PMTurkeyCOLPEm Resource

From: Comar, Manny
Sent: Wednesday, October 03, 2012 8:19 AM
To: TurkeyCOL Resource
Subject: FW: DRAFT RAI Responses FPL Turkey Point 6 & 7 for eRAI 6024 Basic Geologic and Seismic Information - Part 1 of 4
Attachments: Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-23 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-24 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-25 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-27 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-28 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-30 (eRAI 6024).pdf; Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-8 (eRAI 6024).pdf

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From: Franzone, Steve [mailto:Steve.Franzone@fpl.com]
Sent: Monday, September 17, 2012 7:10 PM
To: Comar, Manny
Cc: Maher, William; Burski, Raymond
Subject: DRAFT RAI Responses FPL Turkey Point 6 & 7 for eRAI 6024 Basic Geologic and Seismic Information - Part 1 of 4

Manny,

To support a future public meeting, FPL is providing draft revised responses for eRAI 6024 (RAI questions 02.05.01-8, 02.05.01-23, 02.05.01-24, 02.05.01-25, 02.05.01-27, 02.05.01-28, 02.05.01-30) in the attached files:

DRAFT RAI Responses FPL Turkey Point 6 & 7 for eRAI 6024 Basic Geologic and Seismic Information - email 1 of 4 dated 20120917 and in the following 3 e-mail transmittals

If you have any questions, please contact me.
Thanks

Steve Franzone
NNP Licensing Manager - COLA
" Words may show a man's wit, but actions his meaning" ~ Benjamin Franklin
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Sent Date: 10/3/2012 8:19:10 AM
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MESSAGE	1574	10/3/2012 8:19:19 AM
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-23 (eRAI 6024).pdf	273128	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-24 (eRAI 6024).pdf	840812	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-25 (eRAI 6024).pdf	357934	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-27 (eRAI 6024).pdf	692863	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-28 (eRAI 6024).pdf	841423	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-30 (eRAI 6024).pdf	284252	
Draft Revised Response for NRC RAI Letter No. 041, RAI 02.05.01-8 (eRAI 6024).pdf	245025	

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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 Tayonera, 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 project 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:

912. 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.

913. 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 project 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

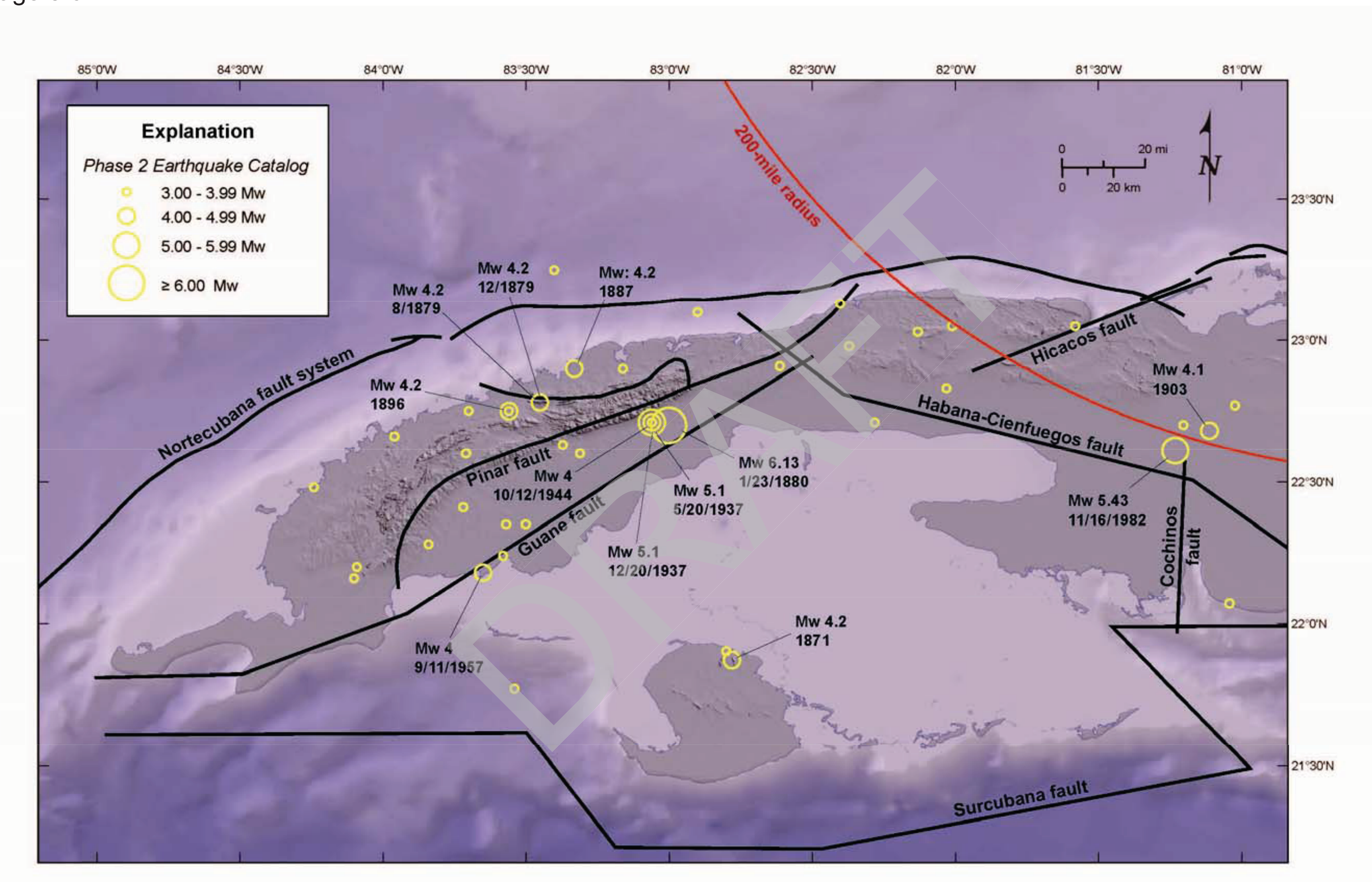


Figure 1A. The Phase 2 Earthquake Catalog and Faults of Western Cuba

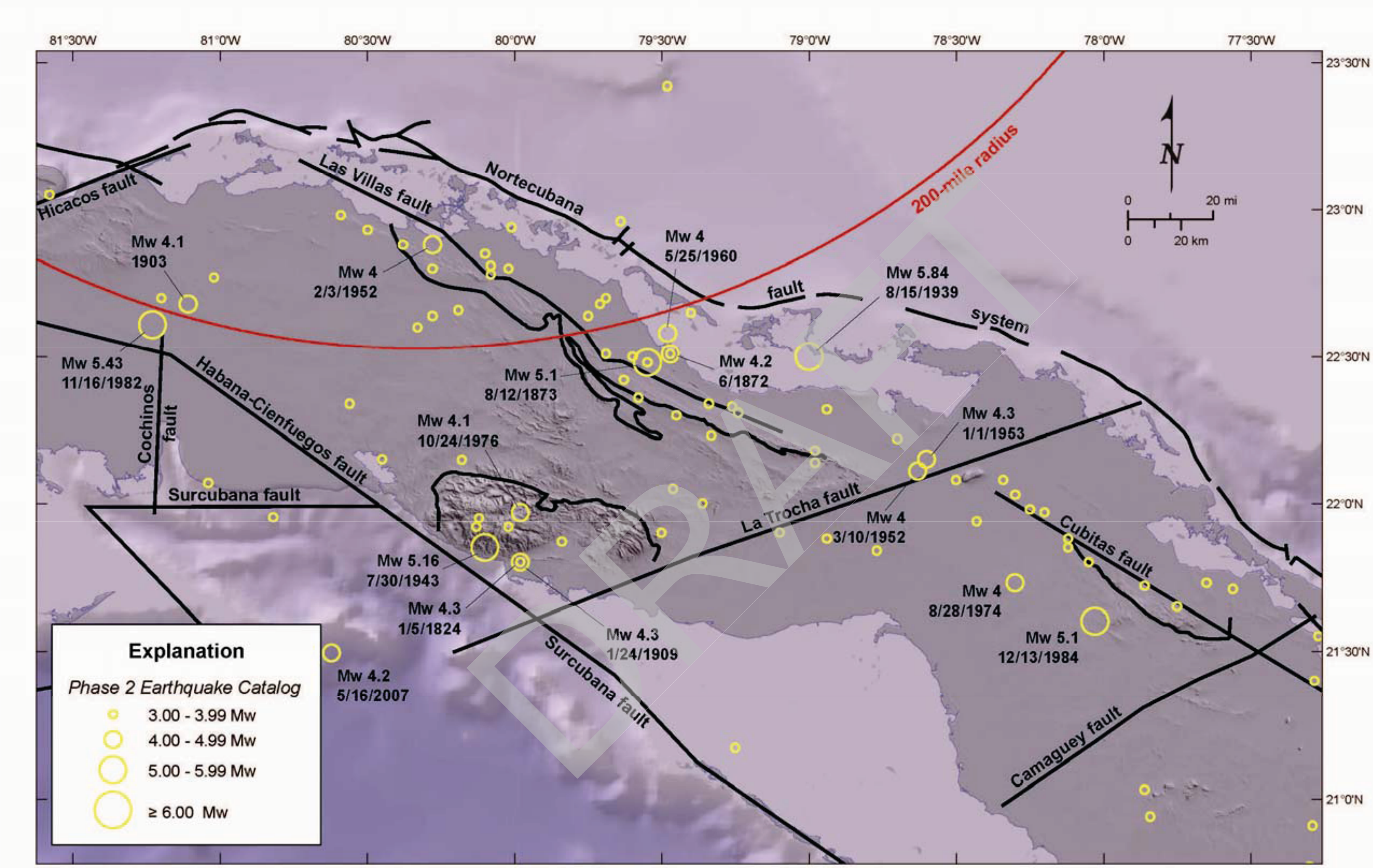


Figure 1B. The Phase 2 Earthquake Catalog and Faults of Central Cuba

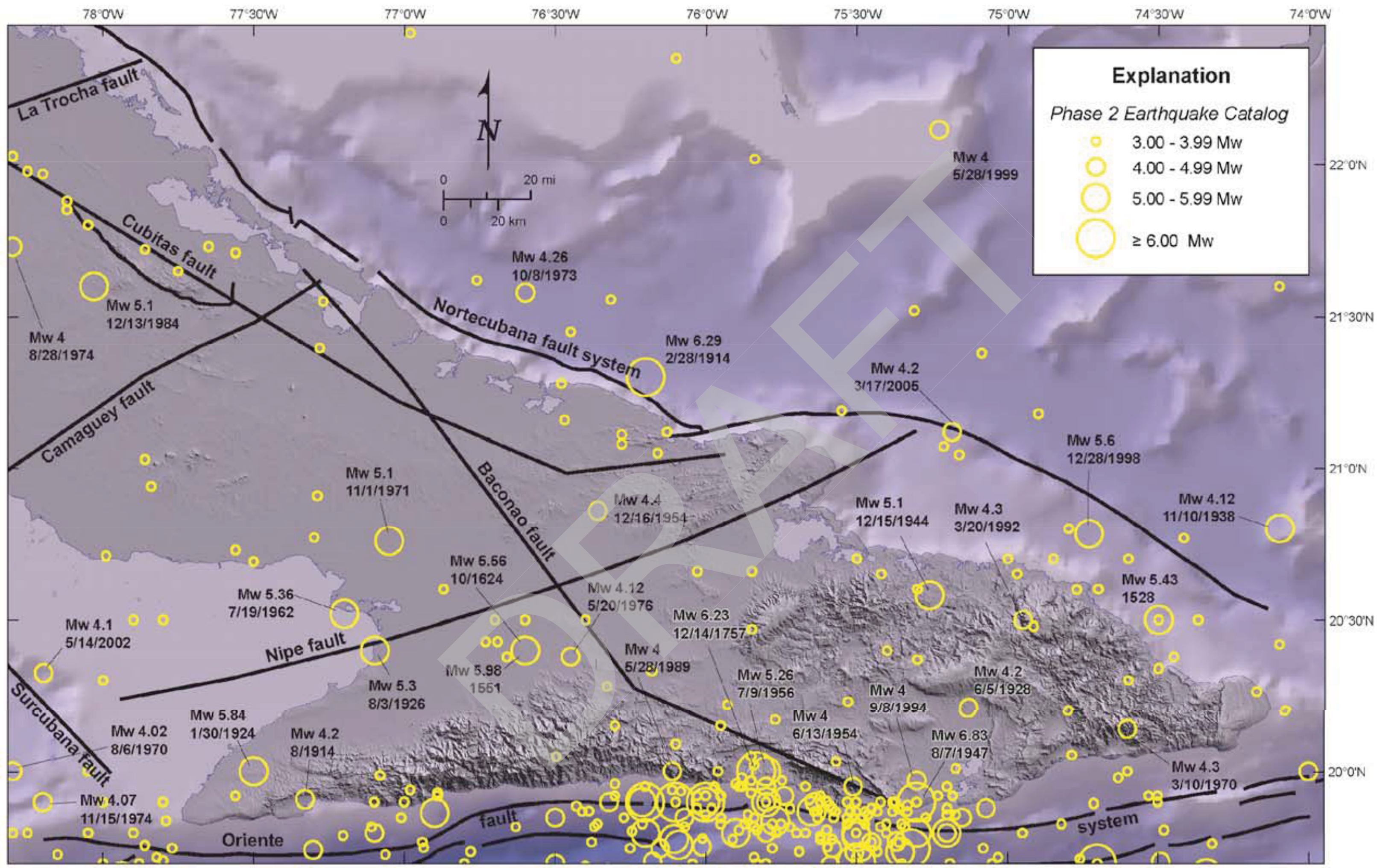


Figure 1C. The Phase 2 Earthquake Catalog and Faults of Eastern Cuba

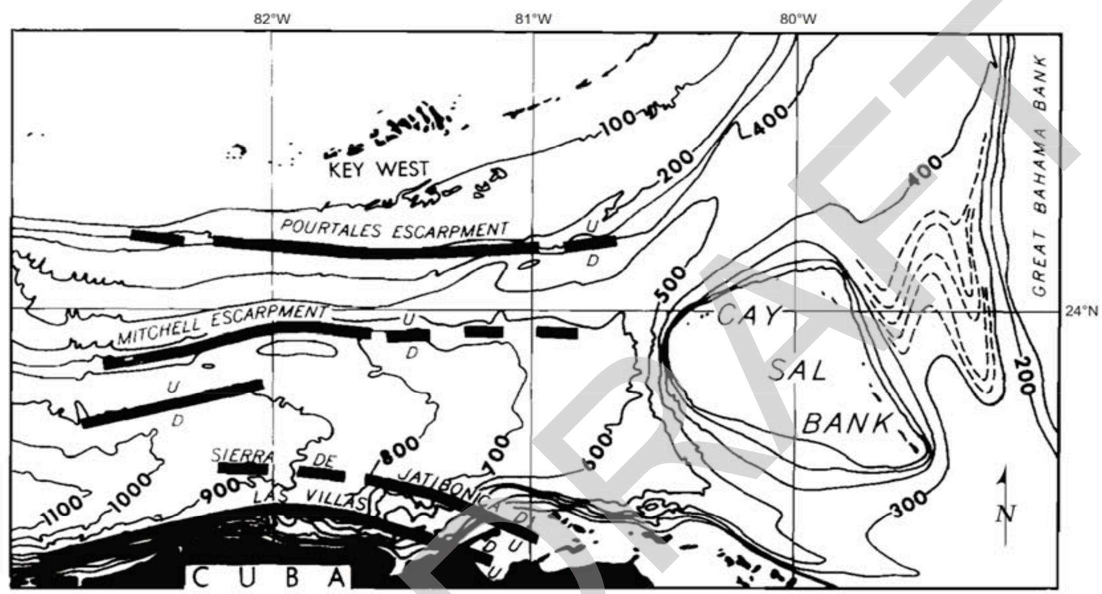


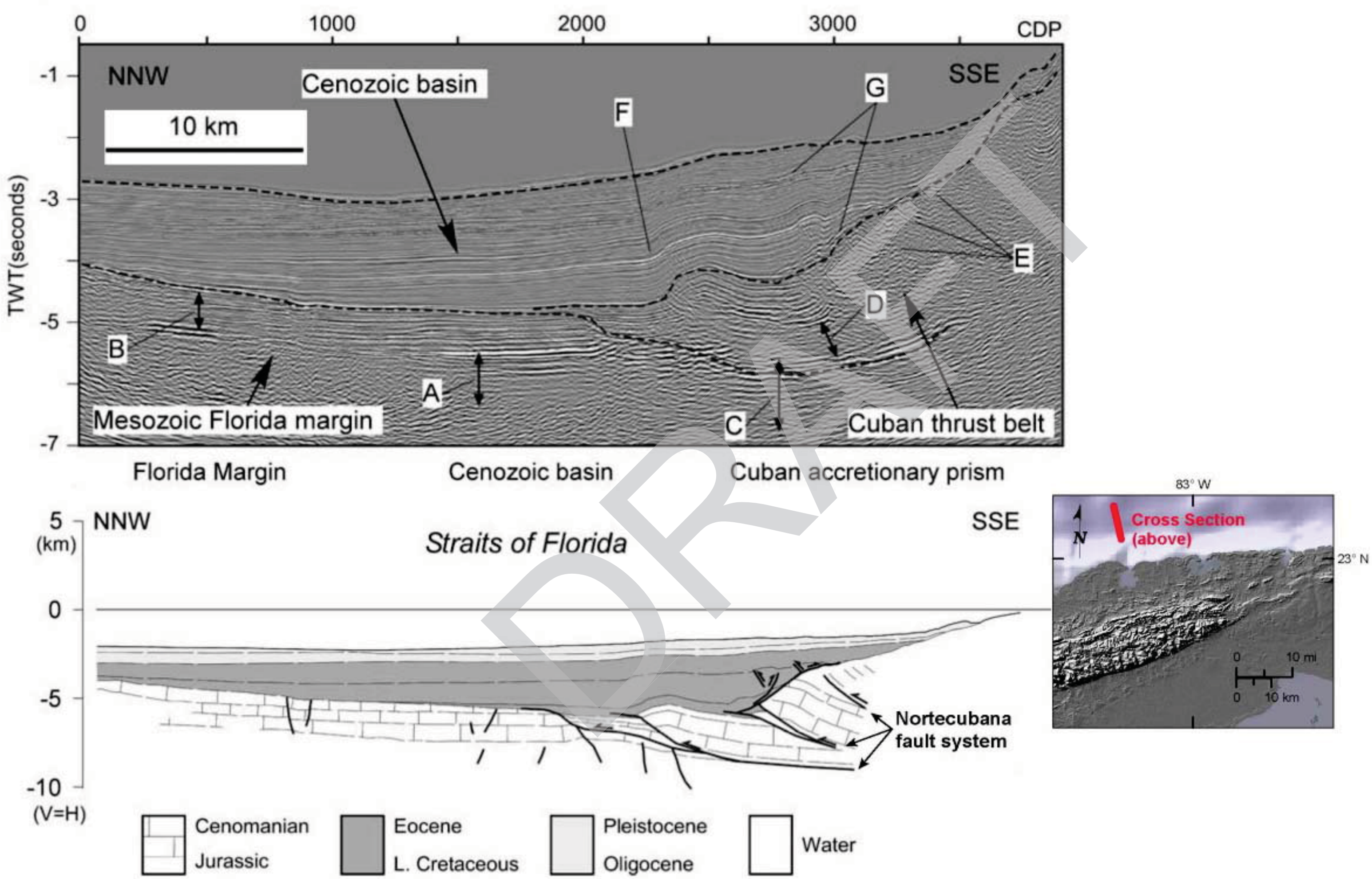
Figure 2. Escarpments and Postulated Faults in the Southern Straits of Florida from Malloy and Hurley (1970)

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, “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 project 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 project 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 project 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 project 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).

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.

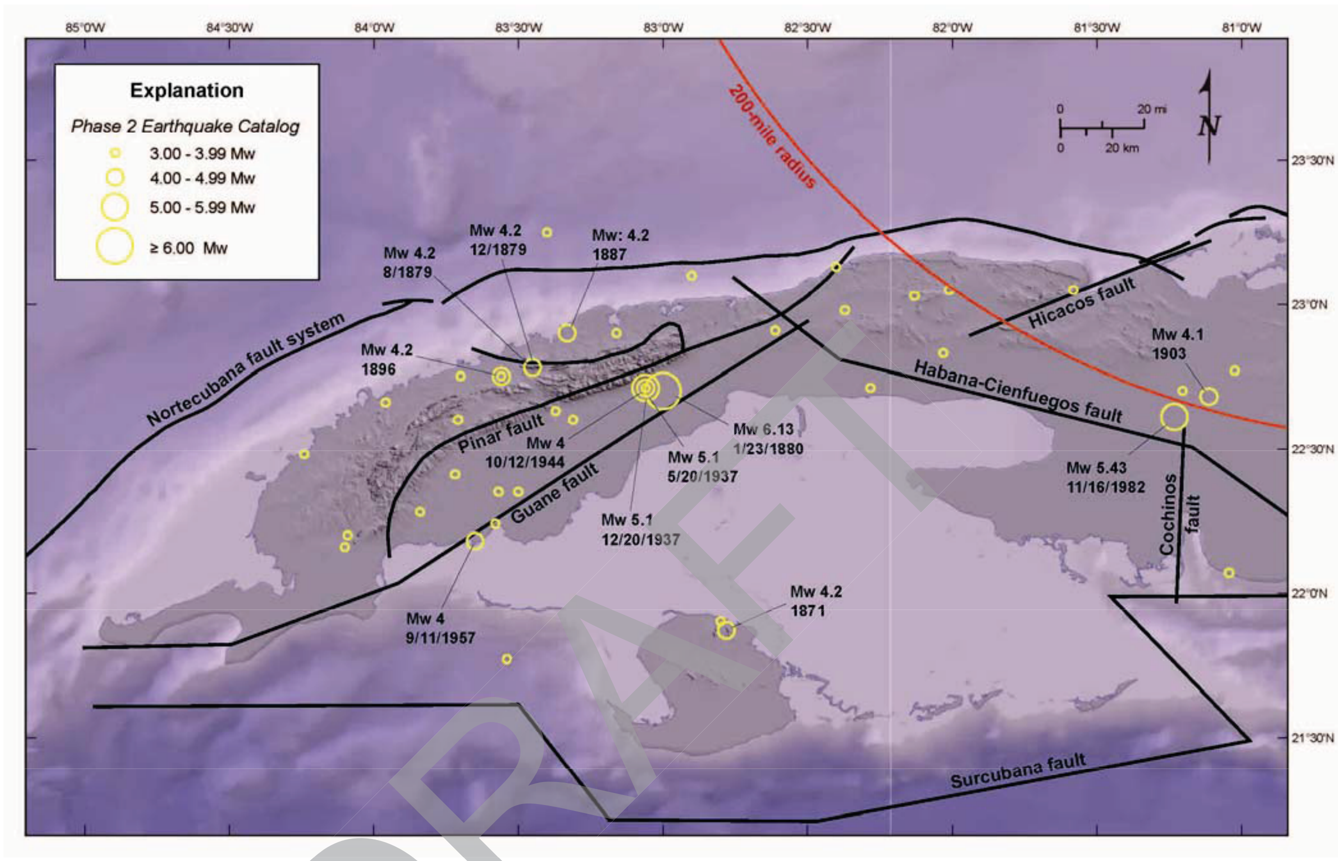


Figure 1. Fault Map of Western Cuba Showing Earthquakes from the Project Phase 2 Earthquake Catalog

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: 02.05.01-27 (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, p. 137 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 project 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 project 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 project 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 project 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 Project 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.

This response is PLANT SPECIFIC.

References:

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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.

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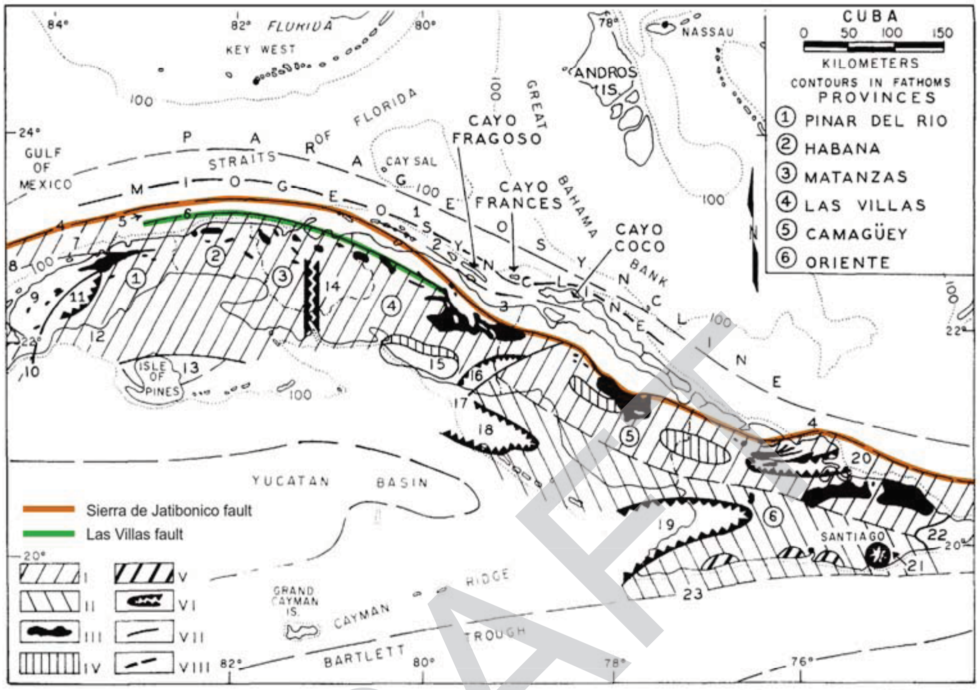


FIG. 1.—Tectonic sketch of Cuba. I–Cretaceous magmatic area (Zaza tectonic unit); II–Tertiary magmatic area (Cauto tectonic unit); III–Upper Cretaceous basic and ultrabasic intrusives; IV–Cretaceous granitoids; V–Tertiary granitoids; VI–Tertiary depressions; VII–deep fault; VIII–boundary between facies-structural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

Principal structures (north-south): *parageosyncline; 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–Bahía Honda tectonic unit; 8–Consolación del Norte deep fault; 9–Pinar del Río 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

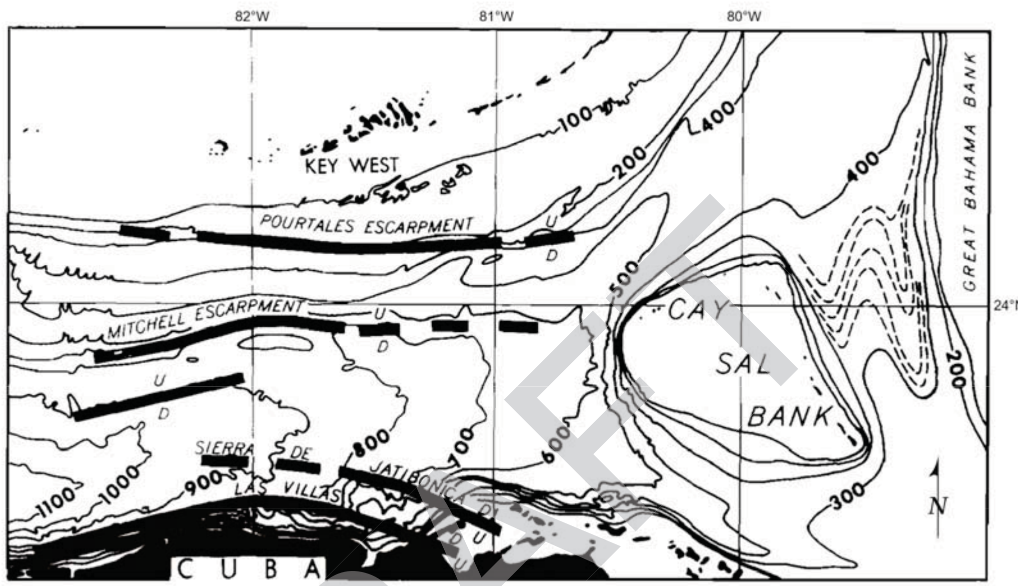


Figure 2. Escarpments and Postulated Faults in the Southern Straits of Florida from Reference 2

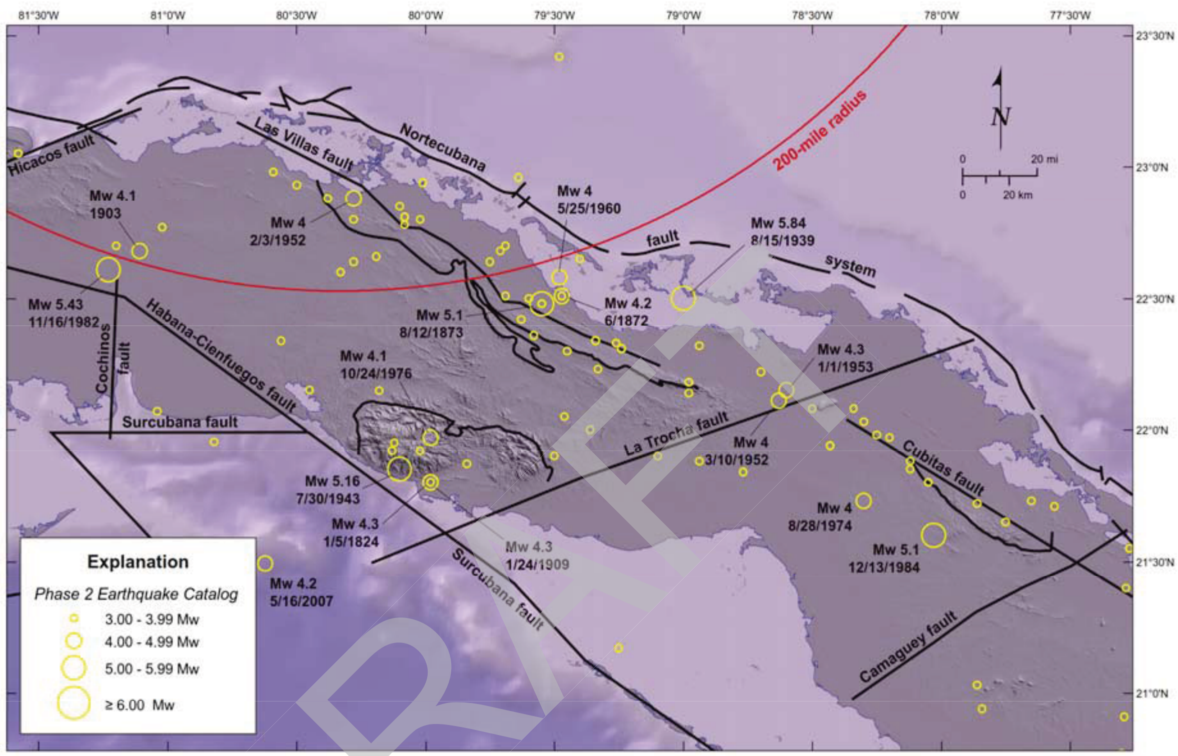
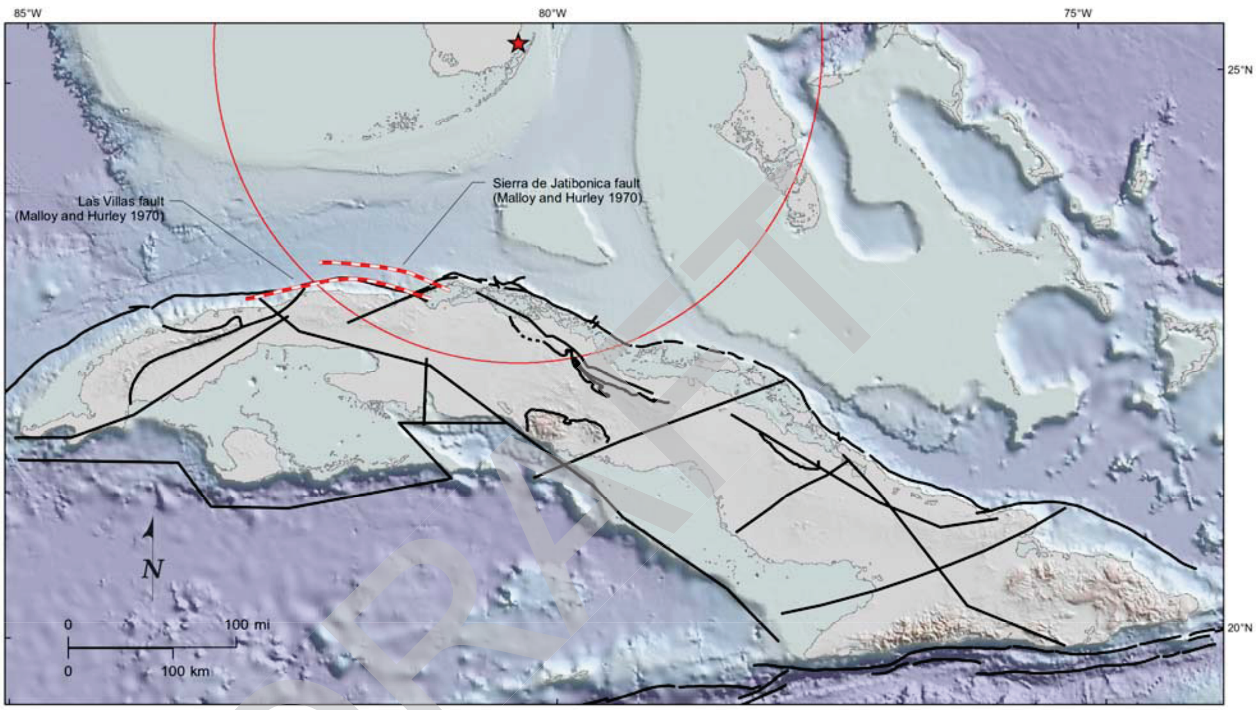


Figure 3. Fault Map of Central Cuba Showing Earthquakes from the Project Phase 2 Earthquake Catalog



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

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 project 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 project 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 project 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 project 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).

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.

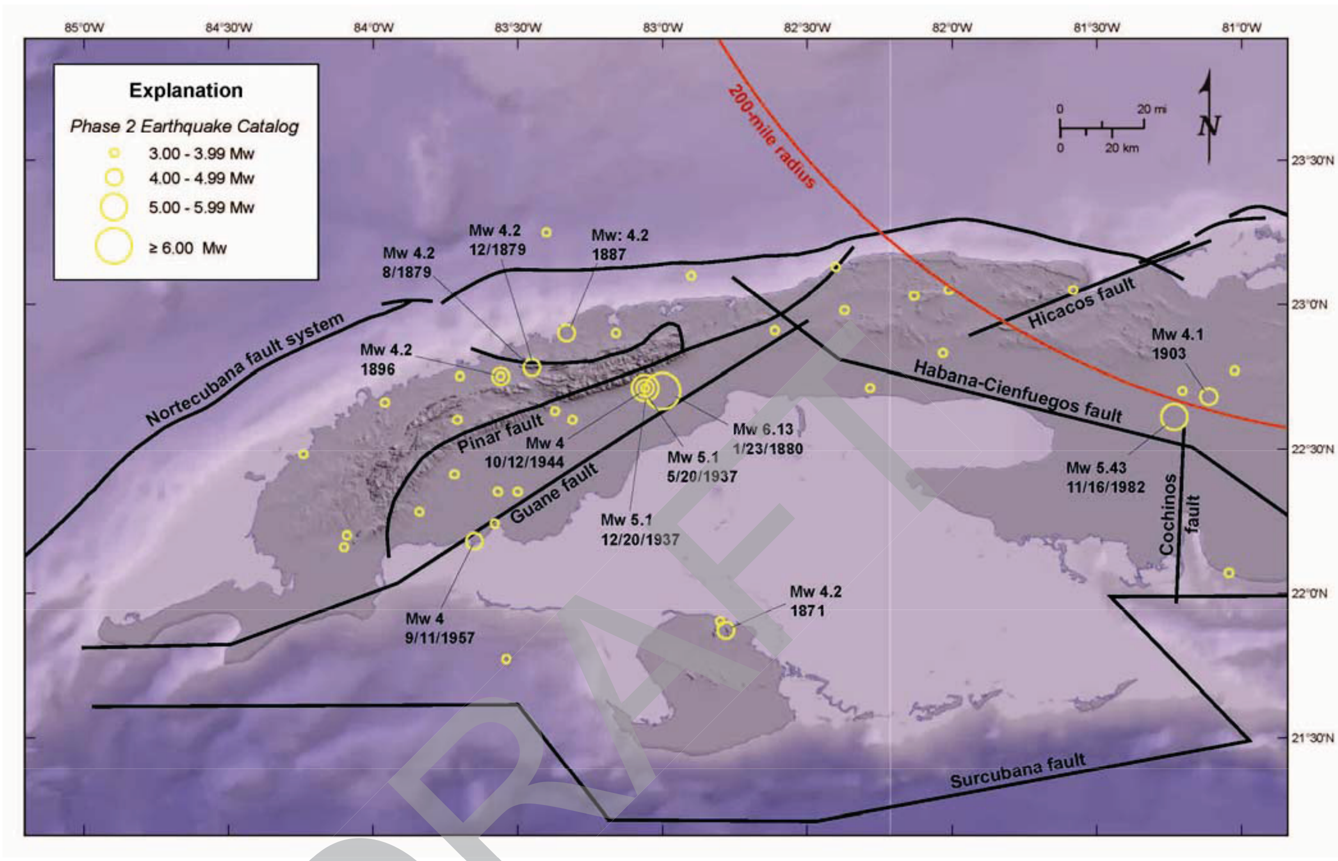


Figure 1. Fault Map of Western Cuba Showing Earthquakes from the Project Phase 2 Earthquake Catalog

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: 02.05.01-30 (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-Rodríguez et al. (FSAR Subsection 2.5.1, Reference 494, p. 516) describe the Pinar fault as having "very nice relief

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: 02.05.01-8 (eRAI 6024)

FSAR Section 2.5.1.1.5, “Tsunami Geologic Hazard Assessment,” Section 2.5.1.2.1, "Site Physiography and Geomorphology," and Section 2.5.1.2.4, "Site Geologic Hazards," state that an extensive review of scientific literature resulted in no evidence of Quaternary seismically induced or landslide-generated tsunami deposits within the 200-mile radius of the Units 6 & 7 site region. The FSAR adds that sampling performed as part of the subsurface investigations at the Turkey Point site encountered about 1 meter (3 feet) of organic muck overlying Pleistocene and older carbonate strata and that the muck is the dominant surficial sediment type varying in thickness across the site from 2 to 6 feet (0.6 to 1.8 meters). FSAR Figure 2.5.1-332 shows the organic muck section as Holocene. Finally, the FSAR states that examination of Units 6 & 7 has provided no evidence of known tsunami deposits. In light of the foregoing conclusion, the staff notes that the FSAR does not provide an analysis of the Holocene section (muck layers) in the site vicinity with respect to paleo-tsunami or paleo-storm surge events and core data regarding the muck layers is absent from the FSAR.

In order for the staff to understand the Holocene geologic setting of the TPNPP and in support of 10 CFR 100.23 please address the following questions:

a) Provide justification for your conclusion that there are no tsunami deposits at the site with a detailed presentation of the Holocene section, including how it varies across the site in terms of thickness and internal structure.

b) Discuss the organic sediment (“muck”) and included silt layers within an appropriate framework for the description of biogenic deposits, such as the Troels-Smith sediment classification system. Provide sufficient detail to illustrate how you evaluated silt layers as either potential storm or tsunami-derived sources.

FPL RESPONSE:

The information requested in part a) and the second sentence of part b) of this RAI is addressed in the responses to RAI 02.05.01-6 and 02.05.01-7. The part b) response of this RAI addresses the use of the Troels-Smith sediment classification system and an example of how the organic sediment (“muck”) and included silt layers are described within this sediment classification system.

The muck soils at the Turkey Point Units 6 & 7 site are classified under the Unified Soil Classification System (USCS) in accordance with ASTM D2488-06 and D2487 instead of the Troels-Smith sediment classification system. The USCS was used because the geotechnical engineering subsurface investigation was conducted for the purpose of foundation design. The USCS provides nomenclature to describe soil in terms of gradation, plasticity, and organic content as determined visually or based on laboratory testing. This widely used classification system is applicable to a wide variety of geotechnical engineering projects. The major soil divisions of the USCS are coarse grained (gravel and sand), fine grained (silts and clays or clays and silts that are either organic or inorganic), organic soils (organic matter with gravel, sand, silt or clay), and peat.

The Troels-Smith classification system is not applicable for standard geotechnical practice for field subsurface investigations because the focus of the Troels-Smith classification system is to reconstruct paleodepositional environments and climate. The Troels-Smith sediment classification system is a comprehensive classification system that is used by palynologists, paleoclimatologists, paleoecologists, and limnologists to describe organic-rich sediments deposited in northern temperate lakes, and wetlands. The classification was originally designed primarily as a field-based system but could be expanded to include laboratory analysis (i.e. determining peat humification, quantifying peat bulk density, organic matter, and carbon content). It has been widely applied by European paleoecologists because the more specialized terms are applicable to northwestern Europe (i.e. Finland, Sweden, Norway, northern Russia, Great Britain, and Ireland), the region for which they were originally devised (Reference 1).

The Troels-Smith classification system describes deposits based on physical properties, humicity (the degree of decomposition of organic substances), and composition. Physical properties are further characterized in terms of the degree of darkness (Nigror), the degree of stratification (Stratifacto), the degree of elasticity (Elasticitas), and the degree of dryness (Siccitas). Composition comprises six classes to describe the properties of sediments. The classes are Substantua humosa, Turfa, Detritus, Limus, Argilla and Grana. For all composition classes, a scale of 0-4 is used for characterization. Zero describes the absence of the element concerned and 4 the maximum presence (References 1 and 2). If FPL had used the Troels-Smith classification system at the Turkey Point Units 6 & 7 site, a hypothetical example of sample descriptions of the deposits of marl and muck with silt layers would be as follows:

Class: Limus calcareus

Symbol: Lc

Description: Marl

Degree of Darkness: clear

Degree of Stratification: 0

Degree of Elasticity: 0

Degree of Dryness: 2

Color: very dark gray

Structure: homogenous

Sharpness of Boundary: diffuse

Humicity: no record

Class: Argilla granosa

Symbol: Ag

Description: Silt

Degree of Darkness: 0

Degree of Stratification: 3, 4

Degree of Elasticity: 1

Degree of Dryness: 2

Color: white

Structure: homogenous mixed with marl and or muck

Sharpness of Boundary: gradual and sharp

Humicity: no record

Class: Argilla granosa

Symbol: Ag

Description: Silt

Degree of Darkness: 0

Degree of Stratification: 3, 4

Degree of Elasticity: 1

Degree of Dryness: 2

Color: white

Structure: homogenous mixed with marl and or muck

Sharpness of Boundary: gradual and sharp

Humicity: no record

This response is PLANT SPECIFIC.

References:

1. Schnurrenberger, D., Russell, J., and Kelts, K, 2003. Classification of lacustrine sediments based on sedimentary components, Journal of Paleolimnology, Vol 29, pp. 141-154.
2. Kershaw, A. P., 1997. A modification of the Troels-Smith system of sediment description and portrayal, Quaternary Australasia, Vol 15, no. 2, pp. 63-68.

ASSOCIATED COLA REVISIONS:

None

ASSOCIATED ENCLOSURES:

None