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.

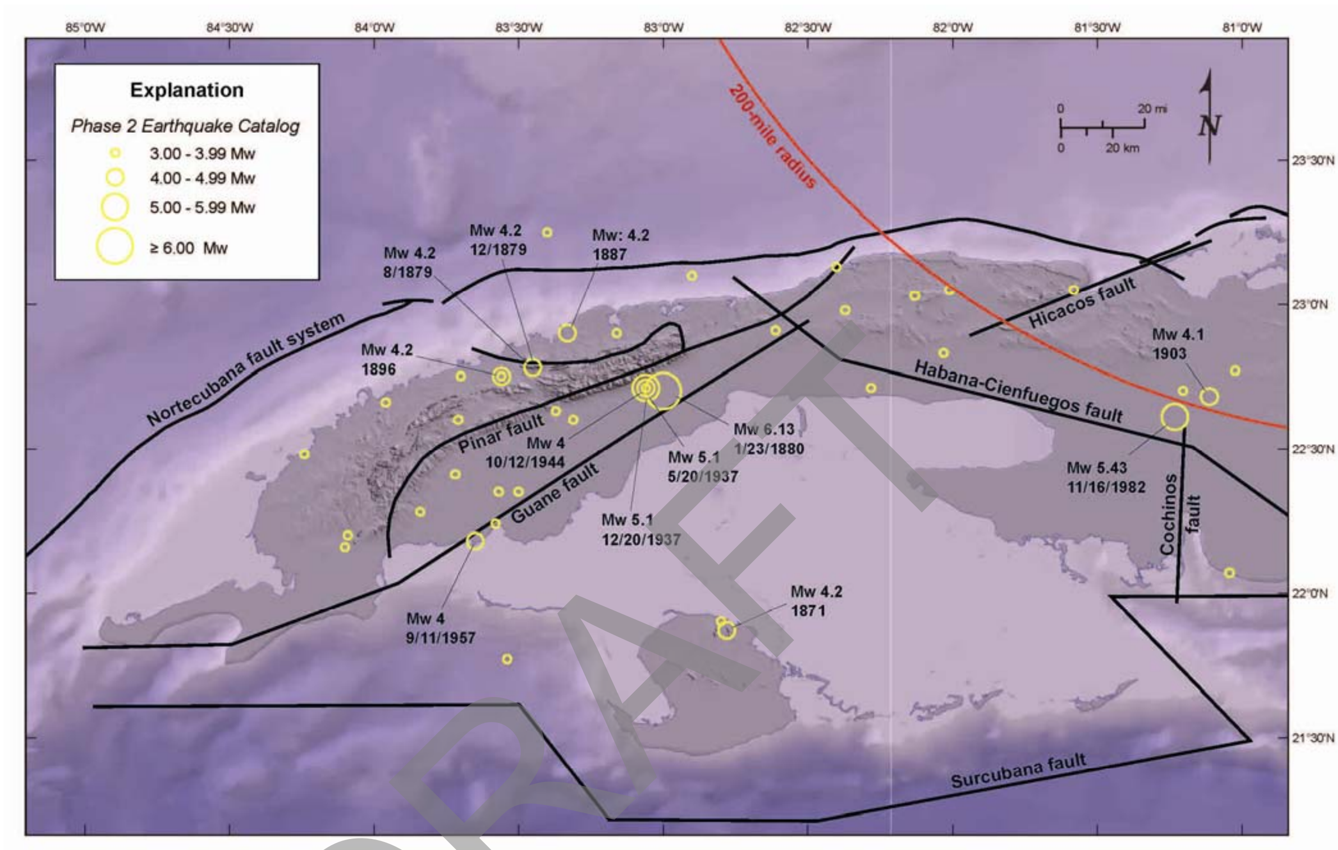

Figure 1. Fault Map of Western Cuba Showing Earthquakes from the Project Phase 2 Earthquake Catalog

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