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:

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

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

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

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

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

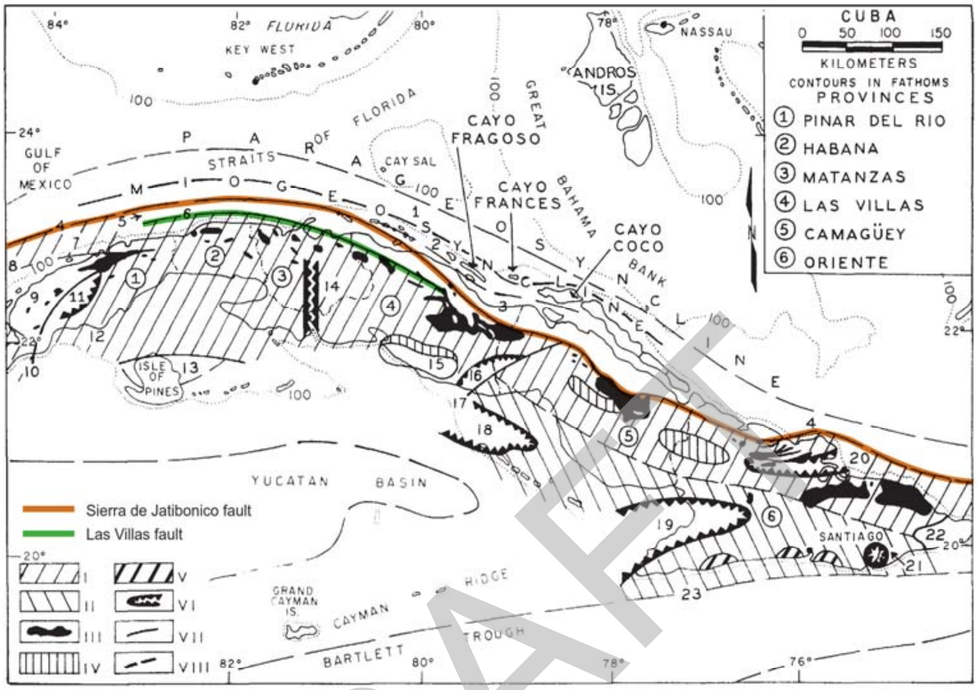


Fig. 1.—Tectonic sketch of Cuba. I–Cretaceous magmatic area (Zaza tectonic unit); II–Tertiary magmatic area (Cauto tectonic unit); III–Upper Cretaceous basic and ultrabasic intrusives; IV–Cretaceous granitoids; V–Tertiary granitoids; VI–Tertiary depressions; VII–deep fault; VIII–boundary between facies-structural 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–Bahia Honda tectonic unit; 8–Consolación del Norte deep fault; 9–Pinar del Rio tectonic unit; 10–Pinar del Río deep fault; 11–Palacios depression; 12–San Diego de los Baños tectonic unit; 13–Isla de Pinos tectonic unit; 14–Cochinos depression; 15–Trinidad tectonic unit; 16–Central basin depression; 17–La Trocha deep fault; 18–Ana María depression; 19–Cauto depression; 20–Nipe depression; 21–Guantánamo depression; 22–Oriente tectonic unit; 23–North Bartlett deep fault.

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

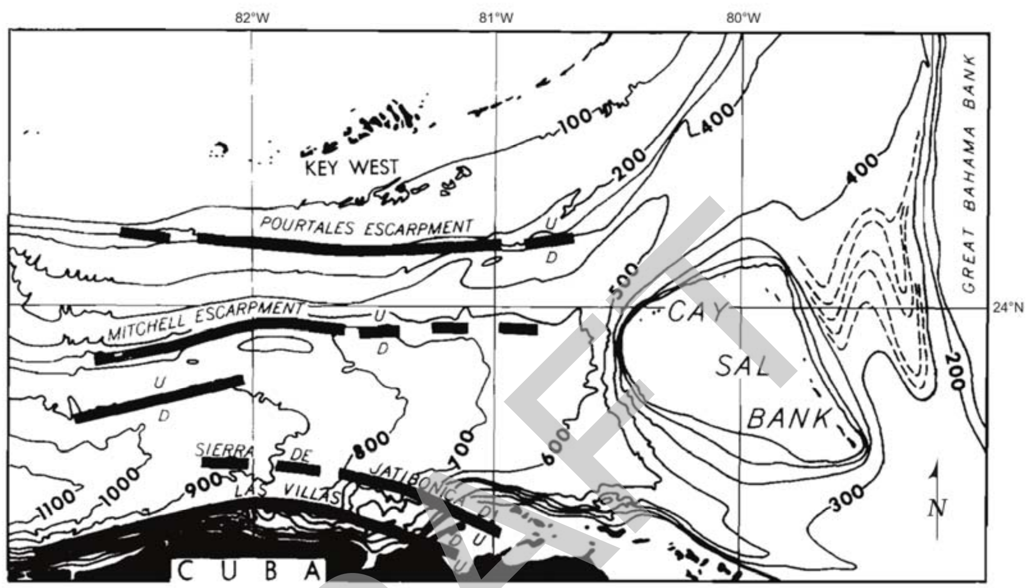


Figure 2. Escarpments and Postulated Faults in the Southern Straits of Florida from Reference 2

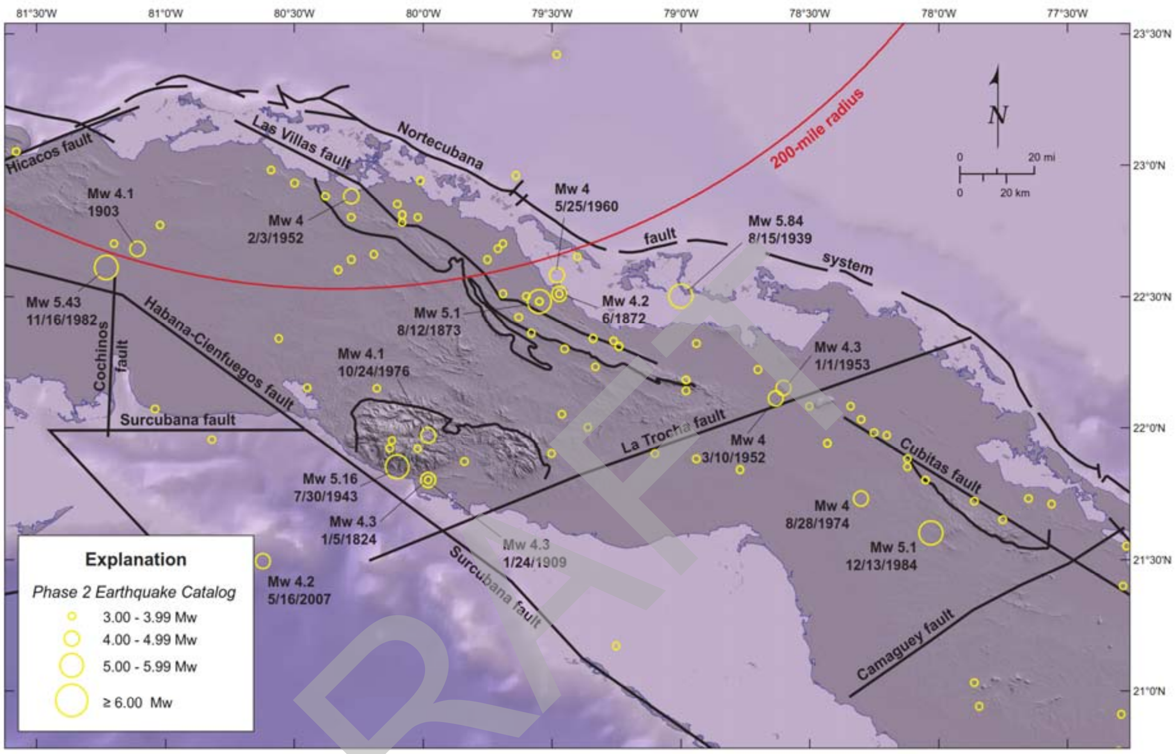
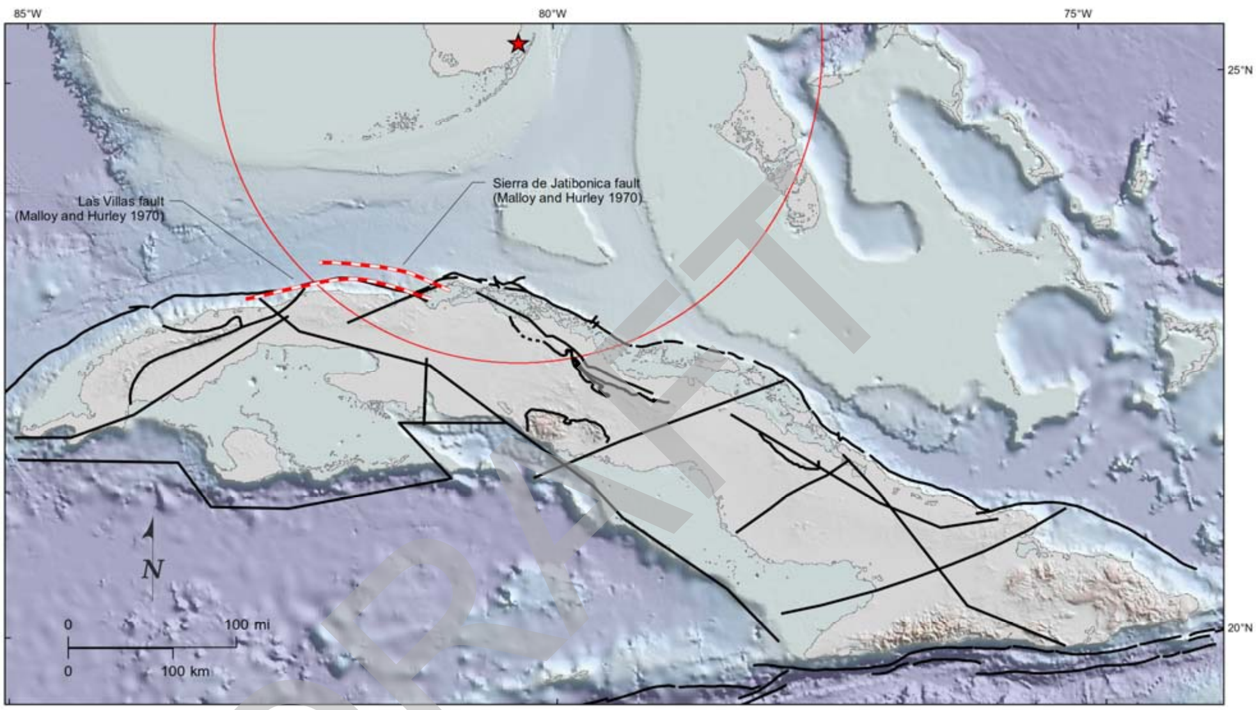


Figure 3. Fault Map of Central Cuba Showing Earthquakes from the Project Phase 2 Earthquake Catalog



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