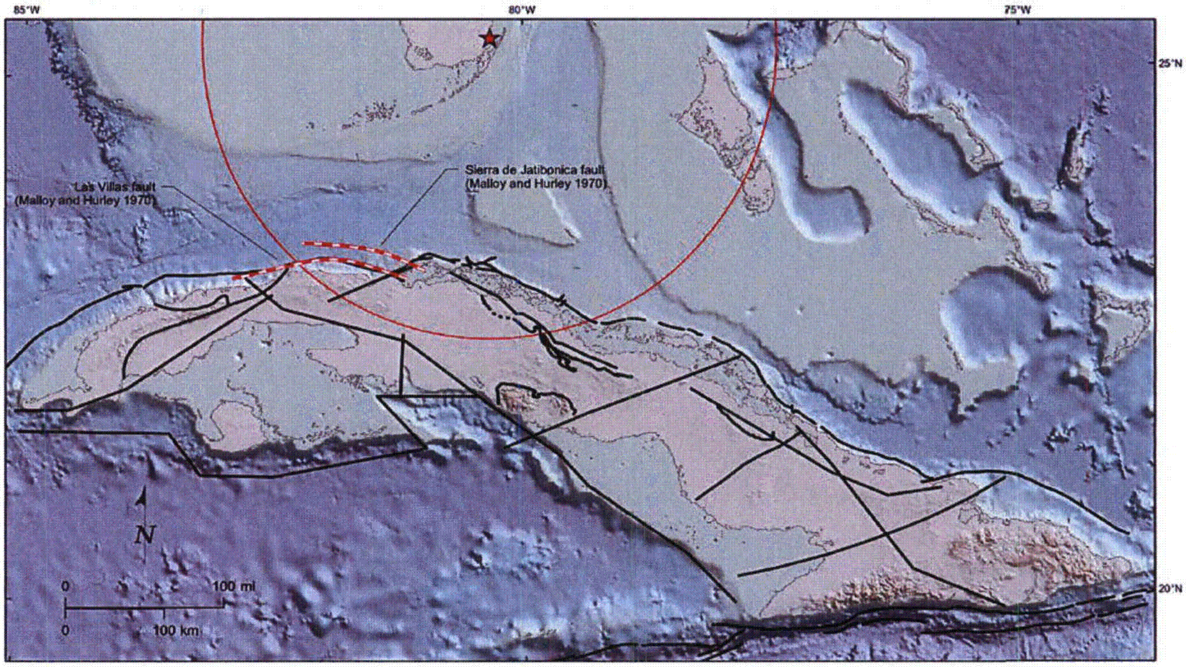


Figure 3 Fault Map of Central Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog



RAI 27 - Malloy and Hurley 1970 (Las Villas fault + Sierra de Jatibonica fault)

Figure 4 Fault Map of Cuba including Postulated Offshore Las Villas and Sierra de Jatibonico Faults from Reference 2

This response is PLANT SPECIFIC.

References:

1. Khudoley, K.M., "Principal features of Cuban geology," *American Association of Petroleum Geologists Bulletin*, Vol. 51, No. 5, pp. 668–677, 1967.
2. Malloy, R.J. and Hurley, R.J., "Geomorphology and geologic structure: Straits of Florida," *Geological Society of America Bulletin*, Vol. 81, pp. 1947–1972, 1970.
3. Oliva Gutierrez, G., Sanchez Herrero, E.A. (directors), *Nuevo Atlas Nacional de Cuba*, Instituto de Geografía de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesia y Cartografía, and the Instituto Geográfico Nacional de España, 220 pp., 1989.
4. Shanzer, E.V., Petrov, O.M., and Franco, G., Sobre las formaciones costeras del Holoceno en Cuba, las terrazas Pleistocenicas de la region Habana-Matanzas y los sedimentos vinculados a ellas, Serie Geologica no. 21, Acadamia de Ciencias de Cuba, Instituto de Geologia y Paleontologia, pp. 1–26, 1975.
5. Toscano, M.A., Rodriguez, E., and Lundberg, J., "Geologic investigation of the late Pleistocene Jaimanitas formation: science and society in Castro's Cuba," *Proceedings of the 9th Symposium on the Geology of the Bahamas and Other Carbonate Regions*, Bahamian Field Station, Ltd., San Salvador, Bahamas. pp. 125–142, 1999.

ASSOCIATED COLA REVISIONS:

COLA revisions as a result of this response related to the Las Villas fault are included in the response to RAI 02.05.01-21.

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: 02.05.01-28 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4, "Seismicity of Cuba", states that two of the largest earthquakes in the central and western region of Cuba occurred in January 1880 (MMI VIII and magnitude 6.0 to 6.6) near the Pinar fault in western Cuba, and February 1914 (Mw 6.2) offshore northeastern Cuba near the Nortecubana fault. However, the FSAR also states that there is no direct evidence that these earthquakes occurred on the Pinar and the Nortecubana faults.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following questions:

a) Provide a thorough discussion of the Pinar fault zone including plotting seismicity, and location uncertainties, with respect to the Pinar fault.

b) Discuss the possible sources of the January 22, 1880 M 6.0 - 6.6 San Cristobal earthquake and clarify what evidence is required to establish a connection between the 1880 earthquake and the Pinar fault. If the 1880 earthquake did not occur on the Pinar fault, please provide a detailed discussion of other faults or tectonic features that might have been responsible for the 1880 event.

c) If the Pinar fault is not active, please discuss geological processes that might lead to preservation of the continuous, linear fault trace through map units of variable ages and lithologies.

FPL RESPONSE:

a) Provide a thorough discussion of the Pinar fault zone including plotting seismicity, and location uncertainties, with respect to the Pinar fault.

The Pinar fault is a northeast-striking, steeply southeast-dipping fault in western Cuba (Figure 1). As mapped by Tait (2009) (FSAR Subsection 2.5.1, Reference 448) and shown in Figure 1, the Pinar fault is located, at its nearest point, approximately 205 miles (330 kilometers) from the Turkey Point Units 6 & 7 site. As mapped by Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489), the Pinar fault is approximately 200 miles (320 kilometers) southwest of the site at its nearest point. As mapped by Cotilla-Rodríguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494), the Pinar fault is approximately 225 miles (360 kilometers) southwest of the site at its nearest point. Rosencrantz (1990) (FSAR Subsection 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 Phase 2 earthquake catalog, which is declustered and includes earthquakes M_w 3 and larger, indicates generally sparse seismicity in the vicinity of the Pinar fault (Figure 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 of the fault in

the Sierra del Rosario mountains and south of the fault in the Palacios Basin. A M_w 6.13 earthquake occurred on January 23, 1880, in western Cuba, leading some to speculate that this earthquake may have occurred on either the Pinar fault (Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489) or the Guane fault (Cotilla-Rodriguez et al.) (2007) (FSAR Subsection 2.5.1, Reference 494) and Cotilla-Rodriguez and Cordoba-Barba (2011). Part b of this response provides an additional description of the 1880 earthquake. The Phase 2 earthquake catalog also 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 1). Earthquake location errors are not shown in Figure 1 because the data with which to estimate these errors for each earthquake are not available. As Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489) suggest, however, locational uncertainties for historical earthquakes in Cuba could be on the order of 9 to 12 miles (15 to 20 kilometers) or more.

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. However, there are conflicting opinions in the literature regarding whether the Pinar fault is active. Garcia et al. (2003) (FSAR Subsection 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" (p. 2571) and may have produced the January 23, 1880, M_w 6.13 earthquake (Figure 1). Cotilla-Rodríguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) describe the Pinar fault as having "very nice relief expression" but conclude it is "inactive" (p. 516). Cotilla-Rodríguez et al. (2007) (FSAR Subsection 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 Las Palacios basin to the southeast (Figure 1).

More recently, 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. They conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" (p. 514) and that it is "subordinate to" (p. 514) the Guane fault. Gordon et al. (1997) (FSAR Subsection 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" (pp. 10,078–10,079).

The Pinar fault is depicted on many regional geologic maps of Cuba at scales of 1:250,000 and smaller. Much of this geologic mapping is consistent with an active Pinar fault. However, these data do not 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 Subsection 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 kilometers) 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.

However, along strike immediately to the south (near Playa de Galafre, on Cuba's southern coast), the fault is covered by the same upper Pliocene to lower Pleistocene unit with no apparent deformation (Pushcharovskiy et al. (1988) [FSAR Subsection 2.5.1, Reference 846]). Along the central portion of the fault near Pinar del Rio, Pushcharovskiy et al.'s (1988) (FSAR Subsection 2.5.1, Reference 846) 1:250,000 scale geologic mapping shows an approximately 4-mile-long (6-kilometer-long) section where weakly cemented upper Pliocene-lower Pleistocene undifferentiated alluvial and marine deposits on the southeast are fault-juxtaposed against the 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 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 Subsection 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 Subsection 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 Subsection 2.5.1, Reference 848) mapping, and unlike Pushcharovskiy et al.'s (1988) (FSAR Subsection 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 Subsection 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 Subsection 2.5.1, Reference 848) show an approximately 1- to 2-mile-long (2- to 4-kilometer-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 Subsection 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 Subsection 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 Subsection 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.

b) Discuss the possible sources of the January 23, 1880 M 6.0 - 6.6 San Cristobal earthquake and clarify what evidence is required to establish a connection between the 1880 earthquake and the Pinar fault. If the 1880 earthquake did not occur on the Pinar fault, please provide a detailed discussion of other faults or tectonic features that might have been responsible for the 1880 event.

As described in part a) of this response, 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 1). The epicenter of this poorly located, pre-instrumental earthquake is approximately 7 miles (11 kilometers) south of the trace of the southeast-dipping Pinar fault and approximately 5 miles (8 kilometers) north of the Guane fault. As Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489) suggest, however, locational uncertainties for historical earthquakes in Cuba could be on the order of 9 to 12 miles (15 to 20 kilometers) or more.

There are conflicting opinions in the recent literature regarding the source of the January 23, 1880, M_w 6.13 San Cristobal earthquake. Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489) suggest that the Pinar fault produced the 1880 earthquake, but they do not provide evidence in support of this statement. Moreover, Garcia et al. (2003) (FSAR Subsection 2.5.1, Reference 489) provide no discussion of the Guane fault. On the other hand, Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) indicate the Pinar fault is "inactive" (p. 516), but do not provide evidence in support of this statement. They suggest that the 1880 earthquake instead occurred on the subsurface Guane fault, which is subparallel to the Pinar fault and is located within the Las Palacios basin to the southeast of the Pinar fault (Figure 1). Cotilla-Rodriguez et al. (2007) (FSAR Subsection 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" (p. 516). Cotilla-Rodríguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) characterize the Guane fault as active based on its possible association with seismicity. They list 19 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 6.13 earthquake. According to 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 kilometers) 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 1).

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 that were made shortly after the earthquake. 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, but rather within the Palacios Basin near the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (2011) cite the damage pattern as evidence that the 1880 earthquake occurred on the Guane fault. However, this is not conclusive evidence that the 1880 earthquake occurred on the Guane fault. Alternatively, if the earthquake occurred on the Pinar fault, the pattern of 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. Nevertheless, Cotilla-Rodriguez and Cordoba-Barba (2011) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" (p. 514) and that the Pinar fault is "subordinate to" (p. 514) the Guane fault.

Based on available information, it is not possible to definitively state whether the 1880 earthquake occurred on the Pinar fault, the Guane 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. Definitive association of this earthquake with a particular fault would require one or more of the following lines of evidence: a well-located hypocenter and focal mechanism for the earthquake that is consistent with the fault orientation, numerous aftershocks that show a well-defined rupture plane, observations of surface rupture or other coseismic surface deformation features, and paleoseismic trench evidence, including well-constrained age data. A thorough review of literature and geologic maps performed for the Turkey Point Units 6 & 7 project failed to reveal such data for the 1880 earthquake.

c) If the Pinar fault is not active, please discuss geological processes that might lead to preservation of the continuous, linear fault trace through map units of variable ages and lithologies.

A continuous, linear fault trace on a geologic map can be the result of: (1) the continuity of the fault (e.g., a mature, well-developed fault versus an immature, highly discontinuous fault zone), (2) the dip of the fault, and (3) the scale at which the fault mapping was performed and is presented. For example, a continuous, high-angle fault will appear very linear on a coarse-scale map, whereas a discontinuous, low-angle fault on a fine-scale map will appear as more sinuous or irregular.

The Sierra del Rosario in western Cuba displays a prominent and fairly linear southeast-facing mountain front, suggesting recent or ongoing uplift, possibly associated with the Pinar fault. However, the geomorphic expression of this mountain front is not conclusive evidence for an active Pinar fault. Recurrent normal faulting along the southeastern margin of the Sierra del Rosario could have formed the observed relatively linear mountain front. Gordon et al. (1997) (FSAR Subsection 2.5.1, Reference 697) describe multiple phases of deformation in western Cuba in general and on the Pinar fault in particular. Their deformation Phase IV on the Pinar fault is characterized by early Miocene normal faulting.

It is possible that the present-day morphology of the Sierra del Rosario front reflects this Miocene deformation phase. The southeast-facing linear mountain front could also be the result of differential erosion of varying rock types juxtaposed by the Pinar fault. As described in part a) of this response, the Pinar fault generally separates Jurassic-age limestones and carbonate rocks on the northwest from Paleogene to Miocene rocks and younger deposits on the southeast. It is possible that the present-day morphology of the Sierra del Rosario front reflects a contrast in rock resistance to erosion across the Pinar fault. The southeast-facing linear mountain front could also be the result of differential erosion along southeast-facing dip-slopes. The dip-slope hypothesis is consistent with bedding orientation information shown on Pushcharovskiy et al.'s (1988) 1:250,000 scale geologic mapping, which indicates generally steeply southeast-dipping beds within Jurassic carbonate rocks along the central section of the Pinar fault. This central section of the fault is coincident with the geomorphically best-expressed section of the fault (Figure 1).

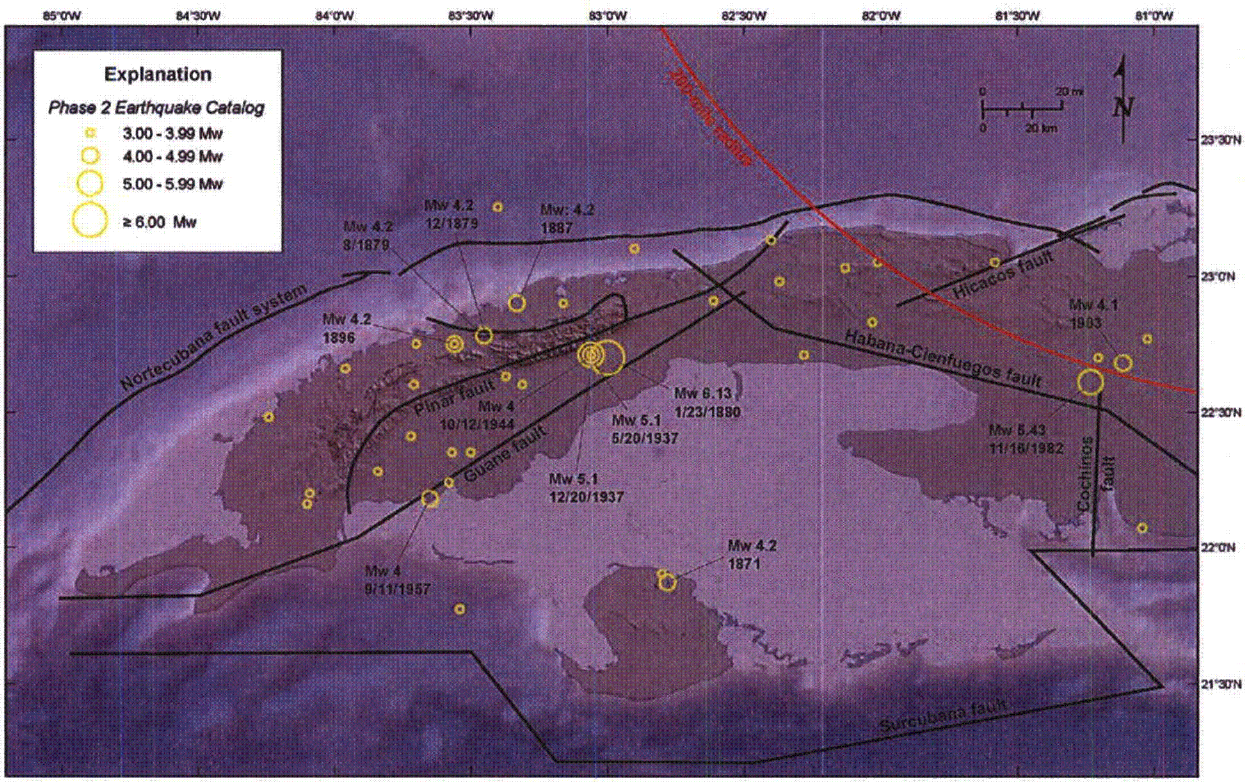


Figure 1 Fault Map of Western Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog

This response is PLANT SPECIFIC.

References:

1. Cotilla-Rodriguez, M.O. and Cordoba-Barba, D., 2011. Study of the earthquake of the January 23, 1880, in San Cristobal, Cuba and the Guane Fault, *Physics of the Solid Earth*, Vol. 47, No. 6, pp. 496–518.
2. Oliva Gutierrez, G. and Sanchez Herrero, E.A. (directors), 1989. *Nuevo Atlas Nacional de Cuba*, Instituto de Geografía de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesia y Cartografía, and the Instituto Geográfico Nacional de España, 220 pp.

ASSOCIATED COLA REVISIONS:

The COLA will be revised to include information provided in this response pertaining to the Pinar fault. These COLA revisions are provided as part of the response to RAI 02.05.01-21.

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: 02.05.01-29 (eRAI 6024)

FSAR Figure 2.5.1-251, "Lithostratigraphic Map of Cuba", depicts the Matanzas fault zone within the site region; however, the staff notes that the Matanzas fault zone is not discussed in the FSAR.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following questions:

a) Provide a discussion of the Matanzas fault zone in the FSAR, including a larger-scale map showing the fault trace.
b) Clarify if there is a relationship between the Matanzas fault zone and elevated Pleistocene terraces along the coast near Matanzas.
c) Discuss the relationship of the Matanzas fault zone to nearby seismicity.

FPL RESPONSE:

a) Provide a discussion of the Matanzas fault zone in the FSAR, including a larger-scale map showing the fault trace

The terms Matanzas fault and Hicacos fault refer to the same geologic feature. Most newer publications use the term Hicacos fault, and the FSAR follows this convention. The Hicacos fault is discussed in FSAR Subsection 2.5.1.1.1.3.2.4 and is shown in FSAR Figure 2.5.1-247. FSAR Figure 2.5.1-251 is a reproduction of Stanek et al.'s (2009) Figure 2 (FSAR Subsection 2.5.1, Reference 769), which labels this fault as Matanzas fault. The text of FSAR Subsection 2.5.1.1.1.3.2.4 and FSAR Figure 2.5.1-251 will be modified to indicate that Matanzas fault and Hicacos fault are two names for the same geologic feature. Figures 1 and 2 provide larger-scale maps of the Hicacos fault trace.

Garcia et al. (2003) (FSAR Subsection 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" (FSAR Subsection 2.5.1, Reference 489, p. 2571). They state that the "earthquakes reported in Matanzas and more recently in the Varadero-Cardenas area are associated with this structure" (FSAR Subsection 2.5.1, Reference 489, p. 2571). However, no additional information regarding these earthquakes is provided.

Cotilla-Rodríguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) characterize the Hicacos fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (2007) (FSAR Subsection 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" (FSAR Subsection 2.5.1, Reference 494, p. 516). Further to the west-southwest, they indicate that the Hicacos fault is "weakly represented"

(FSAR Subsection 2.5.1, Reference 494, p. 516) in the geomorphology. Cotilla-Rodríguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) indicate a lack of instrumental seismicity associated with the Hicacos fault but suggest that eight earthquakes of MSK intensity III–V (approximately MMI III–V) are located in the general vicinity of the Hicacos fault. They indicate two additional earthquakes in 1854 and 1880 occurred somewhere near the Hicacos fault that were "noticeable without specification [of intensity]" (FSAR Subsection 2.5.1, Reference 494, p. 516). The Phase 2 earthquake catalog, which is declustered and includes earthquakes M_w 3 and larger, indicates very sparse, minor-magnitude seismicity located near the trace of the Hicacos fault (Figure 1). 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 km) southwest of, the mapped fault trace. Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Case and Holcombe's (1980) (FSAR Subsection 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 Subsection 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 (upper panel of Figure 2). 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 Subsection 2.5.1, Reference 848) inset map of fault ages in Cuba. However, they indicate a Mesozoic age for an unnamed fault in the vicinity of the northeastern-most portion of the Hicacos fault. Pushcharovskiy et al.'s (1988) (FSAR Subsection 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, but their mapping does not extend this fault as far northeast as the north coast of Cuba. However, 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 Subsection 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 1 that terminates to the southwest at Cuba's southern coast (middle panel of Figure 2).

The Hicacos fault is depicted differently on various maps from the *Nuevo Atlas Nacional de Cuba* (Reference 2). The 1:1,000,000 scale geologic map from this atlas (Reference 2, 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 (lowest panel of Figure 2). This unnamed fault is mapped within lower to middle Miocene-age deposits (shown as bright yellow in the lowest panel Figure 2) and does not appear to cut Holocene-age deposits (shown by the gray stippled pattern in the lowest panel of Figure 2) near Matanzas at the northeastern end of the fault. The 1:1,000,000 scale geomorphic map from this atlas (Reference 2, 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 2,

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 northeasternmost 20 miles (35 kilometers) of this feature are shown as a dashed line. The 1:2,000,000 scale neotectonic map from this atlas (Reference 2, 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, along the narrow peninsula near Matanzas, and offshore where it is terminated by an unnamed fault that likely is the Nortecubana fault.

b) Clarify if there is a relationship between the Matanzas fault zone and elevated Pleistocene marine terraces along the coast near Matanzas

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 or absence of tectonic deformation. Ducloz (Reference 1) and Shanzer et al. (Reference 4) provide observations of three Pleistocene-age terraces in this region. The first (youngest) of these is the Terraza de Seboruco terrace, which is currently a few meters above sea level. Shanzer et al. (Reference 4) document heights of between 3 and 5 meters above sea level for this terrace. The second terrace, the Terraza de Yucayo (Reference 1), is found at 8–10 meters above sea level near Havana, and between 15–25 meters above sea level in the northwest portion of Matanzas (Reference 4). The third terrace, the Terraza de Rayonera, is found at 20–25 meters above sea level near Havana and at no less than 23–25 meters above sea level in the northwest portion of Matanzas (Reference 1). Shanzer et al. (Reference 4) note a minimum height of 35–40 meters above sea level for this terrace in Matanzas. Both Ducloz (Reference 1) and Shanzer et al. (Reference 4) speculate that Pleistocene-age terraces in this region may have formed as the result of both tectonic uplift and global fluctuations in sea level. Shanzer et al. (Reference 4) speculate that the lower terrace elevations near Havana could be the result of differential tectonic uplift between Havana and Matanzas, although no causative faults are identified by the authors. Alternatively, these differences in elevation could be the result of erosion or miscorrelation of surfaces (Reference 5).

More recent studies conclude that ongoing tectonic uplift is not required to explain the present elevations of terraces in northern Cuba near the Hicacos fault. Toscano et al.'s (Reference 5) radiometric age dating of coral samples collected from the Terraza de Seboruco terrace indicates this surface formed at approximately 120–140 ka. Based on extensive literature review performed for this project, to FPL's knowledge, the Terraza de Seboruco is the only terrace in northern Cuba for which radiometric age control is available. Based on these ages, Toscano et al. (Reference 5) associate the Terraza de Seboruco terrace with the global Substage 5e sea level high-stand at approximately 122 ka.

Toscano et al. (Reference 5) 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 5) conclude that "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba" (Reference 5, p. 137). Similarly, Pedoja et al. (Reference 3) investigated late Quaternary coastlines

worldwide and observe minor uplift relative to sea level of approximately 0.2 millimeters per year, even along passive margins, outpacing eustatic sea level decreases by a factor of four. They suggest that the Substage 5e terrace in the Matanzas area has been uplifted at an average rate that, when accounting for eustatic changes in sea level, ranges from approximately 0.00 to 0.04 millimeters per year 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 3) data allow for an uplift rate at Matanzas of approximately 0.06 millimeters per year over the last approximately 122 ka, following this "conservative" (Reference 3, 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 (Reference 5 and Reference 3), 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.

c) Discuss the relationship of the Matanzas fault zone to nearby seismicity

As in most of Cuba, the association of seismicity with individual faults in the Matanzas Bay area is problematic due to the uncertainties associated with the locations of both earthquakes and mapped faults. Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) indicate that, due to the lack of seismic stations in the area, there are no instrumental records of earthquakes on the Hicacos fault and that there are no earthquake focal mechanisms associated with this fault. Cotilla-Rodriguez et al. (2007) (FSAR Subsection 2.5.1, Reference 494) do, however, suggest that 10 intensity-based epicenters may be associated with the Hicacos fault. They suggest that eight earthquakes of MSK intensity III–V (approximately MMI III–V) are located in the general vicinity of, and may have occurred on, the Hicacos fault in 1812, 1843, 1852, 1854, 1914 (two earthquakes), 1974, and 1978. Additionally, they suggest two other earthquakes with intensity "noticeable without specification" (FSAR Subsection 2.5.1, Reference 494, p. 516) that may also have occurred on the Hicacos fault in 1854 and 1880.

The Phase 2 earthquake catalog, which is declustered and includes earthquakes M_w 3 and larger, indicates very sparse, minor-magnitude seismicity associated with the trace of the Hicacos fault (Figure 1). 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 from the Phase 2 earthquake catalog occurred in 1777 with M_w 3.7, located on strike with, but approximately 7 miles (11 kilometers) southwest of, the mapped fault trace. It is possible that at least some of these minor-magnitude earthquakes occurred on the Hicacos fault. It is also possible that these earthquakes occurred on some other fault or faults in the region. In the absence of well-located hypocenters, focal mechanisms, and surface faulting for these earthquakes, these earthquakes cannot be definitively attributed to a particular fault or faults.

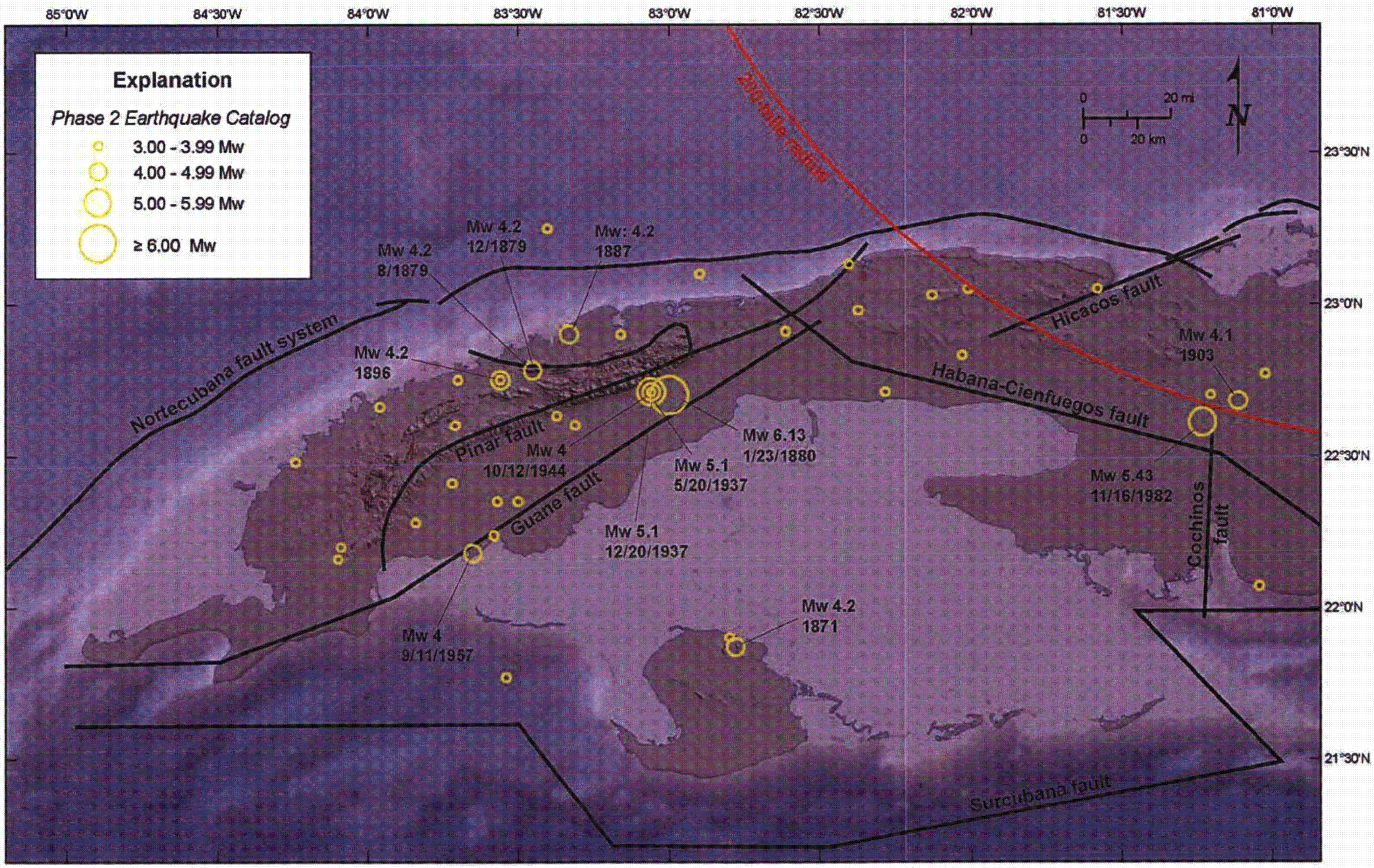


Figure 1 Fault Map of Western Cuba Showing Earthquakes from the Phase 2 Earthquake Catalog

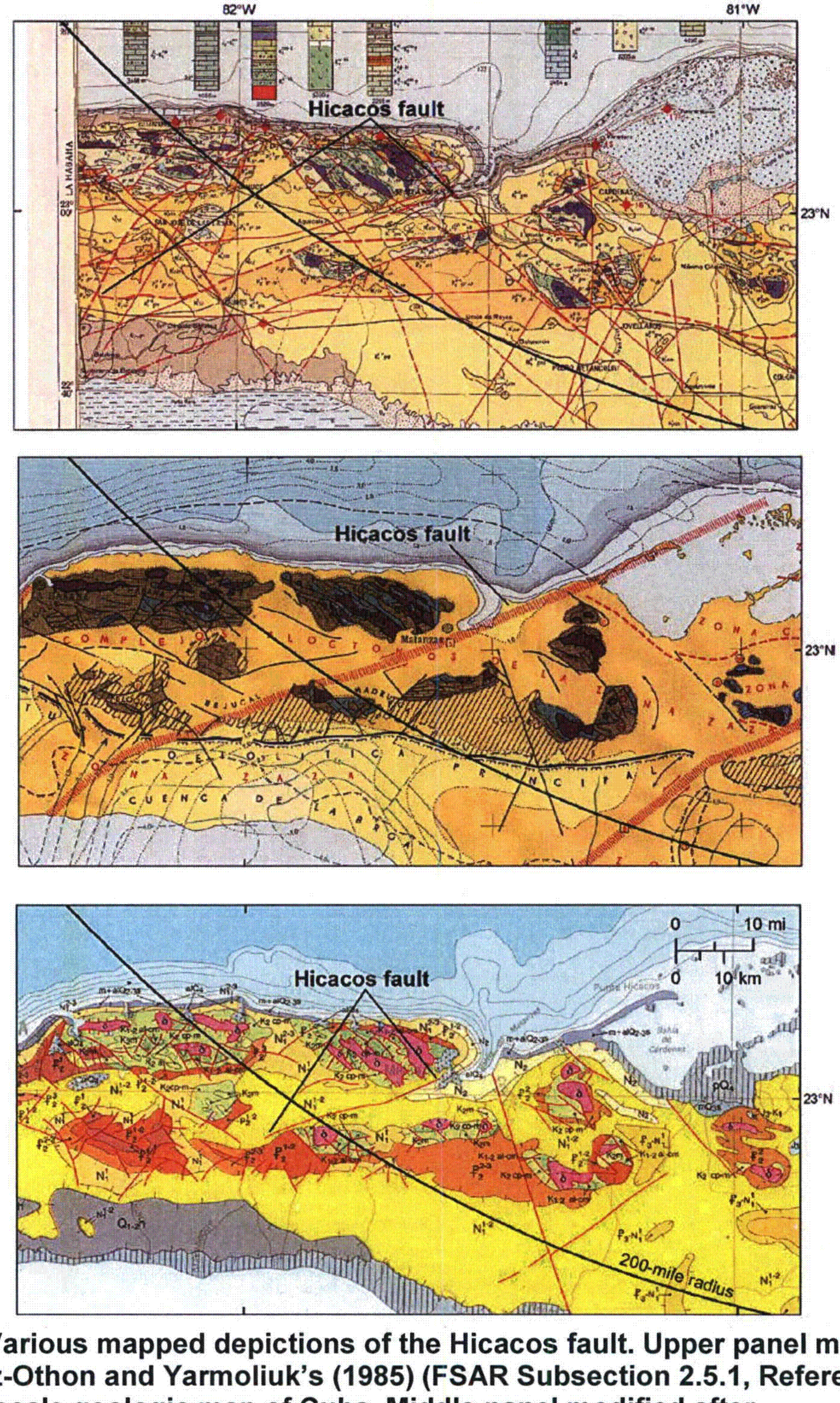


Figure 2 Various mapped depictions of the Hicacos fault. Upper panel modified after Perez-Othon and Yarmoliuk's (1985) (FSAR Subsection 2.5.1, Reference 848) 1:500,000 scale geologic map of Cuba. Middle panel modified after Pushcharovskiy's (1989) (FSAR Subsection 2.5.1, Reference 847) 1:500,000 scale tectonic map of Cuba. Lower panel modified after the 1:1,000,000 scale geologic map from the 1989 *Nuevo Atlas Nacional de Cuba* (Reference 2).

This response is PLANT SPECIFIC.

References:

1. Ducloz, C., Etude geomorphologique de la region de Matanzas, Cuba avec une contribution a l'etude des depots quaternaires de la zone Habana-Matanzas, Archives des Sciences, Societe de Physique et d'Histoire Naturelle de Geneve, Imprimerie Kundig, 402 pp., 1963.
2. Oliva Gutierrez, G., and Sanchez Herrero, EA. (directors), Nuevo Atlas Nacional de Cuba, Instituto de Geograffa de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesiay Cartograffa, and the Instituto Geografico Nacional de Espana, 220 pp., 1989.
3. Pedoja, K., Husson, L., Regard, V., Cobbold, P.R., Ostanciaux, E., Johnson, M.E, Kershaw, S., Saillard, M., Martinod, J., Furgerot, L., Weill, P., and Delcaullau, B., "Relative sea-level fall since the last interglacial state: Are coasts uplifting worldwide?," Earth Science Reviews, v. 108, pp. 1-15,2011.
4. Shanzer, EV., Petrov, a.M., and Franco, G., "Sobre las formaciones costeras del Holoceno en Cuba, las terrazas Pleistocenicas de la region Habana-Matanzas y los sedimentos vinculados a elias," Serie Geologica No. 21, Acadamia de Ciencias de Cuba, Instituto de Geologia y Pa]eontologia, pp. 1-26, 1975.
5. Toscano, M.A., Rodriguez, E, and Lundberg, J., "Geologic investigation of the late Pleistocene Jaimanitas fonnation: science and society in Castro's Cuba," Proceedings of the 9th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Bahamian Field Station, Ltd., San Salvador, Bahamas. p. 125-142, 1999.

ASSOCIATED COLA REVISIONS:

A discussion of marine terraces will be included in a future update to the FSAR, as detailed in the response to RAI 02.05.01-22.

The discussion of Cuban faults in FSAR Subsection 2.5.1.1.1.3.2.4 will be revised in a future update to the FSAR, as detailed in the response to RAI 02.05.01-21.

The footnote to FSAR Table 2.5.1-204 will be revised in a future update to the FSAR.

c) Mapa Geologico de la Republica de Cuba (Reference 848) ~~(Figure 2.5.1-288)~~

The following note will be added to FSAR Figure 2.5.1-251 in a future update of the FSAR.

Note: The Matanzas fault shown here is the same structure as the Hicacos fault shown on Figure 2.5.1-247.

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: 02.05.01-30 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4, the "Seismicity of Cuba" passage, states that "In summary, many faults have been mapped on the island of Cuba...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." The staff notes that this statement appears to contradict other statements in FSAR Sections 2.5.1.1.1.3.2.4 and FSAR 2.5.1.1.2.1.3 that suggest recent tectonic deformation such as:

- "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' and may have produced the January 22, 1880 M 6.0 earthquake."
- "...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 ...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."
- "The La Trocha fault strikes east-northeast in Cuba, within the Greater Antilles deformed belt province, and continues southwest as the Trans Basin fault across the Yucatan Basin (Figure 2.5.1-286)....the onshore La Trocha fault (in the Greater Antilles deformed belt geologic province) is considered Pliocene- Quaternary seismoactive by Cotilla-Rodríguez et al. (Reference 494), who correlate five macroseismic events with the fault. Additionally, only two Phase 2 earthquake catalog earthquakes of $M_w \geq 7$ are located within the Yucatan Basin, one of which (M_w 7.7) is located well within the province margins and nearly coincident with the Trans Basin fault mapped by Rosencrantz (Reference 529)."

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please clarify the statement: "...the timing of activity for some of the regional structures and largely indicates that the Pleistocene and younger strata are undeformed throughout the island" within the context of the mentioned FSAR statements.

FPL RESPONSE:

The statements in the FSAR regarding potentially active faults in Cuba reflect the ambiguous and sometimes contradictory information available in the published literature and geologic mapping of the island. Based on available information, there is uncertainty

regarding which faults in intraplate Cuba are active. For example, 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. However, there are conflicting opinions in the literature regarding whether the Pinar fault is active. Garcia et al. (FSAR Subsection 2.5.1, Reference 489, p. 2571) 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, Mw 6.13 earthquake. Cotilla-Rodrfguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 516) describe the Pinar fault as having "very nice relief expression" but conclude it is "inactive." Cotilla-Rodriguez et al. (FSAR Subsection 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 Las Palacios basin to the southeast.

Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494) characterize the Cubitas fault as active based on its possible association with seismicity. However, the association of earthquakes with the Cubitas 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. Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494) also describe large scarps associated with this fault but do not provide additional descriptions of the scarps. Van Hinsbergen et al. (FSAR Subsection 2.5.1, Reference 500) describe approximately 650 feet (200 m) of uplift associated with the Cubitas Hills that postdates 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 (FSAR Subsection 2.5.1, Reference 500). Pushcharovskiy et al. (FSAR Subsection 2.5.1, Reference 846) do not label the Cubitas fault on their 1:250,000 scale geologic map of Cuba. Pushcharovskiy (FSAR Subsection 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 inset map of fault ages in Cuba (FSAR Subsection 2.5.1, Reference 848, Figure 2). However, they indicate a Mesozoic age for an unnamed fault in the vicinity of the Cubitas fault.

Garcia et al. (FSAR Subsection 2.5.1, Reference 489) provide minimal discussion of the La Trocha fault. They 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" (FSAR Subsection 2.5.1, Reference 489, p. 2571). Cotilla-Rodriguez et al. (FSAR Subsection 2.5.1, Reference 494) assign the La Trocha fault an age of Pliocene-Quaternary and also suggest a possible association with seismicity. However, the association of earthquakes with the La Trocha 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. The La Trocha fault is not shown on Pushcharovskiy et al. 's (FSAR Subsection 2.5.1, Reference 846) 1:250,000 scale geologic map of Cuba.

Review of Pushcharovskiy et al. 's (FSAR Subsection 2.5.1, Reference 846) maps in the vicinity where Cotilla-Rodriguez et al. (FSAR Subsection 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 (FSAR Subsection 2.5.1, Reference 847) tectonic map of Cuba, however, clearly depicts and labels the La Trocha fault. 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 (FSAR Subsection 2.5.1, Reference 848) inset map of fault ages in Cuba. However, they indicate a Neogene-Quaternary age for an unnamed fault in the vicinity of the La Trocha fault.

The FSAR will be revised to clarify the issue of timing of activity for faults in Cuba. Specifically, FSAR Subsection 2.5.1.1.1.3.2.4 will be modified by deleting the sentence "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 mm per year of deformation is occurring within Cuba relative to North America (References 502 and 503)."

This response is PLANT SPECIFIC.

References:

None

ASSOCIATED COLA REVISIONS:

The text in FSAR Subsection 2.5.1.1.1.3.2.4, 22nd paragraph under the subheading Other Cuban Structures will be revised as follows in a future update of the FSAR:

> 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.

Additionally, the COLA will be revised to include information provided in this response pertaining to the Pinar, Cubitas, and La Trocha faults. These COLA revisions are provided as part of the response to RAI 02.05.01-21.

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: 02.05.01-31 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4, the "Seismicity of Cuba" passage, states that available geologic mapping (at 1:250000 and1:500000 scales) "largely indicates that the Pleistocene and younger strata are undeformed throughout the island." The staff notes that the same paragraph in the FSAR states that, "The scales of available geologic mapping do not provide sufficient detail to adequately assess whether or not individual faults in Cuba can be classified as capable tectonic structures." These two statements are seemingly contradictory.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Clarify if available geologic mapping in Cuba is suitable for neotectonic fault evaluation.

b) If available geologic mapping is insufficient for the assessment of active faulting as stated above, clarify the first statement that mapping "largely indicates that the Pleistocene and younger strata are undeformed throughout the island."

c) If available geologic mapping is insufficient for the assessment of active faulting, as stated above, further discuss your fault-activity-conclusions based on small scale mapping.

FPL RESPONSE:

a) Clarify if available geologic mapping in Cuba is suitable for neotectonic fault evaluation.

Available geologic and tectonic maps for Cuba generally are from the 1980s and are small in scale, including, for example:

- Case and Holcombe's (1980) (FSAR Reference 2.5.1-480) 1:2,500,000 scale map of the Caribbean;
- Perez-Othon and Yarmoliuk's (1985) (FSAR Reference 2.5.1-848) 1:500,000 scale geologic map of Cuba;
- Pushcharovskiy et al.'s (1988) (FSAR Reference 2.5.1-846) 1:250,000 scale geologic map of Cuba;
- Pushcharovskiy's (1989) (FSAR Reference 2.5.1-847) 1:500,000 scale tectonic map of Cuba; and
- Various geologic, tectonic, and lineament maps from the 1989 *Nuevo Atlas Nacional de Cuba* (Reference 1) that range in scale from 1:1,000,000 to 1:2,000,000.

Pardo (2009) (FSAR Reference 2.5.1-439) presents an overview of the stratigraphy, tectonics, and geologic structures of Cuba, written from the perspective of a hydrocarbon research and exploration geologist. Regarding the quality of available geologic and tectonic mapping of Cuba, Pardo (2009) (FSAR Reference 2.5.1-439, p. 311) states:

> *[T]he available material generally only shows very small-scale drawings; generalized very small-scale cross sections and maps are characteristic of Cuban structural literature.*
>
> *The Tectonic Map of Cuba 1:500,000 (Pushcharovsky et al., 1989)* [FPL COLA FSAR Reference 2.5.1-847] *is a good summary map. From an interpretive point of view, it shows only the case in which the basic igneous-volcanic province originated between metamorphic massifs and the North American continent. This map, as well as the older 1985 geologic map (Cuba, 1985a)* [FPL COLA FSAR Reference 2.5.1-848], *shows several large crustal faults or deep fractures cutting across all structural trends. The bases for postulating these discontinuities are many: topography, gravity, magnetics, crustal seismic, and surface geology. These deep fractures might well exist, but most of them are very questionable. They date from the 1960s when Soviet experts, who did not believe in a thrusted orogenic belt origin for the island, invoked classic Soviet-era block faulting and in-situ magmatism (a la Beloussov [Khudoley, 1967; Khudoley and Meyerhoff, 1971]). Subsequently, most of these crustal fractures have disappeared from the literature, but some of them remain on the maps. Most such fractures probably do not exist or are not applicable in unraveling the geologic history of Cuba.*

Based on the small scales of these available maps, they are not well suited for use in neotectonic evaluations of individual faults in Cuba. However, these are the best-available maps that cover the whole of Cuba. These geologic and tectonic maps provide information on differing interpretations of lengths and locations for faults in Cuba, but do not necessarily provide clear geologic map relations and cross-cutting information that can be used to infer the ages of these faults. 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.

b) If available geologic mapping is insufficient for the assessment of active faulting as stated above, clarify the first statement that mapping "largely indicates that the Pleistocene and younger strata are undeformed throughout the island".

The statements in the FSAR regarding potentially active faults in Cuba reflect the ambiguous and sometimes contradictory information available in the published literature and geologic mapping of the island. Based on available information, there is uncertainty regarding which faults in intraplate Cuba are active. The FSAR will be revised to clarify the issue of timing of activity for faults in Cuba and the usefulness of the available small scale geologic maps for the assessment of potentially active faults. Specifically, these geologic maps largely indicate that Pleistocene and younger strata throughout intraplate Cuba are undeformed. Given their coarse resolution, however, observations made from these maps alone are insufficient to characterize whether individual faults in intraplate Cuba are Quaternary active.

c) If available geologic mapping is insufficient for the assessment of active faulting, as stated above, further discuss your fault-activity-conclusions based on small scale mapping.

Conclusions regarding fault activity in intraplate Cuba are based on the best available data, including assessment of small scale (1:250,000 to 1:2,000,000) geologic and tectonic maps of Cuba, published literature (e.g., Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494), and the possible association of mapped faults with seismicity, including earthquakes included in the Phase 2 earthquake catalog. It is possible that some of the faults mapped in intraplate Cuba could be active or capable tectonic sources. However, there are no definitive data to support which, if any, of the faults mapped in intraplate Cuba are active or capable tectonic sources. Therefore, based on limitations for evaluating neotectonic activity in intraplate Cuba, the seismic source characterization developed for the Turkey Point Units 6 & 7 project utilizes an areal source zone for Cuba instead of discrete fault sources.

This response is PLANT SPECIFIC.

References:

1. Oliva Gutierrez, G., Sanchez Herrero, E.A. (directors), *Nuevo Atlas Nacional de Cuba*, Instituto de Geografía de la Academia de Ciencias de Cuba, the Instituto Cubano de Geodesia y Cartografía, and the Instituto Geográfico Nacional de España, 220 pp., 1989.

ASSOCIATED COLA REVISIONS:

The COLA will be revised to include information provided in this response. These COLA revisions are provided as part of the response to RAI 02.05.01-21.

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: 02.05.01-32 (eRAI 6024)

FSAR Section 2.5.1.1.1.3.2.4 states: "In an effort to explain seismicity that continues on intraplate Cuba, 12 faults on the island of Cuba have been designated as 'active' (Reference 494), but that published analysis does not provide sufficient information to conclude that a structure is capable". The staff notes that this statement does not corroborate conclusions made by published experts in the area (e.g. Cotilla-Rodríguez et al. 2007, Garcia et al. 2003) regarding active faults in Cuba.

In order for the staff to assess the tectonic and structural features within the site region and in accordance with 10 CFR 100.23, please address the following:

a) Clarify the distinction between active and capable fault.

b) If the 12 faults are not capable tectonic sources, please discuss what is the structure or source of the seismicity of northern Cuba in light of Cotilla-Rodríguez et al. 2007 and Garcia et al. 2003 alternative conclusions.

FPL RESPONSE:

The terms "capable tectonic source" and "active fault" appear in FSAR Subsection 2.5.1.1.1.3.2.4. These terms have similar, but not identical, definitions. The term capable tectonic source is defined in RG 1.208 and is used throughout the FSAR. The term active fault in this context is defined by Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) and applied by them to 12 faults in Cuba.

Part (a) of this response defines these two terms and clarifies the distinction between them. Part (b) of this response provides discussion of whether or not faults in northern Cuba satisfy one or both of these definitions and describes the lack of knowledge regarding the sources of seismicity in northern Cuba.

<u>(a) Clarify the distinction between an active and a capable fault.</u>

The FSAR adopts the definition of a capable tectonic source as presented in RG 1.208. According to RG 1.208, a capable tectonic source is a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the earth's surface in the present seismotectonic regime. A capable tectonic source is described by at least one of the following characteristics:

- Presence of surface or near-surface deformation of landforms or geologic deposits of a recurring nature within the last approximately 500,000 years or at least once in the last approximately 50,000 years.
- A reasonable association with one or more moderate-to-large earthquakes or sustained earthquake activity that is usually accompanied by significant surface deformation.

- A structural association with a capable tectonic source that has characteristics of either item above, such that movement on one could be reasonably expected to be accompanied by movement on the other.

The term active fault is defined differently by different researchers and regulatory agencies. Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) define a fault as active if it satisfies criteria spelled out by various other published sources, including the definition of an active fault from Hatter et al. (1993) and the definition of a Type I fault from NUREG-1451. Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494, pp. 507-508) summarize Hatter et al.'s (1993) definition of an active fault as follows:

> *"On the basis of Hatter et al. (1993) a fault, fault zone or fault system are considered seismically active if one or several of the following criteria are satisfied: a) direct observation of faulting in connection with at least one earthquake; b) occurrence of well-located earthquake or microearthquake activity close to a known fault. In addition, a well-constrained fault-plane solution with one nodal plane showing the same orientation and sense of displacement as the fault is required; c) close correspondence of orientation of nodal planes and senses of displacement of well-constrained fault-plane solutions to the type and orientation of young faults or fault zones observed in the epicentral region; d) mapping of hypocenters by high-precision location of individual events of local clusters of earthquakes displaying almost identical signal forms, controlled by well-constrained fault-plane solution(s)."*

To FPL's knowledge, however, the reference Hatter et al. (1993) does not exist. The full citation provided by Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494, pp. 520-521) for Hatter et al. (1993) is:

> Hatter, K.M., Michael, N., Richard, L.D., 1993. *Guidelines for US database and map for the maps of major active faults, Western Hemisphere, International Lithosphere Program (ILP),* Project II-2. US Department of Interior, US Geological Survey, 45 p.

For this response, FPL assumes that Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) intended to cite Haller et al. (1993) (Reference 1):

> Haller, K.M., Machette, M.N., and Dart, R.L., 1993. *Maps of major active faults, Western Hemisphere, International Lithosphere Program (ILP), Project II-2,* Guidelines for U.S. database and map, U.S. Geological Survey Open-File Report 93-338, 45 p.

FPL believes this is a reasonable assumption, given the similarity in the names and initials of the authors in each citation, the similarity in the titles of each citation, and the identical number of pages listed for each reference. Despite the quotation above from Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) in which they summarize "Hatter et al.'s (1993)" definition of an active fault, Haller et al. (1993) (Reference 1) do not provide this (or any) definition for an active fault in their report. Thus, the source of "Hatter et al.'s

(1993)" definition for an active fault remains unclear. Regardless of the origin of the definition of the term active fault provided by Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494), however, part (b) of this response provides discussion of whether or not any faults in northern Cuba satisfy the criteria presented.

Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) also indicate that their definition of the term active fault is based on that provided by NUREG-1451. However, NUREG-1451 does not provide a definition for an active fault as Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494, p. 507) suggest. Instead, NUREG-1451 provides rationale for distinguishing between Type I, Type II, and Type III faults. NUREG-1451 defines a Type I fault as a fault that: (1) is subject to displacement; and (2) may affect the design and/or performance of structures important to safety. To be considered a Type I fault, a fault must show evidence for Quaternary displacement. In cases where the Quaternary record is incomplete or unclear, faults are considered subject to displacement if they satisfy one or more of the following criteria:

- Have instrumentally determined seismicity with records of sufficient precision that suggest a direct relationship with a candidate fault.
- Have a structural relationship (i.e., displacement on one fault could cause displacement on another) to a fault that meets one or more of the other criteria.
- Have an orientation that makes them subject to displacement in the existing stress field.

Although NUREG-1451 does not equate a Type I fault with an active fault, Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) seemingly treat these terms as synonymous. Part (b) of this response provides discussion of whether or not any faults in northern Cuba satisfy the NUREG-1451 criteria for a Type I fault.

(b) If the 12 faults are not capable tectonic sources, please discuss what is the structure or source of the seismicity of northern Cuba in light of Cotilla-Rodríguez et al. 2007 and Garcia et al. 2003 alternative conclusions.

Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) characterize 12 faults in Cuba as active. Garcia et al. (2003) (FSAR Reference 2.5.1-489) define 24 seismogenic source zones (SZs) that represent faults or groups of faults in Cuba. FPL recognizes that there is recent and ongoing seismicity in northern Cuba and that many of these earthquakes may have ruptured along or near one of Cotilla-Rodriguez et al.'s (2007) (Reference 2.5.1-494) active faults or within one of the Garcia et al.'s (2003) (FSAR Reference 2.5.1-489) SZs. However, there are no data to demonstrate that any fault in northern Cuba is a capable tectonic source according to the criteria established in RG 1.208. Seismicity in northern Cuba is ongoing, generally at low rates and low-to-moderate magnitudes, much like areas in the central and eastern United States. Also, like much of the central and eastern United States, these earthquakes are not definitively attributable to any mapped fault or faults. Across Cuba the association of earthquakes with individual faults is highly problematic due to the uncertainties associated with the locations of both earthquakes and mapped faults and the paucity of available focal plane solutions. This is especially true for lower-

magnitude earthquakes in the region. It is possible that at least some of this earthquake activity in northern Cuba occurred on mapped faults, but it is also possible that many of these earthquakes occurred on faults that have yet to be mapped. The remainder of this response provides discussion of Cotilla-Rodriguez et al.'s (2007) (FSAR Reference 2.5.1-494) 12 active faults and Garcia et al.'s (2003) (FSAR Reference 2.5.1-489) 24 SZs and their relation to the seismicity of northern Cuba.

Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494, pp. 511-512) summarize the assessment of active faults in Cuba as follows:

> *"Figure 5 shows the twelve faults that demonstrate contemporary activity in Cuba, according to the criteria of Hatter et al. (1993). Specifically, these faults meet the above criteria a) and b), while only two of them (Bartlett-Cayman and Nortecubana) satisfy the third criterion, that of focal mechanism. Also, all of the faults meet well-known criteria of geomorphic type (Yeats et al., 1997). All are attributed to type I of the faults of NUREG-1451 (1992) and fulfill the conditions of Lay and Wallace (1995) and Reiter (1990) for active seismic structures. Hence, the Habana-Cienfuegos and Cauto-Nipe faults are hidden structures, since they agree with the description of the Working Group on California Earthquake Probabilities (1995)."*

According to Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494), 12 faults in Cuba meet their definition of active. These 12 faults include the Bacanao, Oriente, Cochinos, Camaguey, Caute-Nipe, Cubitas, Guane, Habana-Cienfuegos, Hicacos, La Trocha, Las Villas, and Nortecubana faults (Figure 1). Of these 12 faults, only seven are located in northern Cuba. These seven faults are the Cochinos, Guane, Habana-Cienfuegos, Hicacos, La Trocha, Las Villas, and Nortecubana faults.

Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) state that each of these seven faults satisfies criteria (a) and (b) (attributed above to Hatter et al. 1993) and that two faults (Oriente and Nortecubana) satisfy criterion (c). Criterion (a) requires direct observation of faulting in connection with at least one earthquake. However, there are no direct historical observations of surface rupture on any faults in northern Cuba. Additionally, there are no paleoseismic trench studies that constrain the time of most-recent earthquake slip on faults in northern Cuba. Therefore, no faults in northern Cuba appear to satisfy criterion (a).

Criterion (b) requires the occurrence of well-located earthquake activity close to a known fault and a well-constrained fault-plane solution with one nodal plane showing the same orientation and sense of displacement as the fault. Depending upon the definition of "close" in this context, it can be argued that some epicenters in northern Cuba are close to mapped faults. However, none of these epicenters are well located, and very few, if any, focal mechanisms are available for earthquakes in northern Cuba. Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494, p. 327) 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." Similarly, Cotilla-Rodriguez and Cordoba-Barba (2011, pp. 502-503) (Reference 2) 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." Regarding the locations of pre-instrumental earthquakes in Cuba, Garcia et al. (2003) (FSAR Reference 2.5.1-489, p. 2569) state, "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 et al.'s (2007) (FSAR Reference 2.5.1-494) Figure 6 depicts numerous focal mechanisms for fault zones along the modern plate boundary south of Cuba and throughout the Caribbean region, but none are depicted for northern Cuba. Therefore, no faults in northern Cuba appear to satisfy criterion (b).

Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) state that two faults (Oriente and Nortecubana) satisfy criterion (c), which requires close correspondence of orientation of nodal planes and senses of displacement of well-constrained fault-plane solutions to the type and orientation of young faults or fault zones observed in the epicentral region. Cotilla-Rodriguez et al.'s (2007) (FSAR Reference 2.5.1-494) Table 2 indicates that focal mechanisms are available for some earthquakes on the Oriente fault (listed as the Bartlett-Cayman fault [BC] in their table) offshore of southern Cuba and the Nortecubana fault. Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) indicate that the Nortecubana fault system is a long, segmented structure and that focal mechanisms are available only for its easternmost portion. Earthquake focal mechanisms are lacking for earthquakes in intraplate Cuba away from the modern plate boundary. Therefore, no faults in northern Cuba appear to satisfy criterion (c).

In addition, Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) state that each of these 12 faults satisfies the NUREG-1451 criteria for a Type I fault. To be considered a Type I fault, a fault must show evidence for displacement during the Quaternary Period, which in 2007 was defined as extending back to approximately 1.8 million years before present (and since revised to 2.6 million years before present) (Gibbard et al. 2009) (Reference 3). There are faults in intraplate Cuba away from the modern plate boundary that potentially meet this criterion of a Type I fault. It is also likely that some faults in intraplate Cuba meet the NUREG-1451 criterion that faults are potentially subject to displacement if they are oriented such that they are subject to displacement in the existing stress field. The existing stress field in Cuba is not well constrained, but, given the range of orientations of faults in intraplate Cuba away from the modern plate boundary (Figure 1), it is likely that at least some are favorably oriented. However, it is possible for a fault to be Type I and yet not satisfy the RG 1.208 criterion for a capable tectonic source of evidence for tectonic deformation of a recurring nature within the last approximately 500,000 years or at least once in the last approximately 50,000 years.

Garcia et al. (2003) (FSAR Reference 2.5.1-489) present seismic hazard maps for Cuba that are based on their seismic source model that includes seismogenic zone sources

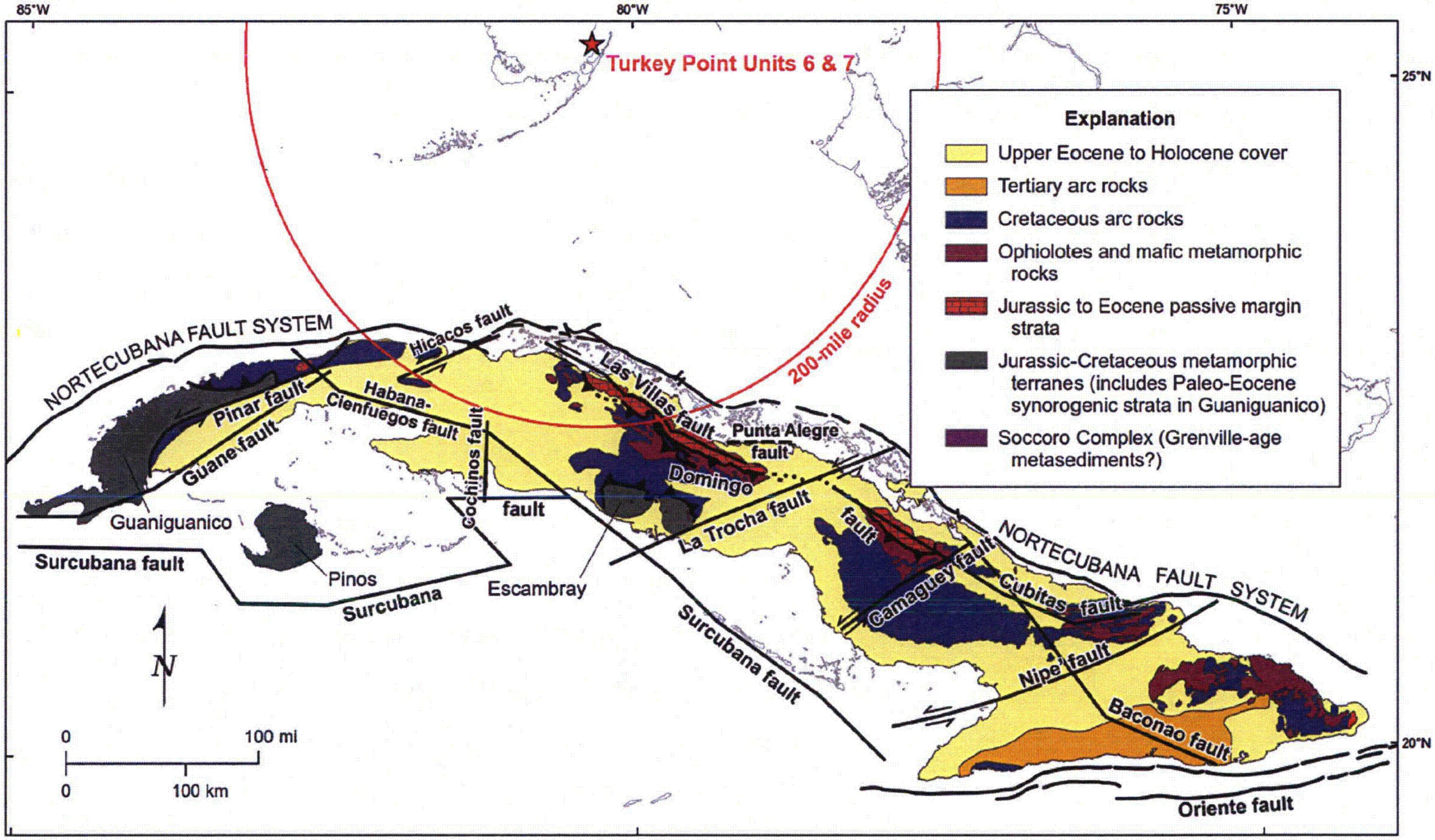
(SZs). They do not define fault sources in their model and they do not provide a systematic assessment of whether individual faults in Cuba are active. Instead, according to Garcia et al. (2003) (FSAR Reference 2.5.1-489), SZs are elongated areal seismic sources, each of which represents a potentially active fault zone or group of faults. According to Garcia et al.'s (2003) (FSAR Reference 2.5.1-489) seismic source model, each SZ must be large enough to envelop sufficient numbers of earthquakes to estimate separate rates of seismicity for each source from the earthquakes observed within that zone. The result is that their SZs in Cuba are tens of kilometers wide. Garcia et al. (2003) (FSAR Reference 2.5.1-489) allow for border uncertainty of 0 to 20 km (0 to 12 miles) for their SZs. As shown on Figure 6 of FSAR Reference 2.5.1-489), SZs collectively account for a significant percentage of the area of Cuba. As such, a significant percentage of past, and presumably future, seismicity is located within these zones.

In general, Garcia et al. (2003) (FSAR Reference 2.5.1-489) do not provide specific information indicating whether a particular fault in intraplate Cuba is active, because this is not the focus of their study. They do, however, provide very brief descriptions of the geologic and seismic settings of each of their SZs, which typically are named after a fault located within that zone. For example, the Pinar fault is located within their "Seismogenic Region Pinar" and the Hicacos fault is located within their "Seismic Region Hicacos". This naming convention implies that the individual faults that lend their names to the SZs are active, when in fact this may not necessarily be the case.

In a more recent study, Garcia et al. (2008) (FSAR Reference 2.5.1-490) present seismic hazard maps for Cuba that are based on a spatially smoothed seismicity approach. Garcia et al. (2008) (FSAR Reference 2.5.1-490) compare the results from the smoothed seismicity approach with those based on the Garcia et al. (2003) (FSAR Reference 2.5.1-489) SZ approach. From this comparison, Garcia et al. (2008) (FSAR Reference 2.5.1-490) conclude that, relative to the smoothed seismicity approach, the SZ approach tends to result in slightly higher PGA values in northwestern Cuba. Garcia et al. (2008) (FSAR Reference 2.5.1-490, p. 193) indicate that "an improvement of the seismicity data collection would be welcome for a better knowledge of the seismicity in northwestern Cuba." Moreover, Garcia et al. (2008) (FSAR Reference 2.5.1-490, p. 174) indicate that "although the definition of SZs is positive because it focuses on understanding the regional tectonics, this exercise could be misleading when not supported by data. Consequently, a mixture of the two approaches would probably be the best solution: a seismotectonic approach for the more seismic areas and only seismicity elsewhere." According to Garcia et al. (2008) (FSAR Reference 2.5.1-490, p. 182), "the northern intraplate region [of Cuba] is related to a moderate to low seismicity." This is consistent with observations made from the Phase 2 earthquake catalog, which indicate a higher concentration of earthquakes and higher magnitudes in southernmost Cuba at and near the modern plate boundary. Therefore Garcia et al.'s (2003) (FSAR Reference 2.5.1-489) SZ modeling approach may not be applicable to the moderate to low seismicity areas of northern Cuba.

In light of the above, it is unclear whether the faults identified in Cotilla-Rodriguez et al. (2007) (FSAR Reference 2.5.1-494) as active fit the definition of the term and whether the ongoing seismicity in northern Cuba can be associated with those faults. Garcia et al.'s

(2003) (FSAR Reference 2.5.1-489) 24 SZs occupy a large percentage of the area of Cuba and, therefore, it is not surprising that much of the broadly distributed seismicity in northern Cuba occurs within these collective zones. Throughout northern Cuba, the association of earthquakes with individual faults is highly problematic due to the uncertainties associated with the locations of both earthquakes and mapped faults and the paucity of available focal plane solutions. It is possible that at least some of this earthquake activity has occurred on mapped faults, but it is also possible that many of these small- to moderate-magnitude earthquakes have occurred on small faults within the crust that have yet to be mapped.



Note: Multiple sources were used to compile this map, including FSAR References 443, 448, 439. 770, 492 and 494.

Figure 1 Fault Map of Cuba

This response is PLANT SPECIFIC.

References:

1. Haller, K.M., Machette, M.N., and Dart, R.L., 1993. *Maps of major active faults, Western Hemisphere, International Lithosphere Program (ILP), Project II-2*, Guidelines for U.S. database and map, U.S. Geological Survey Open-File Report 93-338, 45 p.

2. Cotilla-Rodriguez, M.O. and Cordoba-Barba, D., 2011. *Study of the earthquake of the January 23, 1880, in San Cristobal, Cuba and the Guane fault*, Physics of the Solid Earth, v. 47, no. 6, p. 496-518.

3. Gibbard, P.L., Head, M.J., and Walker, J.C., 2009. *Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with base at 2.58 Ma*, Journal of Quaternary Science, v. 25, no. 2, p. 96-102.

ASSOCIATED COLA REVISIONS:

The text in FSAR Subsection 2.5.1.1.1.3.2.4, fourth paragraph, will be revised as follows in a future COLA revision:

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 designated **by Cotilla-Rodriguez et al. (Reference 494)** as "active" ~~(Reference 494)~~ **based on their ambiguous definition of the term.** ~~, but that published~~ **However, Cotilla-Rodriguez et al.'s (Reference 494)** analysis does not provide sufficient information to conclude that a structure is capable **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.

Additional COLA revisions will be made in a future COLA revision as presented in the response to RAI 02.05.01-21.

ASSOCIATED ENCLOSURES:

None