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