However, beds with ages of approximately 1 Ma and younger show no evidence of deformation (Reference 479, Figure 2.5.1-278). Horizontal shortening rates over the last 3.6 Ma are estimated to be 0.0003 millimeter/year and seismicity near this structure is sparse (Reference 426, Figure 2.5.1-350). The fold may be rooted in Jurassic evaporites, such as the Punta Allegre formation (References 307 and 477), which could account for this structure's apparent longevity without clear tectonic mechanisms. PTN RAI 02.05.01-15

Straits of Florida Normal Faults

A series of short, steep normal faults exist in the western Straits of Florida southwest of Turkey Point (Reference 480) (Figure 2.5.1-229). These faults are mapped using seismic data in Paleocene and Eocene strata and are buried by undeformed Miocene and younger strata (Figures 2.5.1-209 and 2.5.1-273). This faulting represents syn-tectonic deformation of the Cuban foreland basin during its collision with the Florida-Bahama Platform (References 794 and 482). Seismic studies in central Straits of Florida indicate that Paleocene to Eocene strata dip to the south indicating the flexure of the southern margin of the Bahama Platform in response to loading from the Cuban orogeny (Reference 221). These syntectonic Paleocene and Eocene strata are terrigenous and were shed directly from Cuba into northward tapering wedges observed in seismic data (Figure 2.5.1-209). In contrast, the late middle Eocene to early middle Miocene strata were deposited uniformly over most of the southern straits of Florida, with pelagic to hemipelagic sedimentation, indicating that the Straits of Florida had subsided to 'near-modern' depths with a change in tectonic regime. The development of sediment drifts in Middle Miocene and younger strata reveal increased current strength in the Straits of Florida at this time (Reference 221). Just outside of the site region, but in a comparable tectonic environment in the southeastern Gulf of Mexico, interpretation of seismic lines indicate that generally no major displacements affect strata above an upper Eocene unconformity (Reference 482), and lines in the site region indicate unfaulted strata above the late middle Eocene unconformity (Reference 221). However, cases of later Tertiary reactivation of faults in the area have been documented (Reference 484). PTN RAI 02.05.01-16 PTN RAI 02.05.01-16 LDP-CS564

Also in the Straits of Florida, initial workers hypothesized faulting along the edges of the Pourtales and Miami terraces and along other seafloor escarpments, but also suggested that the escarpments could be original sedimentary features associated with sediments deposited against the steeper face of old reef fronts (Reference 967) (Figure 2.5.1-379). Higher resolution, more detailed seismic imaging has allowed the Pourtales escarpment and similar steep-sided escarpments throughout the Gulf of Mexico, Straits of Florida, and Bahamas to be recognized as relict carbonate platform margins, sometimes steepened and modified by erosion, with drifts of younger sediment resting adjacent (Figure 2.5.1-380) (References 687, 951, and 968). For example, Mullins and Neuman (Reference 968) conclude that there is no evidence for faulting at the eastern edge of the Miami terrace and that truncated reflectors near the surface indicate erosion was responsible for the observed stratigraphic variations. PTN RAI 02.05.01-16 LDP-CS564

South of the Straits of Florida normal faults, thrust faults are expected within a narrow apron offshore of the Cuban coastline. These thrusts, such as the Nortecubana fault, are discussed as part of the Cuban fold-and-thrust belt.

Cuban Fold-and-Thrust Belt

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). Syntectonic 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). In two offshore seismic lines, Reference 497 indicates that north-vergent thrusts terminate either above an Upper Cretaceous horizon (Figure 2.5.1-281) or just below a Tertiary horizon (Figure 2.5.1-280). Based on 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. For example, in Figure 2.5.1-287, seismic horizons are not traced near the imbricate thrusts, but the faults terminate upward between 0.3 and 0.7 seconds below the seafloor (two-way travel time). 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 syntectonic strata (References 220, 439, and 485) and published structural interpretations indicating unfaulted Quaternary strata above these structures offshore (References 484 and 485), 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 217and 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 920 and 925).

PTN RAI 02.05.01-18

PTN RAI 02.05.01-18

PTN RAI 02.05.01-23

Submarine Surficial Slumps

Marine seismic reflection data have recognized evidence for gravity-driven slumping of surficial strata in the site region. Shallow slumps have been identified along the margin of the Little Bahama Bank, in Exuma Sound, (Reference 476) and in the southeastern Gulf of Mexico (Reference 482). These gravitational features are generally confined to submarine valleys or escarpments (Reference 476). Evidence for submarine landslides in and around the Bahama Platform is discussed in more detail in Subsection 2.5.1.1.1.1.2.

Seismicity of the Bahama Platform

{The Phase 1 earthquake catalog (Subsection 2.5.2.1.2) indicates sparse seismicity within the Bahama Platform (Figure 2.5.1-267). Earthquakes within the Bahama Platform are widely distributed, the largest being an Emb 4.3 earthquake that occurred near Ackins Island, approximately 700 kilometers (430 miles) southeast of the Units 6 & 7 site. Two earthquakes are located northeast of the site at distances of 53 and 175 kilometers (33 and 109 miles) with Emb 2.7 and 3.2, respectively. About a dozen earthquakes are located about 600 kilometers to the southeast in the vicinity of the central portion of the Bahamas Islands. The dates of these earthquakes range from 1894 to 2007, suggesting that this is a zone of low-level but persistent activity. Ten earthquakes are located within a few tens of kilometers of the northern coastline of Cuba. The overall seismicity pattern within the Bahama Platform shows no correlation with geologic or tectonic features (Subsection 2.5.2.3).} SOF 2.5.1-1

2.5.1.1.1.3.2.3 Continental Slope and Rise

Structures of the Continental Slope and Rise

The site region includes a small corner of the Blake Plateau, the intermediate depth plateau just north of Little Bahama Bank (Figure 2.5.1-229). North of the Little Bahama Bank, the Atlantic Continental Shelf extends seaward from the shoreline to a steeper continental slope, located approximately 50 miles (80 kilometers) offshore. This slope has been in existence since the Eocene, but prior to that, the Florida Platform and Blake Plateau were continuous. Seaward, the Blake Plateau extends up to 300 kilometers (185 miles) to the Blake Escarpment, the steep transition to deep ocean basin (Reference 487) (Figure 2.5.1-283). It is east of the Blake Escarpment, where the Blake Spur magnetic anomaly likely represents a transition to oceanic crust, rather than rifted continental material that underlies the Florida Platform, Bahama Platform, and Blake Plateau (Reference 409) (Figure 2.5.1-229).

The plateau is dominantly underlain by Jurassic to Cretaceous carbonates (Reference 307) (Figure 2.5.1-284). The Jurassic and younger strata of the Blake Plateau are generally flat and unfaulted, but Paull and Dillon (Reference 487) identify minor faulting on the Blake Plateau, beyond the site region. This minor faulting is characterized as vertical normal faults exhibiting throws of less than 10 meters that do not affect beds younger than Cretaceous, and are interpreted to be the result of sediment compaction (Reference 487) (Figure 2.5.1-285). In addition, shallow slumps or other gravity-driven faulting has occasionally been noted in the Blake Plateau (Reference 487).

Seismicity of the Continental Slope and Rise

{The Phase 1 earthquake catalog (Subsection 2.5.2.1.2) indicates sparse, low-magnitude seismicity in the Atlantic Continental Shelf and Slope region, north of the Bahama Platform (Figure 2.5.1-267). According to the updated Phase 1 earthquake catalog, the two earthquakes in the Atlantic Continental Slope and Rise that are nearest to the Units 6 & 7 site are the June 3, 2001, Emb 3.30 and the June 11, 2001, Emb 3.30 earthquakes, at distances of approximately 310 and 330 miles (500 and 530 kilometers) from the site, respectively.} SOF 2.5.1-1

2.5.1.1.1.3.2.4 Cuba

This subsection discusses available geological and geophysical information pertaining to seismic hazard characterization for Cuba. While only a small portion of northern Cuba is within the site region, a discussion of the regional structures on the entire island is presented. Within the past ten years, international groups have published research conducted in Cuba, though many of these concentrate on geochemistry of the arc-related rocks (e.g., Reference 488), rather than any potential recent faulting or seismicity. From a seismic hazard perspective, potential seismic sources in Cuba are summarized by Garcia et al. (References 489 and 490) and Cotilla-Rodríguez (Reference 494) to support seismic hazard mapping. PTN RAI 02.05.01-21 PTN RAI 02.05.01-21

The major geologic units and their stratigraphic relations are described in Subsection 2.5.1.1.1.2.3. The plate tectonic history of Cuba and the northern Caribbean, including the origin and emplacement timing of the geologic units, are discussed in Subsection 2.5.1.1.3. PTN RAI 02.05.01-21

Structures of Cuba

Most regional faults in Cuba, particularly in northern Cuba, are north-directed thrusts or east- to northeast-striking strike-slip faults responsible for transferring the Cretaceous Greater Antilles Arc onto the Bahama Platform (Figures 2.5.1-247, 2.5.1-250, and 2.5.1-251). The Oriente fault zone, located directly off the southern coast of the island, forms the boundary between the modern North America Plate and the Gonâve microplate and is a capable tectonic source. The Oriente fault zone is discussed further in Subsection 2.5.1.1.2.3.1.2, and its characterization in the Cuba and northern Caribbean seismic source model is described in Subsection 2.5.2.4.4.3. PTN RAI 02.05.01-21 PTN RAI 02.05.01-21 PTN RAI 02.05.01-21

In an effort to explain seismicity that continues on intraplate Cuba, 12 faults on the island of Cuba are designated by Cotilla-Rodriguez et al. (Reference 494) as "active" based on their ambiguous definition of the term. For many faults in intraplate Cuba, the Cotilla-Rodriguez et al. (Reference 494) analysis does not provide sufficient information to conclude that a structure is a capable tectonic source according to RG 1.208. Table 2.5.1-204 provides a summary of these and other regional fault zones of Cuba. Available geologic and tectonic maps are 1:250,000 (Reference 846) and 1:500,000 scale (References 848 and 847) and therefore do not have sufficient detail to properly characterize fault activity based on map relations alone. Available information for the regional Cuban faults that extend to within the site region, and several that lie beyond it, is summarized below. LDP-CS564 PTN RAI 02.05.01-21

Baconao Fault PTN RAI 02.05.01-21

The Baconao fault is a northwest-striking fault located in southeastern Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 3). At its nearest point, the Baconao fault is approximately 530 kilometers (330 miles) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489) provide only minimal discussion of this fault but describe it as "better defined in its eastern part, where it has a clear expression mainly in relief and significant seismic activity at the intersection with the (Oriente fault zone)."

Cotilla-Rodríguez et al. (Reference 494) characterize the Baconao fault as active, based on geologic map relations, geomorphology, and its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494) describe the Baconao fault as "normal and reverse type with left strike-slip." Cotilla-Rodriguez et al. (Reference 494) note that, along the easternmost portion of the fault near the modern plate boundary, there are "vast, continuous and abrupt escarpments and many distorted and broken fluvial terraces of the Quaternary and Pleistocene." These observations, coupled with the proximity to the modern plate boundary (i.e., Oriente fault, Figure 2.5.1-247), suggest that the eastern portion of the Baconao fault may be Quaternary active.

Cotilla-Rodriguez et al. (Reference 494) list five earthquakes that they suggest may have occurred on the Baconao fault, all of which occurred between 1984 and 1987. Each of these five earthquakes is assigned Medvedev-Sonheuer-Karnik (MSK) intensity IV (approximate Modified Mercalli Intensity [MMI] IV) (Reference 494). As shown on Figure 2.5.1-368 Sheet 3, however, there is little to no seismicity from the Phase 2 earthquake catalog along much of the length of the Baconao fault, especially along the northwestern two-thirds of its length northwest of the intersection of the Nipe fault. It should be noted that the Phase 2 catalog is a declustered catalog that includes earthquakes of M_w 3 and larger. Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault. PTN RAI 02.05.01-21 LDP-CS564

The Baconao fault is not shown on Case and Holcombe's (Reference 480) 1:2,500,000 scale map of the Caribbean. Perez-Othon and Yarmoliuk (Reference 848), however, show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba. This unnamed fault is located in the vicinity of the Baconao fault and is depicted cutting Oligocene-Miocene strata, but covered by apparently unfaulted mid-Quaternary-age strata (Reference 848). According to mapping by Perez-Othon and Yarmoliuk (Reference 848), the Baconao fault appears to be offset in a right-lateral sense by two strands of the northeast-striking Nipe fault. As an inset to their geologic map, Perez-Othon and Yarmoliuk (Reference 848) provide an additional map that shows their estimates of fault ages in Cuba. A modified version of their inset map is provided as Figure 2.5.1-369. The inset map presented in Figure 2.5.1-369 was modified by enhancing the color-coding of the Perez-Othon and Yarmoliuk (Reference 848) age estimates and by adding fault name labels based on their relative locations. Most of the fault name labels added to the inset map are queried, however, indicating the uncertainty regarding which faults are, and which are not, shown on the inset map. If the unnamed fault depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba represents the Baconao fault, as is assumed on Figure 2.5.1-369, then they indicate a Neogene-Quaternary age for the southeastern one-third of the Baconao fault. The northwestern two-thirds of the Baconao fault as shown on Figure 2.5.1-368 Sheet 3 does not clearly appear on Perez-Othon and Yarmoliuk's (Reference 848) inset map (Figure 2.5.1-369). LDP-CS564 LDP-CS564

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Reference 944, plate III.1.2-3) and a 1:2,000,000 scale neotectonic map of Cuba (Reference 944, plate III.2.4-8). No fault names appear on these two maps so it is not clear whether the Baconao fault is shown. The geologic map of Cuba

PTN RAI 02.05.01-21

from this atlas shows an approximately 50-kilometer-long (30-mile-long), northwest-striking fault near Santiago de Cuba that may be the Baconao fault, but this fault is restricted to southernmost Cuba, southeast of the Nipe fault. This fault appears to cut middle Eocene strata. Likewise, the neotectonic map of Cuba from this atlas shows an approximately 75-kilometer-long (45-mile-long), northwest-striking fault in the same area of southernmost Cuba that could be the Baconao fault. The Baconao fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11). The Baconao fault is shown and labeled on Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba.

Camaguey Fault

The Camaguey fault is a northeast-striking fault located in southeastern Cuba (Figures 2.5.1-247, 2.5.1-251, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). At its nearest point, the Camaguey fault is approximately 530 kilometers (330 miles) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489) describe the Camaguey fault as a "regional transverse fault with lateral displacement that affects the whole crust and constitutes the boundary between two megablocks" and that "cuts young as well as old sequences." In their Figure 5, Garcia et al. (Reference 489) show the Camaguey fault as a normal fault with unspecified dip direction and sense of throw. Garcia et al. (Reference 489) also note that "the gravimetric and magnetic fields show apparent inflections."

Cotilla-Rodríguez et al. (Reference 494) classify the Camaguey fault as active based on the possible association of seismicity with the fault. Cotilla-Rodriguez et al. (Reference 494) describe the Camaguey fault as a sinistral strike-slip fault with an almost vertical plane associated with a low "level of seismic activity." They list ten earthquakes that they suggest may have occurred on the Camaguey fault. Three of these earthquakes are assigned MSK intensity III–IV (approximately MMI III–IV), with the remaining seven unspecified (Reference 494). As shown on Figures 2.5.1-368 Sheets 2 and 3, however, there is little to no seismicity from the Phase 2 earthquake catalog located along the length of the Camaguey fault, with the possible exception of a single, minor-magnitude earthquake near the northeastern end of the fault. Alternatively, this minor earthquake may be associated with the northwestern end of the Baconao fault or some other unmapped structure (Figure 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

The Camaguey fault is not consistently shown on geologic and tectonic maps of Cuba. For example, it is not labeled on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba, Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba, the Nuevo Atlas Nacional de Cuba 1:1,000,000 scale geologic map (Reference 944, plate III.1.2-3), and van Hinsbergen et al.'s (Reference 500) mapping of the Camaguey area. The Camaguey fault is depicted and labeled on the 1:2,000,000 scale lineament map from the national atlas (Reference 944, plate III.3.1-11) and shown but not labeled on the 1:2,000,000 scale neotectonic map from the same atlas (Reference 944, plate III.2.4-8). Because they do not label faults by name, it is not clear whether the Camaguey fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Camaguey fault (Figure 2.5.1-369). PTN RAI 02.05.01-21

Cochinos Fault

The Cochinos fault is a north- (References 494 and 770) to north-northwest-striking (Reference 493) fault in south-central Cuba. Figures 2.5.1-247, Figure 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2 show the location of the Cochinos fault after Hall et al. (Reference 770). As mapped by Hall et al. (Reference 770), the fault at its nearest point is approximately 330 kilometers (205 miles) from the Turkey Point Units 6 & 7 site. Alternatively, mapping by Cotilla-Rodriguez et al. (Reference 494) suggests this fault may extend northward to within 280 kilometers (175 miles) of the site, whereas mapping by Mann et al. (Reference 493) indicates a closest distance of approximately 340 kilometers (210 miles). The Cochinos fault is the only onshore feature in intraplate Cuba identified as "neotectonic" by Mann et al. (Reference 493) (Figure 2.5.1-286). They map the Cochinos fault as two parallel, north-northwest-striking normal faults that form a graben (Figures 2.5.1-286, 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2). The morphology of Bahia de Cochinos is consistent with this interpretation and suggests the possibility of fault control on the landscape.

Cotilla-Rodriguez et al. (Reference 494) describe the Cochinos fault as a "normal fault with a few inverse type sectors which demonstrates transcurrence to the left" and "normal and reverse type with left strike-slip." Recorded seismicity near the Cochinos fault is sparse. They list six earthquakes that they suggest may have occurred on the Cochinos fault. The largest of these is the December 16, 1982 M_s 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 site does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_w 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Based on the similarity in location, magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (Reference 494) manuscript. The remaining five earthquakes that Cotilla-Rodriguez et al. (Reference 494) associate with the Cochinos fault "are all of low [and unspecified] intensity." In the Phase 2 earthquake catalog, the 1982 earthquake is located approximately 5 kilometers (3 miles) northwest of the Cochinos fault trace (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) suggest that the 1982 earthquake may instead have occurred on the Habana-Cienfuegos fault. In addition to the 1982 earthquake, the Phase 2 earthquake catalog shows only four other earthquakes within 32 kilometers (20 miles) of the Cochinos fault, the largest of which is assigned M_W4.1 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault. PTN RAI 02.05.01-21

Cotilla-Rodríguez et al. (Reference 494) classify the Cochinos fault as active based on the possible association of seismicity with the fault. Cotilla-Rodríguez et al. (Reference 494) provide no geologic evidence for activity on the Cochinos fault and describe the fault as "covered by young sediments." Indeed, the most detailed geologic maps inspected in the area (1:250,000 scale) show no fault cutting Miocene and younger strata (Reference 846). Because they do not label faults by name, it is not clear whether the Cochinos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for a northern extension of this fault (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba shows and labels the approximately 100-kilometer-long (60-mile-long) Cochinos fault. The southern approximately 80 kilometers (50 miles) of this fault are shown as a dashed line. Garcia et al. (Reference 489) provide no discussion of the Cochinos fault.

The Cochinos fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map of Cuba from this atlas (Reference 944, plate III.1.2-3) shows an approximately 140-kilometer-long (87-mile-long) unnamed fault in the vicinity of the Cochinos fault that extends from Cuba's northern coast where it is mapped in Pliocene-age deposits southward into the Bahia de Cochinos. The southernmost 30 kilometers (18 miles) of this fault are shown by a dashed line. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Reference 944, plate III.2.4-8) shows an approximately 140-kilometer long (87-mile-long) unnamed fault in the vicinity of the Cochinos fault, the southernmost 50 kilometers (30 miles) of which is offshore southern Cuba and shown by a dashed line. To the north, this fault on the neotectonic map is truncated by the Hicacos fault. The Cochinos fault is depicted and labeled on the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11). The 1:1,000,000 scale geomorphic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate IV.3.2-3) shows an approximately 60-kilometer-long (37-mile-long) unnamed fault in the vicinity of the Cochinos fault. The map explanation indicates that this fault cuts a Quaternary-age marine abrasion platform that is at an elevation of either 2– 3 meters (6.6-9.8 feet) or 5–7 meters (16.4-23 feet) above sea level. They do not provide explanation for the lack of specificity in elevation of the platform nor do they provide a precise age for the Quaternary abrasion platform. PTN RAI 02.05.01-21

Cubitas Fault

The Cubitas fault is a northwest-striking, steeply south-dipping fault located in southeastern Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). At its nearest point, the Cubitas fault is approximately 435 kilometers (270 miles) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489) describe the Cubitas fault as a "deep fault that constitutes a portion of the Cuban marginal suture and is considered to be the main structure in central Cuba. It is cut by the Camaguey and the La Trocha transverse faults, where seismicity is documented." They associate the 1974 M_s 4.5 MSK VII Esmeralda earthquake (month and day unspecified) with the Cubitas fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Cubitas fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494) describe the Cubitas fault as "an almost vertical normal fault with some sectors of inverse type" and as "normal and reverse type." They describe large scarps associated with this fault but do not provide additional descriptions of the scarps. They assign a Pliocene to Quaternary age for this fault. Cotilla-Rodriguez et al. (Reference 494) list 15 earthquakes that they suggest may have occurred on the Cubitas fault. Eight of these earthquakes are assigned MSK intensity III–V (approximately MMI III–V), with the remaining seven unspecified (Reference 494). The Phase 2 earthquake catalog includes several low-magnitude earthquakes that may be spatially associated with the northwestern half of the Cubitas fault (Figures 2.5.1-368 Sheet 2 and 2.5.1-368 Sheet 3). The central and southeastern portions of the fault appear largely devoid of seismicity. The Phase 2 earthquake catalog indicates M_w 4.0 and M_w 5.1

earthquakes occurred approximately 24 kilometers (15 miles) south of the mapped trace near the northwestern end of the fault in 1974 and 1984, respectively, which may be associated with the Cubitas fault. Cotilla-Rodriguez et al (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault. PTN RAI 02.05.01-21

Van Hinsbergen et al. (Reference 500) describe the Cubitas fault as a post-Middle Eocene, south-dipping normal fault that forms a steep slope along the southern margin of the Cubitas Hills. They describe approximately 200 meters (650 feet) of uplift associated with the Cubitas Hills that post-dates deposition of Pliocene-Pleistocene (?) fluvial deposits north of the hills. If this interpretation is correct, then this uplift may have occurred in the hanging wall of the Cubitas fault, which may be Quaternary-active (Reference 500).

Pushcharovskiy et al. (Reference 846) do not label the Cubitas fault on their 1:250,000 scale geologic map. Pushcharovskiy (Reference 847) shows the Cubitas fault as an approximately 85 kilometers long (50-mile-long), south-dipping thrust fault on the 1:500,000 scale tectonic map. Because they do not label faults by name, it is not clear whether the Cubitas fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Cubitas fault (Figure 2.5.1-369).

The Cubitas fault does not appear on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3), but seemingly does appear as an unnamed fault on the 1:2,000,000 scale neotectonic map from this same atlas (Reference 944, plate III.2.4-8). The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) labels an approximately 85-kilometer-long (50-mile-long) feature as the Cubitas fault.

Domingo Fault

At its nearest point, the low-angle Domingo fault is located 282 kilometers (175 miles) south of the Turkey Point Units 6 & 7 site. This northwest-striking, south-dipping thrust fault carried the Cretaceous arc and serpentinites over the carbonate platform rocks and can be considered the former suture between North America and Caribbean plates (References 439 and 440) (Figure 2.5.1-247). The Domingo fault does not cut the uppermost Eocene and younger sedimentary units, and is late Eocene in age (References 430 and 440). A myriad of other thrusts are mapped in detail (though not shown Figure 2.5.1-247), which imbricate both the autochthonous and allochthonous units on the island (Reference 439).

On 1:250,000 scale maps and interpreted cross sections, these faults also do not cut the uppermost Eocene and younger deposits, and so are not Quaternary in age (References 439, 440, 497, and 846) (Figure 2.5.1-248). PTN RAI 02.05.01-21

Guane Fault

The subsurface Guane fault is a northeast-striking fault in western Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 1). At its nearest point, the Guane fault is approximately 370 kilometers (230 miles) from the Turkey Point Units 6 & 7 site. Garcia et al. (Reference 489) provide no discussion of the Guane fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Guane fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494) describe he Guane fault as a “large and complex structure totally covered by young sediments in the Palacios Basin” that is “predominantly vertical with left transcurrence.” 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 6.1 San Cristobal earthquake. In the Phase 2 earthquake catalog, seismicity in the vicinity of the Guane fault is sparse, but other light- to-moderate magnitude earthquakes within 32 kilometers (20 miles) 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 2.5.1-368 Sheet 1). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Based on their review of aerial photographs and satellite imagery, Cotilla-Rodriguez and Cordoba-Barba (Reference 942) note two rivers in the Palacios Basin (Bayate and San Cristobal rivers) that show, in plan view, what they call “fluvial inflections” that they interpret as the result of surface deformation associated with the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 942) indicate this allows for “the identification of an SW-NE alignment on the south plain of Pinar del Rio, corresponding to the Guane fault, whith *[sic]* was responsible for the San Cristobal earthquake on the 28.01.1880.” However, other rivers along strike to the northeast and southwest do not appear to show such inflections. Moreover, Cotilla-Rodriguez et al. (Reference 494) indicate the Guane fault is “totally covered by young sediments in the Palacios Basin.” Likewise, Cotilla-Rodriguez and Cordoba-Barba (Reference 943) indicate the Guane fault “is located under ample thicknesses of sediments of the plain in southern Pinar del Rio.” The Cotilla-Rodríguez et al. (Reference 494) and Cotilla-Rodriguez and Cordoba-Barba (Reference 943) studies do not specify a burial depth for the Guane fault, but seemingly are at odds with Cotilla-Rodriguez and Cordoba-Barba's (Reference 942) interpretation of surface manifestation of deformation. PTN RAI 02.05.01-21

Cotilla-Rodriguez and Cordoba-Barba (Reference 943) 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. 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 (discussed below) but rather within the Palacios Basin near the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 943) cite this as evidence that the 1880 earthquake occurred on the Guane fault. Cotilla-Rodriguez and Cordoba-Barba (Reference 943) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Alternatively, however, the pattern of 1880 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. In other words, the pattern of 1880 damage is not conclusive evidence that the earthquake occurred on the Guane fault, as opposed to on the Pinar fault or other structure.

The Guane fault is not depicted on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Perez-Othon and Yarmoliuk (Reference 848) show an unnamed, dashed fault on their 1:500,000 scale geologic map of Cuba in the vicinity of the Guane fault that cuts Miocene strata, but is covered by unfaulted Pliocene-Pleistocene units. Because they do not label faults by name, it is not clear whether the Guane fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Guane fault (Figure 2.5.1-369). The Guane fault does not seem to appear on any maps in the Nuevo Atlas Nacional de Cuba (Reference 944).

Habana-Cienfuegos Fault

The Habana-Cienfuegos fault is a northwest-striking, left-lateral strike-slip fault in western and central Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 1, and 2.5.1-368 Sheet 2). At its nearest point, the Habana-Cienfuegos fault is approximately 355 kilometers (220 miles) from the Turkey Point Units 6 & 7 site. Cotilla-Rodriguez et al. (Reference 494) map the Habana-Cienfuegos fault as extending offshore in northern Cuba, where it terminates at or south of the Nortecubana fault, with which it forms a "morphostructural knot" (Reference 494) (Figures 2.5.1-368

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Sheet 1 and 2.5.1-368 Sheet 2). Offshore of southern Cuba, the Habana-Cienfuegos fault is shown as intersected and terminated by the Surcubana fault in a similar “morphostructural knot” (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2, and Figure 5 of Reference 494). Cotilla-Rodriguez et al. (Reference 494) indicate that the Habana-Cienfuegos fault is expressed in the topography in the northwest at Havana Bay and in the southeast at Cienfuegos Bay.

Garcia et al. (Reference 489) provide minimal discussion of the Habana-Cienfuegos fault. Garcia et al. (Reference 489) indicate “although the earthquakes reported in Havana and some locations of its province cannot be attributed to the western portion of the Norte Cubana seismic region, the seismic activity of the Havana fault system is still under debate.” Further to the southeast, Garcia et al. (Reference 489) indicate that the Cienfuegos fault “coincides with a deep fault located under younger tectonic sequences, it does not have a well-defined character.”

In the Phase 2 earthquake catalog, seismicity is sparse in the vicinity of the Habana-Cienfuegos fault (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (Reference 494) list nineteen earthquakes that they suggest may have occurred on the Habana-Cienfuegos fault, many of which are listed by year only without month, day, intensity, and magnitude information. The largest of these earthquakes is the December 16, 1982 M_s 5.0 earthquake. The Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 site does not include an earthquake on that date with similar magnitude and location. The Phase 2 earthquake catalog does, however, include an M_W 5.4 earthquake near the Cochinos fault that occurred on November 16, 1982 (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). Based on the similarity in location, magnitude, and year for the December 16 and November 16 earthquakes, it is assumed that these are the same earthquake and that the discrepancy in month is the result of a typographical error in Cotilla-Rodríguez et al.'s (Reference 494) manuscript. In the Phase 2 earthquake catalog, this earthquake is located approximately 11 kilometers (7 miles) north of the Habana-Cienfuegos fault trace (Figure 2.5.1-368 Sheet 1). Cotilla-Rodriguez et al. (Reference 494) alternatively suggest that this earthquake may have occurred on the Cochinos fault instead. They also associate an M_s 2.5 earthquake and nine MSK intensity III–V earthquakes (approximately MMI III–V) with the Habana-Cienfuegos fault. Cotilla-Rodriquez et al. (Reference 494) suggest that the March 9, 1995, M_s 2.5 earthquake could have occurred on the Habana-Cienfuegos fault or on the nearby Guane fault.

Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault. PTN RAI 02.05.01-21

The Habana-Cienfuegos fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba and Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba. Because they do not label faults by name, it is not clear whether the Habana-Cienfuegos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the Habana-Cienfuegos fault (Figure 2.5.1-369).

The 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3) shows an approximately 40-kilometer-long (25-mile-long) unnamed fault near Havana in the vicinity of the northwestern-most portion of the Habana-Cienfuegos fault as shown on Figures 2.5.1-368 Sheet 1. Similarly, the 1:2,000,000 scale neotectonic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.2.4-8) shows an approximately 60-kilometer-long (37-mile-long) unnamed fault in the same vicinity, the southeastern 20 kilometers (12 miles) of which is shown as a dashed line. Neither of these maps from the Nuevo Atlas Nacional de Cuba (Reference 944, plates III.2-3 and III.2.4-8) shows a fault extending from Havana southeastward to the southern coast of Cuba, as shown by Cotilla-Rodríguez et al. (Reference 494).

Hicacos Fault

The Hicacos fault is an east-northeast-striking fault in north-central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 1). At its nearest point, the Hicacos fault is approximately 250 kilometers (155 miles) south of the Turkey Point Units 6 & 7 site. Based on mapping by Cotilla-Rodriguez et al. (Reference 494), the Hicacos fault is the nearest fault in Cuba to the site identified as active by these authors. Some publications (Reference 769) refer to this fault as the Matanzas fault. LDP-CS564

Garcia et al. (Reference 489) provide minimal discussion of the Hicacos fault. They indicate it is “a deep fault above Paleocene-Quaternary formations, splitting the ophiolites sequence that makes the main Cuban watershed deviate abruptly, causing different types of fluvial networks.” Garcia et al. (Reference 489) state that the “earthquakes reported in Matanzas and more recently in the Varadero-Cardenas area are associated with this structure.” They provide no additional information regarding these earthquakes.

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Cotilla-Rodríguez et al. (Reference 494) characterize the Hicacos fault as active based on its possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494) describe the Hicacos fault as a "normal fault, transcurrent to the left" that is "expressed throughout the Peninsula de Hicacos and is internal in the island territory by the eastern edge of Matanzas Bay, delineating very well the Matanzas Block." Further to the west-southwest, Cotilla-Rodriguez et al. (Reference 494) indicate that the Hicacos fault is "weakly represented" in the geomorphology.

Seismicity in the vicinity of the Hicacos fault is sparse (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). The nearest epicenters from the Phase 2 earthquake catalog to the Hicacos fault are four co-located M_W 3.1 to 3.7 earthquakes that occurred near the central portion of the fault in 1812, 1852, 1854, and 1970. Another earthquake occurred in 1777 with M_W 3.7, located on strike with, but approximately 11 kilometers (7 miles) southwest of, the mapped fault trace. Likewise, Cotilla-Rodriguez et al. (Reference 494) indicate sparse seismicity near the Hicacos fault, and note that no focal mechanisms are associated with earthquakes in the vicinity of this fault. According to Cotilla-Rodriguez et al. (Reference 494), historical accounts suggest ten earthquakes of less than or equal to MSK intensity V (approximately MMI V) occurred in the vicinity of the Hicacos fault (Reference 494). However, the association of these earthquakes with the Hicacos fault or another mapped or unmapped fault is problematic due to the uncertainties associated with the locations of both faults and earthquakes in Cuba and the paucity of available focal plane solutions.

Case and Holcombe's (Reference 480) 1:2,500,000 scale map of the Caribbean region shows segments of the Hicacos fault cutting upper Tertiary rocks. Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map of Cuba shows an unnamed fault in the vicinity of the Hicacos fault that extends from Matanzas for approximately 80 kilometers (50 miles) to the southwest. Because they do not label faults by name, it is not clear whether the Hicacos fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba. They indicate, however, a Mesozoic age for an unnamed fault in the vicinity of the northeastern-most portion of the Hicacos fault (Figure 2.5.1-369). Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba shows an unnamed fault cutting lower Miocene rocks in the vicinity of the central Hicacos fault as shown on Figure 2.5.1-368 Sheet 1, but their mapping does not extend this fault as far northeast as the north coast of Cuba. The locally northeast-trending shoreline and a narrow peninsula near Matanzas are notably linear and on-trend with the fault, likely influencing where the fault is mapped in other representations. Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba shows the northeastern extent of the Hicacos fault similar to the depiction shown in Figure 2.5.1-368 Sheet 1, and terminating to the southwest at Cuba's southern coast. PTN RAI 02.05.01-21

The Hicacos fault is depicted differently on different maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map from this atlas (Reference 944, plate III.1.2-3) shows an unnamed, northeast-striking, approximately 40-kilometer-long (25-mile-long) fault in the in the vicinity of the Hicacos fault. This unnamed fault is mapped within lower to middle Miocene-age deposits and does not appear to cut Holocene-age deposits near Matanzas at the northeastern end of the fault. The 1:1,000,000 scale geomorphic map from this atlas (Reference 944, plate IV.3.2-3) shows an unnamed fault offshore along the narrow peninsula that may be the Hicacos fault, but this offshore fault does not extend onshore to the southwest. The Hicacos fault is labeled on the lineament map from this atlas (Reference 944, plate III.3.1-11) as an approximately 175-kilometer-long (110-mile-long), northeast-trending feature that extends from near Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas on Cuba's north coast. On the lineament map, the northeastern-most 35 kilometers (20 miles) of this feature are shown as a dashed line. The 1:2,000,000 scale neotectonic map from this atlas (Reference 944, plate III.2.4-8) shows an unnamed, northeast-striking fault in the vicinity of the Hicacos fault that extends from Cuba's south coast, across Cuba, and along the narrow peninsula near Matanzas, and offshore where it is terminated by an unnamed fault that likely is the Nortecubana fault.

Various researchers describe elevated marine terraces west of Matanzas Bay near the Hicacos fault along Cuba's north coast. Continuous and planar geomorphic surfaces like these can be used as Quaternary strain markers with which to assess the presence of tectonic deformation. Ducloz (Reference 915) and Shanzer et al. (Reference 923) provide observations of Pleistocene-age terraces in this region, including the Terraza de Seboruco terrace, which is currently a few meters above modern sea level. Both Ducloz (Reference 915) and Shanzer et al. (Reference 923) speculate that Pleistocene-age terraces in this region may have formed as the result of both tectonic uplift and global fluctuations in sea level.

More recent studies, however, conclude that tectonic uplift is not required to explain the present elevation of the Pleistocene-age Terraza de Seboruco terrace west of Matanzas Bay and near the Hicacos fault. Toscano et al.'s (Reference 925) radiometric age dating of coral samples collected from the

Terraza de Seboruco terrace indicates this surface formed at approximately 120–140 ka. Based on these ages, they associate the Terraza de Seboruco terrace with the global Substage 5e sea level high-stand at approximately 122 ka. Toscano et al. (Reference 925) also observe that this terrace in the Matanzas area is just a few meters above mean sea level, similar to the elevation of other Substage 5e reef deposits throughout "stable" portions of the Caribbean and, therefore, can be explained solely by changes in sea level. Toscano et al. (Reference 925) conclude that "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba." Similarly, Pedoja et al. (Reference 920) investigated late Quaternary coastlines worldwide and observe minor uplift relative to sea level of approximately 0.2 millimeter/year, even along passive margins, outpacing eustatic sea level decreases by a factor of four. They suggest that, when accounting for eustatic changes in sea level, the Substage 5e terrace in the Matanzas area (i.e., the Terraza de Seboruco terrace) has been uplifted at an average rate that ranges from approximately 0.00 to 0.04 millimeters/year over the last approximately 122 ka, consistent with uplift rates observed from other stable margins worldwide. If the effects of eustasy are ignored, Pedoja et al.'s (Reference 920) data allow for an uplift rate at Matanzas of approximately 0.06 millimeter/year over the last approximately 122 ka, following this "conservative" (Reference 920) approach. PTN RAI 02.05.01-21

Whereas recent studies indicate that tectonic uplift is not required to explain the present elevation of the Terraza de Seboruco terrace west of Matanzas Bay (References 920 and 925), these data do not preclude activity on the Hicacos fault. As described above, the location and extent of the Hicacos fault differs between various geologic maps and published figures, so it is unclear whether the Hicacos fault is overlain by the Terraza de Seboruco terrace. Furthermore, if the sense of slip on the Hicacos fault were primarily strike-slip as opposed to dip-slip, it could be difficult to observe surface manifestation of fault-related deformation on the Terraza de Seboruco terrace.

La Trocha Fault

The La Trocha fault is a northeast-striking fault in central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 2). At its nearest point, the La Trocha fault is approximately 420 kilometers (260 miles) from of the Turkey Point Units 6 & 7 site. Rosencrantz (Reference 529) maps a northeast-striking structure across the Yucatan basin south of Cuba (Figure 2.5.1-286) and interprets it as the southwestern extension of the La Trocha fault.

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Garcia et al. (Reference 489) provide minimal discussion of the La Trocha fault. Garcia et al. (Reference 489) indicate it is a “deep fault more than 180 kilometers (112 miles) long, with neotectonic transcurrent activity” and “its seismicity is documented by the earthquakes in the Santi Spiritus region.” They also indicate that the La Trocha fault is expressed in geophysical data, but they do not elaborate.

Cotilla-Rodríguez et al. (Reference 494) assign the La Trocha fault an age of Pliocene-Quaternary and also suggest a possible association with seismicity. Cotilla-Rodriguez et al. (Reference 494) describe the La Trocha fault as “a fault zone transcurrent to the left with a large angle.” They suggest a possible association between three earthquakes of less than or equal to MSK intensity V (approximately MMI V) and the La Trocha fault. The Phase 2 earthquake catalog shows very sparse seismicity associated with the La Trocha fault (Figure 2.5.1-368 Sheet 2). The largest earthquakes from the Phase 2 earthquake catalog near the La Trocha fault are the March 10, 1952 M_w 4.0 and January 1, 1953 M_w 4.3 events. Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

Leroy et al. (Reference 499) interpret the La Trocha fault as the northern transform limb of a proto-Cayman spreading center that was active in the early Eocene (53 Ma) and was abandoned by 49 Ma. This interpretation is the result of the southward migration of the left lateral strike slip faults that make up the Caribbean-North America plate boundary (Reference 639).

The La Trocha fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Review of Pushcharovskiy et al.'s (Reference 846) maps in the vicinity where Cotilla-Rodriguez et al. (Reference 494) map the La Trocha fault indicates no northeast-striking faults cutting Miocene and younger strata. Potentially, this structure is buried by the overlying strata and could be pre-middle Miocene in age. Pushcharovskiy's (Reference 847) tectonic map of Cuba, however, clearly depicts and labels the La Trocha fault with extent and location similar to the La Trocha fault shown in Figure 2.5.1-368 Sheet 2. Because they do not label faults by name, it is not clear whether the La Trocha fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Neogene-Quaternary age for an unnamed fault in the vicinity of the La Trocha fault (Figure 2.5.1-369).

The La Trocha fault is depicted differently on various maps from the Nuevo Atlas Nacional de Cuba (Reference 944). The 1:1,000,000 scale geologic map of Cuba from this atlas (Reference 944, plate III.1.2-3) does not include the La Trocha fault. The 1:2,000,000 scale neotectonic map of Cuba from this atlas (Reference 944, plate III.2.4-8) shows an unnamed fault in the vicinity of the La Trocha fault. This unnamed fault is mapped as terminating northward at the northern coast of Cuba. The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) depicts and labels the La Trocha fault as an approximately 150-kilometer-long (90-mile-long), northeast-trending feature that extends from Cuba's southern to its northern coast. PTN RAI 02.05.01-21

Las Villas Fault

The Las Villas fault is a northwest-striking fault in central Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 2). At its nearest point, the Las Villas fault is approximately 250 kilometers (155 miles) south of the Turkey Point Units 6 & 7 site. Pardo (Reference 439) maps the Las Villas fault as a south-dipping thrust with up to approximately 30 kilometers (18 miles) of horizontal displacement. According to Pardo (Reference 439), the Las Villas fault displaces middle Eocene units, but exhibits greater displacement of older units, indicating that most of its movement was pre-middle Eocene.

Garcia et al. (Reference 489) describe the Las Villas fault as a "deep fault that divides the younger coastal formations of the north from the older ones of the south, it appears as a negative anomaly in the gravimetric map and with positive and negative anomalies in the magnetic field. Medium-magnitude seismicity is associated with this fault."

Cotilla-Rodríguez et al. (Reference 494) characterize the Las Villas fault as active based on its possible association with seismicity and geomorphic expression. Cotilla-Rodríguez et al. (Reference 494), however, provide only the following minimal description of the Las Villas fault:

> This 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. (Reference 494) do not describe their basis for concluding that the Las Villas fault is Pliocene -Quaternary in age and they do not provide reference to other publications that provide this information. Likewise, Cotilla-Rodríguez et al. (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 limited 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. It is also possible that these "young eroded scarps" formed by preferential erosion of sheared rocks within the fault zone. Based on the scant information provided in Cotilla-Rodríguez et al. (Reference 494), it is not possible to distinguish between these alternatives. There are no known paleoseismic trench studies or detailed geomorphic assessments of the Las Villas fault with which to assess recent earthquake activity on this fault. Where faults exhibit scarps in young deposits or surfaces, such as the Baconao fault in southernmost Cuba, Cotilla-Rodriguez et al. (Reference 494) provide clear description and do not include "eroded" in the description.

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Figure 2.5.1-368 Sheet 2 indicates moderately sparse seismicity from the Phase 2 earthquake catalog that may be roughly aligned with the Las Villas fault, as mapped by Pardo (Reference 439). A total of 33 earthquakes from the Phase 2 earthquake catalog are located within approximately 10 kilometers (6 miles) 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 5 kilometers (3 miles) northeast of the fault (Figure 2.5.1-368 Sheet 2). Cotilla-Rodriguez et al. (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. (Reference 494) suggest that the largest recorded earthquake associated with the Las Villas fault is the M_S 5.6 event on August 15, 1939 (listed in the Phase 2 earthquake as M_W 5.84). Based on the fault mapping of Pardo (Reference 439) and the location of this earthquake from the Phase 2 earthquake catalog, however, this earthquake is located approximately 32 kilometers (20 miles) northeast of this southwest-dipping fault (Figure 2.5.1-368 Sheet 2), suggesting a fault other than the Las Villas ruptured during this event.

Review of geologic mapping (References 480, 846, and 848) reveals that no units of Quaternary age are faulted, but the coarse scale of mapping (1:250,000 to

1:2,500,000) does not preclude recent activity. Because they do not label faults by name, it is not clear whether the Las Villas fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Las Villas fault (Figure 2.5.1-369). PTN RAI 02.05.01-21

The Las Villas fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Reference 944, plate III.2.4-8) shows an unnamed fault in the vicinity of the Las Villas fault. Likewise, the 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) depicts and labels the Las Villas fault as an approximately 190-kilometer-long (120-mile-long), northwest-trending feature.

Nipe Fault

The Nipe fault is a northeast-striking fault in southern Cuba (Figures 2.5.1-247 and 2.5.1-368 Sheet 3) that separates the mountainous Sierra Maestra province on the east from the Camaguey terrane on the west. At its nearest point, the Nipe fault is approximately 675 kilometers (420 miles) from the Turkey Point Units 6 & 7 site. Other names for this fault include the Cauto, Cauto-Nipe, Guacanayabo, and Nipe-Guacanayabo fault.

Leroy et al. (Reference 499) and Rojas-Agramonte et al. (Reference 445) interpret the Nipe fault as the southern transform limb of the early Cayman spreading center. In their models, the Nipe fault was abandoned by the early Oligocene (approximately 20 Ma) as the plate boundary shifted south to its present location at the Oriente fault.

Cotilla-Rodríguez et al. (Reference 494) characterize the Nipe fault as active based on possible association of seismicity with the fault and gross geomorphic expression. Cotilla-Rodriguez et al. (Reference 494) describe the Nipe fault as "a fault system with transcurrence to the left" whose "outline is labeled by several epicenters" including "some epicentral swarms" near its northeastern end. The Phase 2 earthquake catalog shows sparse seismicity associated with the Nipe fault (Figure 2.5.1-368 Sheet 3). The largest earthquakes in the vicinity of the fault include the August 3, 1926 M_W 5.3 and July 19, 1962 M_W 5.36 earthquakes (Figure 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) indicate there are no earthquake focal mechanisms associated with this fault.

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Unnamed faults in the vicinity of the Nipe fault are shown on Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map of Cuba. Because they do not label faults by name, it is not clear whether the Nipe fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Paleogene age for an unnamed fault in the vicinity of the mapped position of the Nipe fault (Figure 2.5.1-369). Unnamed faults in the vicinity of the Nipe fault also are shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic map of Cuba. Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba depicts and labels the Nipe fault as the "Cauto-Nipe" fault.

The Nipe fault is not shown on the 1:1,000,000 scale geologic map of Cuba from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). The 1:2,000,000 scale neotectonic map of Cuba from the same atlas (Reference 944, plate III.2.4-8), however, shows two subparallel, unnamed faults in the vicinity of the Nipe fault. The 1:2,000,000 scale lineament map from this atlas (Reference 944, plate III.3.1-11) labels two faults as "Cauto I" and "Cauto II" in the vicinity of the Nipe fault. On this map, Cauto I strikes northeast and extends from Cuba's southern to its northern coast. Cauto II is more northerly striking and is truncated by Cauto I.

Nortecubana Fault

The Nortecubana fault system is the main structure within the Cuban fold-and-thrust belt offshore of, and nearshore to, northern Cuba (Figures 2.5.1-247, 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). The Nortecubana fault system dips south with a dip angle that varies along strike. At its nearest point, the Nortecubana fault system is approximately 240 kilometers (150 miles) from the Turkey Point Units 6 & 7 site.

The role of the Nortecubana thrust in the evolution of the Caribbean-North America plate boundary has been interpreted in different ways. The Nortecubana fault system may represent the ancestral subduction zone that was abandoned as the plate boundary shifted southward towards its current location south of Cuba. 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 the North America plate south of Cuba (References 439 and 786). Regardless of its ancestral origins, the Nortecubana fault system underlies the preponderance of folding and deformation within and just north of Cuba, which is collectively referred to as the Cuban fold-and-thrust belt. Wells drilled directly offshore of northeastern Cuba have encountered faults and repeated stratigraphy indicating Eocene thrusting (Reference 439), and seismic reflection data have imaged northward thrusting of basin deposits (Reference 307). Seismic lines typically indicate that the offshore north-vergent thrusts are draped by unfaulted late Tertiary to Quaternary sediments (Figures 2.5.1-279, 2.5.1-280, 2.5.1-282, 2.5.1-287, and 2.5.1-288). PTN RAI 02.05.01-21

Cotilla-Rodríguez et al. (Reference 494) characterize the Nortecubana fault as active based on its possible association with seismicity. They note that the preponderance of this seismic activity is associated with eastern portions of the fault nearest the modern plate boundary. In the Phase 2 earthquake catalog developed for the Turkey Point Units 6 & 7 site, seismicity along the west and central portions of the Nortecubana fault is sparse (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2), relative to the easternmost portion of the fault (Figure 2.5.1-368 Sheet 3). The Phase 2 earthquake catalog includes a M_W 6.29 earthquake that occurred on February 28, 1914 off the north coast of southeastern Cuba (Figure 2.5.1-368 Sheet 3). Cotilla-Rodríguez et al. (Reference 494) suggest this earthquake occurred on the Nortecubana fault. Due to the absence of a permanent seismic monitoring network in Cuba, however, this epicenter is poorly located. The given location, at approximately 6 kilometers (4 miles) north-northeast of the south-dipping Nortecubana fault (and approximately 640 kilometers [400 miles] from the Turkey Point Units 6 & 7 site), suggests that this earthquake could have occurred on another fault. Due to uncertainties in the locations of the 1914 earthquake as well as the fault, this does not preclude the 1914 earthquake from having occurred on the Nortecubana fault. No focal mechanism or depth determination for this earthquake is available with which to help identify the causative fault. It is unlikely that an earthquake of this magnitude would have ruptured to surface of the ocean floor but, even if it had, bathymetric data are insufficient to assess the presence of a submarine fault scarp and no detailed submarine paleoseismic studies are available for the region. Thus, it is not possible to definitively state whether the 1914 earthquake occurred on the Nortecubana or another fault.

The submarine Nortecubana fault typically does not appear on regional surface geologic maps. For example, the Nortecubana fault is not shown on Perez-Othon and Yarmoliuk's (Reference 848) 1:500,000 scale geologic map, Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). This fault, however, is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (Reference 847) 1:500,000 scale tectonic map of Cuba shows the Nortecubana fault as an unnamed,

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discontinuous, dashed line north of Cuba. The 1:2,000,000 scale neotectonic and lineament maps from the Nuevo Atlas Nacional de Cuba (Reference 944, plates III.2.4-8 and III.3.1-11) show but do not label the Nortecubana fault as solid and dashed lines, respectively. Because they do not label faults by name, it is not clear whether the Nortecubana fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Nortecubana fault (Figure 2.5.1-369).

Oriente Fault Zone

The most seismically active region of Cuba today is the Oriente fault zone, located offshore south of eastern Cuba (Figures 2.5.1-229, 2.5.1-247, 2.5.1-251, and 2.5.1-368 Sheet 3). This left-lateral fault system is part of the active North America-Caribbean Plate boundary and connects the Cayman Trough spreading center to the Septentrional fault (Figure 2.5.1-202). Geodetic data indicate that between 8 and 13 millimeters/year of slip are accommodated on this structure; hence it is classified as a capable tectonic source. For further discussion, see Subsections 2.5.1.1.2.3.1.2, 2.5.2.4.4.3.2.2, and 2.5.2.4.4.3.2.3.

Pinar Fault

The Pinar fault is a northeast-striking, steeply southeast-dipping fault in western Cuba (Figures 2.5.1-247, 2.5.1-251, 2.5.1-289, and 2.5.1-368 Sheet 1). As mapped by Tait (Reference 448) and shown on Figures 2.5.1-368 Sheet 1, the Pinar fault is located, at its nearest point, approximately 330 kilometers (205 miles) from the Turkey Point Units 6 & 7 site. As mapped by Garcia et al. (Reference 489), the Pinar fault is approximately 320 kilometers (200 miles) southwest of the site at its nearest point. As mapped by Cotilla-Rodríguez et al. (Reference 494), the Pinar fault is approximately 360 kilometers (225 miles) southwest of the site at its nearest point. Rosencrantz (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 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. There are, however, conflicting opinions in the literature regarding whether the Pinar fault is active. 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 23, 1880 M_W 6.13

earthquake (Figure 2.5.1-368 Sheet 1). Cotilla-Rodríguez et al. (Reference 494) describe the Pinar fault as having "very nice relief expression" but conclude it is "inactive." Cotilla-Rodríguez et al. (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 in the Los Palacios basin to the southeast (Figures 2.5.1-368 Sheet 1). PTN RAI 02.05.01-21

Cotilla-Rodriguez and Cordoba-Barba (Reference 943) 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. Cotilla-Rodriguez and Cordoba-Barba (Reference 943) conclude that the Pinar fault "is not the seismogenetic element of the January 23, 1880 earthquake" and that it is "subordinate to" the Guane fault. Gordon et al. (Reference 697) describe multiple phases of deformation in western Cuba in general and on the Pinar fault in particular. Gordon et al. (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."

The Phase 2 earthquake catalog indicates that a M_W 6.13 earthquake occurred on January 23, 1880 in western Cuba in the vicinity of the Pinar and Guane faults (Figures 2.5.1-368 Sheet 1). The epicenter of this poorly located, pre-instrumental earthquake is approximately 11 kilometers (7 miles) south of the trace of the steeply southeast-dipping Pinar fault and approximately 8 kilometers (5 miles) north of the Guane fault. As Garcia et al. (Reference 489) suggest, however, locational uncertainties for historical earthquakes in Cuba could be on the order of 15 to 20 kilometers (9 to 12 miles) or more. Based on available information, it is not possible to definitively state whether the 1880 earthquake occurred on the Guane fault, the Pinar 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. The Phase 2 earthquake catalog indicates generally sparse seismicity in the vicinity of the Pinar fault (Figure 2.5.1-368 Sheet 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 and south of the fault in the Sierra del Rosario mountains and the Palacios Basin. The Phase 2 earthquake catalog 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 2.5.1-368 Sheet 1).

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The Pinar fault is depicted on many regional scale maps of Cuba, including numerous maps in the Nuevo Atlas Nacional de Cuba (Reference 944) and Pushcharovskiy's (Reference 847) 1:500,000 scale tectonic map of Cuba. Available geologic mapping at scales between 1:250,000 and 1:1,000,000 is consistent with an active Pinar fault. These data do not, however, 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 (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 5 kilometers (3 miles) 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. Along strike immediately to the south near Playa de Galafre on Cuba's southern coast, however, the fault is covered by the same upper Pliocene to lower Pleistocene unit with no apparent deformation (Reference 846). Along the central portion of the fault near Pinar del Rio, Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic mapping shows an approximately 6-kilometer-long (4-mile-long) section where weakly cemented upper Pliocene-lower Pleistocene undifferentiated alluvial and marine deposits on the southeast are fault-juxtaposed against 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 preexisting 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 (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 (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 (Reference 848) mapping, and unlike Pushcharovskiy et al.'s (Reference 846) mapping, these Plio-Pleistocene deposits extend very close to, but are not in contact with, the fault. Instead, Perez-Othon and Yarmoliuk (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 (Reference 848) show an approximately 2- to 4-kilometer-long (1- to 2-mile-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) (Reference 848) mapping is insufficient to determine whether these Quaternary alluvial deposits are faulted or if they were deposited against preexisting 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 (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 (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. PTN RAI 02.05.01-21

The Nuevo Atlas Nacional de Cuba includes a 1:1,000,000 scale geologic map of Cuba (Reference 944, 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 (Reference 944, 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 in an "intense" zone.

Surcubana Fault

At its nearest distance, the Surcubana fault as mapped by Cotilla-Rodriguez et al. (Reference 494) is located approximately 370 kilometers (230 miles) from the site (Figures 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). Cotilla-Rodriguez et al. (Reference 494) do not include the Surcubana fault in their list of twelve "seismoactive" faults in Cuba and this fault generally is not described by other studies of faulting in Cuba (References 439, 489, and 786).

In the Phase 2 earthquake catalog, seismicity is sparse along and near the Surcubana fault, with only a dozen or so earthquakes located within approximately 30 kilometers (20 miles) of the more than 800-kilometer-long

(500-mile-long) trace (Figures 2.5.1-368 Sheet 1, 2.5.1-368 Sheet 2, and 2.5.1-368 Sheet 3). Of these earthquakes, all are low to moderate magnitude and most are located at the southeastern end of the fault near the active plate boundary and may instead be associated with the Oriente fault. The closest earthquakes to the central and western sections of the Surcubana fault from the Phase 2 earthquake catalog are located at approximately 81° west longitude (Figures 2.5.1-368 Sheet 1 and 2.5.1-368 Sheet 2). The first of these is located approximately 8 kilometers (5 miles) north of the trace and occurred on March 27, 1964 with M_w 3.7. The second is located approximately 5 kilometers (3 miles) south of the trace and occurred on October 22, 2005 with M_w 3.8. Because they do not label faults by name, it is not clear whether the Surcubana fault is depicted on Perez-Othon and Yarmoliuk's (Reference 848) inset map of fault ages in Cuba, but they indicate a Mesozoic age for an unnamed fault in the vicinity of the Surcubana fault (Figure 2.5.1-369). PTN RAI 02.05.01-21

Like the Nortecubana fault, the submarine Surcubana fault typically does not appear on regional surface geologic maps. For example, the Surcubana fault is not shown on Pushcharovskiy et al.'s (Reference 846) 1:250,000 scale geologic maps, and the 1:2,000,000 scale geologic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.1.2-3). This fault is shown on regional tectonic compilations and other maps. For example, Pushcharovskiy et al.'s (Reference 847) 1:500,000 scale tectonic map of Cuba shows the Surcubana fault as an unnamed, discontinuous, dashed line south of Cuba. The 1:2,000,000 scale neotectonic map from the Nuevo Atlas Nacional de Cuba (Reference 944, plate III.2.4-8) shows, but does not label, the Surcubana fault as a solid line. The lineament map from the same atlas (Reference 944, plate III.3.1-11) shows but does not label the Surcubana fault as discontinuous and dashed lines.

Other Cuban Structures

Numerous other tectonic structures exist on the island of Cuba. Some of these are limited in extent, unstudied, or unnamed. These include the Punta Alegre fault, PTN RAI 02.05.01-21 folds along the northern edge of Cuba, and many short, unnamed northeast- and northwest-striking faults. The Punta Alegre fault was discovered by logging PTN RAI 02.05.01-21 repeated strata in oil wells just offshore north-central Cuba (Figures 2.5.1-247 and 2.5.1-290). This fault is not imaged with seismic data, but postulated from well data. It is depicted with a vertical dip, but its orientation and extent are unknown (Reference 501).

Eocene and older strata along the northern edge of Cuba are deformed in a series of anticlines and synclines typically associated with underlying thrust faults

(Figures 2.5.1-252 and 2.5.1-282). Because these folds are covered by undeformed Miocene and younger strata, they are pre-Miocene in age, and probably formed during the Eocene collision of the Greater Antilles Arc with the Bahama Platform.

Many short (<10 kilometers [<6.2 miles] in length) northeast- and northwest-striking faults, with undetermined sense of slip, do cut strata as young as middle Miocene throughout the island of Cuba. Where younger units (such as Plio-Pleistocene) overlie these same structures, they are consistently unfaulted. This suggests that these short faults are pre-Quaternary in age. Many of these faults do not intersect units younger than Miocene, so the faulting on these structures can only be described as Miocene or younger. These structures may be correlated with post-early Miocene normal faults and cross-cutting strike-slip faults described in outcrops in western Cuba (Reference 697).

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). The available data indicate that the Oriente fault system, located offshore 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.

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

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reactivation of a regional scale anticline may be partly responsible for formation of the terrace surfaces near Matanzas. PTN RAI 02.05.01-22

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

Toscano et al. (Reference 925) also observe that the Terraza de Seboruco in the Matanzas area is just a few meters above mean sea level, similar to the elevation of other Substage 5e reef deposits throughout "stable" portions of the Caribbean, and therefore can be explained solely by changes in sea level. Toscano et al. (Reference 925) conclude, "no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba." LDP-CS564

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

Seismicity of Cuba

Maps of instrumental and pre-instrumental epicenters for Cuba show that seismicity can be separated into two zones: (a) the very active plate boundary region, including the east Oriente fault zone along Cuba's southern coast, and (b) the remainder of the island away from the active plate boundary region, which exhibits low to moderate levels of seismic activity (Figures 2.5.1-267, 2.5.2-220, and 2.5.2-221). Regarding (b) above, along the north coast of Cuba between Havana and Matanzas, the Phase 2 earthquake catalog indicates sparse minor- to light-magnitude seismicity. It is possible that these earthquakes occurred on faults partially responsible for uplift of the marine terraces along Cuba's north coast in the site region. However, the association of the uplift of these terraces and earthquakes with individual faults in northern Cuba is uncertain. Based on the Phase 2 earthquake catalog, earthquakes do not appear to be aligned along faults in the Matanzas-Havana region. In addition, there are no known focal mechanisms available for these earthquakes that would help to constrain the causative fault or faults nor is there sufficient data to correlate uplift of marine terraces with these individual faults in northern Cuba. LDP-CS564 PTN RAI 02.05.01-22

It is possible that the elevations above modern sea level of marine terraces along Cuba's north coast in the site region are partially the result of tectonic uplift (References 915 and 923). The Terraza de Seboruco is the only terrace in northern Cuba for which radiometric age control is available. There is not sufficient data on this or other marine terraces in northern Cuba to assess the implications for active faulting. As discussed in Subsection 2.5.1.1.1.2.3, Toscano et al.'s (Reference 925) U-Th analysis of corals collected from the Terraza de Seboruco indicates that tectonic uplift is not required to explain the present elevation of this Substage 5e terrace. Instead, they conclude that the elevation of this terrace surface is consistent with other Substage 5e terraces in other tectonically stable regions of the Caribbean and that global fluctuations in sea level, not tectonic uplift, are responsible for the Terraza de Seboruco's present elevation above modern sea level. Likewise, Pedoja et al.'s (Reference 920) global study suggests that the elevation of the Terraza de Seboruco is consistent with the elevations of other Substage 5e terraces in tectonically stable regions worldwide. LDP-CS564

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

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

{According to the Phase 2 earthquake catalog (Subsection 2.5.2.1.3), eight approximately M_w 6.8 to 7.5 events (in August 1578, February 1678, June 1766, August 1852, February 1917, February 1932, August 1947, and May 1992) probably occurred offshore southern Cuba, likely in the Cabo Cruz Basin and/or the Santiago deformed belt} (Figure 2.5.2-214). SOF 2.5.1-2

Figures 2.5.2-201 and 2.5.2-210 show that although Cuba is now part of the North America Plate, the central and western portions of the island away from the active plate boundary region exhibit a moderate level of seismicity that is higher than that observed in Florida. Figures 2.5.2-215 and 2.5.2-216 show that microseismicity is distributed roughly evenly throughout this zone, but with a tendency for epicenters to be located to the southeast part of the island. Activity between the Nipe fault and the east Oriente fault zone appears denser than on the rest of the island (Figure 2.5.2-215). This may partially be a detection effect, however, since a denser concentration of seismograph stations exists in this region (Reference 505).

Reported earthquakes in central and western Cuba away from the active plate boundary region typically are of low to moderate magnitude. Two of the largest earthquakes in this region occurred in January 1880 (MMI VIII and magnitude 6.0 to 6.6) near the Pinar fault in western Cuba, and February 1914 (M_w 6.2) offshore northeastern Cuba near the Nortecubana fault (Reference 494) (Figure 2.5.2-214). However, there is no direct evidence that these earthquakes occurred on the Pinar and the Nortecubana faults. The {Phase 2 earthquake catalog (see Subsection 2.5.2.1.3) indicates M_w 6.13 and 6.29 for the 1880 and 1914 earthquakes, respectively.} SOF 2.5.1-2

2.5.1.1.2 Geology beyond the Site Region

This subsection addresses the geologic and seismic data/information on structures outside the 200-mile (320-kilometer) radius of the Units 6 & 7 site region that may be relevant to evaluating geologic hazards to the Units 6 & 7 site. The geologic hazards specifically include seismic hazards evaluated in the PSHA of Subsection 2.5.2 and tsunami hazards discussed in Subsection 2.5.1.1.5 and evaluated in Subsection 2.4.6. This subsection includes a description of the physiography, stratigraphy, structure, and seismicity of portions of the North America Plate and portions of the Caribbean Plate near its boundary with the North America Plate. Due to their remote distance from the Units 6 & 7 site, features of the Caribbean-South America Plate boundary are not discussed in this subsection.

2.5.1.1.2.1 Geology of the Southeastern North America Plate Geologic Provinces

The following subsections describe physiography, stratigraphy, structures, and seismicity of the southeastern North America and northern Caribbean plates.

2.5.1.1.2.1.1 Geology of the Gulf of Mexico

Physiography of the Gulf of Mexico

The Gulf of Mexico is a semi-enclosed, small ocean basin located at the southeastern corner of the North America Plate that covers an area of more than 1.5 million kilometers^2 with a maximum water depth of approximately 3700 meters (12,100 feet). The Gulf of Mexico is a sedimentary basin that consists of thick accumulations of detrital sediments and massive carbonates that have been affected by salt tectonics. Mesozoic to Cenozoic sediments accumulated within the expanding and subsiding basin. Following thermal subsidence, the basin continued to subside due to lithostatic loading, eventually attaining a stratigraphic sequence comprising nearly 15,000 meters (49,200 feet) of evaporites overlain by prograding clastic deltaic and turbidite deposits interbedded with organic rich shales and pelagic carbonates. In the northern, southern, and eastern portions of the Gulf of Mexico, the broad continental shelf is up to 170 kilometers (106 miles) wide. In the western portion, the continental shelf east of Mexico is less than 13 kilometers (8 miles) wide in some places. The physiography of the Gulf of Mexico Basin has been controlled by processes such as subsidence, carbonate platform development, eustatic changes in sea level, salt diapirism, oceanic currents, gravity slumping, and density flows (turbidites) (References 506 and 507).

Antoine (Reference 508) divides the Gulf of Mexico Basin into seven provinces based on morphology. Bryant et al. (Reference 506) divide the Gulf of Mexico into more detailed physiographic provinces based on bathymetry and topographical features (Figure 2.5.1-292). Counterclockwise along the Gulf Coast from Florida to the Yucatan Peninsula, these provinces include the following: Florida Straits, including the Pourtales Escarpment; Florida Plain; Florida Middle Ground, West Florida Shelf, and West Florida Terrace (together known as the Florida Platform in Subsection 2.5.1.1.1); DeSoto Slope and Canyon; Mississippi Alabama Shelf; Mississippi Canyon; Mississippi Fan; Texas-Louisiana Shelf; Texas-Louisiana Slope; Rio Grande Slope; East Mexico Shelf; East Mexico Slope; Western Gulf Rise; Veracruz Tongue; Campeche Knolls; Bay of Campeche; Campeche Canyon; Sigsbee Abyssal Plain, the Yucatan Shelf and Campeche Escarpment; Campeche Terrace; and Yucatan Channel.

Water enters the Gulf of Mexico through the Yucatan Channel, circulates as the Loop Current, and exits through the Straits of Florida, eventually forming the Gulf Stream. Portions of the Loop Current often break away forming eddies or 'gyres' that affect regional current patterns. Smaller wind driven and tidal currents are created in near shore environments.

Drainage into the Gulf of Mexico is extensive and includes 20 major river systems (>150 rivers) covering over 3.8 million kilometers^2 of the continental United States (Reference 510). Annual freshwater inflow to the Gulf of Mexico is approximately 10.6 x 10^{11} meters^3 per year (280 trillion gallons). Eighty-five percent of this flow comes from the United States, with 64 percent originating from the Mississippi River alone. Additional freshwater inputs originate in Mexico, the Yucatan Peninsula, and Cuba.

Stratigraphy of the Gulf of Mexico

The basement beneath the Gulf of Mexico is characterized by a regional unconformity that separates pre- and syn-rift rocks from overlying Lower Jurassic to Recent lithologies that reflect the tectonic history of the southeastern North America Plate and its boundary with the Caribbean Plate. Because the Gulf of Mexico has been subsiding continually since the Pangean rifting event, it contains the most complete sequence of strata that represent nearly 150 m.y. of uninterrupted geologic history.

Based on seismic reflection profiles, the Gulf of Mexico includes a deep zone that contains normal-thickness oceanic crust or “thin” oceanic crust. This crust was created in the Late Jurassic through Early Cretaceous along two seafloor spreading segments (References 511 and 512), a larger southwest-northeast oriented spreading center beneath the abyssal plain north of the Campeche Escarpment, and a shorter northwest-southeast oriented spreading center that lies just east of and parallels the Florida Escarpment (Figure 2.5.1-214). The normal-thickness oceanic crust produced by the southwest-northeast spreading center is about 400 kilometers (250 miles) wide. The normal-thickness oceanic crust produced by the northwest-southeast spreading center is narrower and possibly younger (Reference 410). This normal oceanic crust in the Gulf of Mexico Basin is generally 5 to 6 kilometers thick and is characterized by refraction velocities of 6.8 to 7.2 kilometers/second, probably corresponding to oceanic layer 3 found in most normal ocean basins (Reference 410). Sawyer et al. (Reference 410) could not distinguish oceanic layer 2 in the Gulf of Mexico because of its deep burial and lack of density contrast between it and the compacted clastic and carbonate sediments that overlie it. However, Sawyer et al. (Reference 410) note that a layer identified on their seismic reflection profile (Figure 2.5.1-293) most likely includes this layer and the carbonates. The top of this interval is the mid-Cretaceous sequence boundary that occurs throughout the basin and is interpreted as the top of the oceanic crust.

Surrounding the area of normal oceanic crust is an area of transitional crust (Figures 2.5.1-238, 2.5.1-239, 2.5.1-240, 2.5.1-241, and 2.5.1-242). This area flanks the basin on all sides and occupies narrow belts to the east and west with a wider region to the south and a broad zone to the north (Figure 2.5.1-238). Based on limited refraction data, a prominent, high-amplitude, basinward-dipping reflector/unconformity is interpreted to be the top of the crust. Over much of the area, the surface is relatively smooth (probably erosional), although in places it is offset by small faults. The crustal thickness ranges from 8 to 15 kilometers (5 to 9 miles) with velocities of 6.4 to 6.8 kilometers/second. The surface also truncates a thick older sedimentary sequence (Late Triassic to Early Jurassic syn-rift deposits) (Reference 410). The transitional crust is unconformably overlain by, and shows onlap relationships with, the Middle Jurassic salt and Upper Jurassic and Cretaceous sediments. In the southeastern Gulf of Mexico, the top of the thin transitional crust rises to shallow depths over a northeast-southwest-trending basement arch. The arch area is characterized by Mesozoic-faulted blocky basement (Figure 2.5.1-294). In the eastern Gulf of Mexico beneath the West Florida Basin, the top of the thin transitional crust consists of thick salt and sediments and is seen along the western part of the West Florida Basin (Reference 410).

The thick transitional crust in the Gulf of Mexico generally lies landward of the thin transitional crust. Based on seismic reflection data, thick transitional crust has a thickness from about 20 kilometers (12 miles) up to normal continental crust thickness of about 35 to 40 kilometers (22 to 25 miles) (Figure 2.5.1-238). The crust is characterized by relatively shallow, well-defined basement highs with intervening lows. The high areas overlie crust with thickness close to normal continental crust, while the lows overlie thinner crust, probably extended continental crust (Reference 429). The typical thick transitional crust is seen best in the northeastern Gulf of Mexico Basin (Reference 410) (Figures 2.5.1-240 and 2.5.1-242).

The southeastern portion of the Gulf of Mexico, closest to the Units 6 & 7 site, is located north of Cuba between the Campeche and Florida Escarpments (Figure 2.5.1-210). The seafloor is shallower than in the Gulf of Mexico Basin proper and is characterized by erosional channels (the Straits of Florida and the Yucatan Strait) and large knolls (i.e., Pinar del Rio Knoll, Catoche Knoll, and the Jordan Knoll) (Figure 2.5.1-210). Based on a seismic stratigraphic analysis combined with DSDP drilling data, Schlager et al. (Reference 794) determine that the southeastern Gulf is underlain by rifted and attenuated transitional crust covered by a thick sedimentary section of pre-mid-Cretaceous rocks.

The Late Cretaceous-Cenozoic cover is relatively thin over most of the area, but it thickens to the south towards Cuba. The pre-mid Cretaceous section probably reflects an overall transition upward from nonmarine to shallow marine and then deep marine deposits as the basin subsided. The sedimentary sequences overlying the basement as seen from DSDP Leg 77 cores are grouped into five units: a Late Triassic-postulated Early Jurassic rift basin (TJ); a widespread postulated Jurassic nonmarine to shallow marine unit (J1); a more restricted postulated Late Jurassic shallow to deep marine unit (J2); a widespread Early Cretaceous unit (EK); and a Late Cretaceous-Cenozoic unit (KC) (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

According to Schlager et al. (Reference 794), there are no drilling data for the pre-Cretaceous history of the southeastern Gulf. However, a scenario for the pre-Cretaceous history can be discussed on the basis of interpretation of seismic data and regional comparisons. The basement is approximately early Paleozoic (500 Ma) and consists of metamorphic rocks (such as phyllite and gneiss-amphibolite) intruded by early Mesozoic (160 to 190 Ma) basic dikes and sills. In some places the basement contains some low-amplitude reflections, seen as broad uplifts and basins to the south and north. High relief tilted Mesozoic fault-blocks are in the central part of the southeastern part of the Gulf of Mexico (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

Unit TJ is a Late Triassic-Early Jurassic rift sequence consisting of southeast-dipping parallel reflections filling a northeast-southwest-trending graben system. Unit TJ onlaps the basement and is truncated by prominent unconformity. The unit is probably composed of nonmarine sediments and volcanics (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

Unit J1 is a widespread unit in the south with a relatively uniform thickness of several kilometers, and shows high-amplitude and discontinuous seismic character. The unit onlaps broad basement highs and is undeformed in the southeastern part of the Gulf of Mexico except where the J1 unit is downdropped along prominent northwest-southeast graben system and along the broad trough north of Cuba. Northward, the unit fills half-grabens between tilted fault blocks. The seismic character to the north suggests non-marine synrift sediments such as alluvial fans, lacustrine deposits, volcanics, and evaporites. The upper part of the unit in the south may be shallow marine platform with the lower part nonmarine (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

Unit J2 consists of uniform, variable-amplitude, continuous reflections. The unit is widespread over most of the area, deformed in depressions between horsts and absent on high-standing blocks to the west. The seismic reflection data suggest deep marine deposition in the central part of the southeastern portion of the Gulf of Mexico. Possible low relief shelf margins in places are suggestive of transition to shallow marine conditions around the periphery. Unit J2 most likely represents a major marine transgression, concurrent with the establishment of the seaway (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

Unit EK is widespread throughout the north and eastern portions of the Gulf of Mexico nearest to the Straits of Florida. It is thin or absent to the south and west because of nondeposition on high-standing areas and post mid-Cretaceous erosion. Unit EK has a thickness of up to 2 kilometers (1.2 miles) and thickens to the east along the base of the Florida Escarpment. The unit is a deep-water carbonate whose main source of carbonate supply was the Florida Platform and planktonic carbonate production (Reference 794) (Figures 2.5.1-242, 2.5.1-241, and 2.5.1-295).

Toward the south of the Gulf of Mexico, the lower part of the late Cretaceous-Cenozoic KC unit forms thick wedges of clastic sediment originating from Cuba. The upper part of the KC unit forms a thin blanket with internal unconformities. To the north, the unit thins then thickens into the Gulf of Mexico Basin (Reference 794) (Figures 2.5.1-241, 2.5.1-242, and 2.5.1-295).

Structures of the Gulf of Mexico

The deep basin of the Gulf of Mexico is draped by several kilometers of generally undisturbed Cretaceous to Quaternary sedimentary strata (Figures 2.5.1-241, 2.5.1-240, and 2.5.1-242). Normal faulting and volcanic activity associated with the opening of the Gulf of Mexico Basin was widespread and ended in the Jurassic to Cretaceous (References 368 and 849). In the southeastern Gulf of Mexico, between the Yucatan and Florida Platforms, undisturbed Cretaceous and younger strata cover the Mesozoic normal faults cutting the basement (e.g., Figures 2.5.1-293, 2.5.1-294, and 2.5.1-295). Strike-slip structures exposed in eastern Mexico, and proposed offshore, along the western Gulf of Mexico accommodated the opening of the Gulf of Mexico in the Jurassic (Reference 849). The Gulf of Mexico Quaternary strata are disturbed along the northern Gulf of Mexico coast, from the Florida Panhandle west to Texas, where aseismic gravity-driven growth faults extend the thick fluvial-deltaic sedimentary sections into the Gulf of Mexico Basin (Reference 430). However, because the Florida Platform remained a site of carbonate deposition and lacks a thick clastic section, the eastern Gulf of Mexico adjacent to the Florida Platform is not a site of growth faulting (Reference 513). Some normal faults near the western edge of the Florida Platform accommodated extension during the opening of the Gulf of Mexico in Jurassic and early Cretaceous periods (Figure 2.5.1-264).

Seismicity of the Gulf of Mexico

{The Phase 1 earthquake catalog (Subsection 2.5.2.1.2) indicates that the Gulf of Mexico is characterized by low seismicity rates (Figure 2.5.1-267)}. According to the {Phase 1 earthquake catalog, the two largest earthquakes in the Gulf of Mexico are the September 10, 2006, Emb 5.90 and February 10, 2006, Emb 5.58 earthquakes}. Subsection 2.5.2.4.3.1 provides additional discussion regarding these two earthquakes. The overall seismicity pattern within the Gulf of Mexico shows no correlation with geologic or tectonic features (Subsection 2.5.2.3). SOF 2.5.1-1 SOF 2.5.1-1

2.5.1.1.2.1.2 Geology of the Yucatan Platform

Physiography of the Yucatan Platform

The Yucatan Platform comprises the emergent portion of the Yucatan Peninsula; the broad, shallow carbonate platform that extends mostly north and west of the peninsula; a narrow, deeper water carbonate terrace (the Campeche Bank) that rims the shallow carbonate platform; and a steep walled escarpment that transitions from the Yucatan Platform to the Gulf of Mexico and Yucatan Basin abyssal plains. From east to west at its widest point, the continental shelf of the Yucatan Platform extends about 675 kilometers (420 miles), from the western Gulf Coast of Mexico to the southwestern tip of Cuba. From north to south, the Yucatan Platform extends about 1000 kilometers (620 miles) into the Gulf of Mexico from the western end of the Cayman Trough.

The Yucatan Platform has been the site of limestone and evaporite deposition since the Early Cretaceous. Currently, living reefs and biohermal mounds, wave cut terraces, and small-scale karst features dominate the topography of the area. The broad shelf is surrounded on three sides by the steep Campeche Escarpment that plunges as much as 3600 meters (11,800 feet) from the shelf edge to the Gulf of Mexico floor. The escarpment, with a slope of up to 35°, is broken by the Campeche Terrace and a number of box canyons. The terrace is at a depth of approximately 1000 meters (3300 meters), with a width of 200 kilometers (124 miles) and an average slope of 5°. The Campeche Terrace is analogous to the Blake Plateau, being a drowned portion of an active carbonate platform. Small canyons and large-scale slumping interrupt the linearity of the Campeche Escarpment (Reference 506). The largest canyon, the Catoche Tongue, parallels the north-northeast oriented transform fault margin on the eastern side of the Yucatan Platform (Figure 2.5.1-210).

The Yucatan Platform formed as the result of reef building and upward growth by slow accumulation of carbonate sediments and evaporites. The growth has kept pace or exceeded subsidence since the Early Cretaceous (Reference 506). The Campeche Escarpment, like the Florida Escarpment, represents the eroded margins of the Early Cretaceous carbonate platform. Due to the presence of carbonate talus deposits in localized areas along its base, the Campeche Escarpment has undergone erosion and retreat (Reference 725). The Florida Escarpment has retreated as much as 8 kilometers (5 miles), and the Blake Escarpment has retreated as much as 20 kilometers (18 miles) since the mid-Cretaceous (Reference 725). According to Buffler et al. (Reference 515), these Early Cretaceous margins are interpreted to have been established along a regional tectonic hinge zone separating thick transitional crust from thin transitional crust.

Stratigraphy of the Yucatan Platform

The Yucatan Peninsula is the exposed part of the Yucatan Platform. It is comprised primarily of Cretaceous carbonate platform rocks overlying a Paleozoic crystalline basement. The basement beneath the Yucatan Platform and the possible relationship between the Yucatan Platform and the Florida and Bahama Platforms are described in Subsection 2.5.1.1.1.1.1.2 (as part of the discussion of carbonate platforms: growth, shut downs, and crashes).

A 180- to 200-kilometer (112- to 125-mile) wide impact structure, the Chicxulub crater (which formed 65.55 ± 0.05 Ma [$^{40}Ar/^{39}Ar$ dating of glassy melt rocks/ tektites] at the K/Pg boundary [References 516, 517, and 518]), forms the northwest margin of the peninsula (see discussion of "Oceanic and Atmospheric Reorganization and Extinction Event" in Subsection 2.5.1.1). The deeply buried Chicxulub Crater is located partly onshore and offshore of the northwest part of the Yucatan Peninsula, near the town of Chicxulub. The Chicxulub crater is overlain by up to 1.5 kilometers (4920 feet) of Tertiary sediments (Reference 519). The geomorphology of the peninsula is characterized by a relatively smooth platform with elevations that range between 25 and 35 meters (82 to 115 feet) broken by rounded karstic depressions (locally known as "senates") and uninterrupted by stream valleys (Reference 520).

Pleistocene reef limestones, lagoonal packstone-wackestones, strandline grainstones, and calcretes are exposed in quarries and low sea cliffs along the Caribbean coast of the Yucatan Peninsula from the northern cape to Tulum. These shallow-marine and subaerial limestones are similar in elevation, sedimentology, stratigraphy, and age to similar limestones found on Isla Cozumel. The Isla Cozumel consists of caliche facies in Upper Pleistocene limestones. Sub-Caliche I facies consist of coralline wackestone and molluscan wackestone. Super-Caliche I facies consist of coral-reef facies and skeletal and oolitic grainstone-packstone and burrowed skeletal grainstone-packstone. Holocene eolianites were deposited along the northeastern shoreline that is adjacent to the narrow ramp, but these are absent south of Isla Cancun, where the margins of the peninsula and offshore platforms are steep (Reference 521).

The correlative Upper Pleistocene limestones reflect the same history of late Quaternary sea-level fluctuation for the eastern Yucatan coast and the offshore carbonate islands. The similar elevations of these age-equivalent rocks also suggest there has been little or no differential structural movement along this portion of the Yucatan continental margin for at least the past 200 k.y. As seen from the similarity of the elevations of Upper Pleistocene limestone of Yucatan and those of oxygen isotopic substage 5e, limestones in stable areas of the Caribbean, there has been no significant subsidence or uplift of the eastern Yucatan Peninsula after mid-Pleistocene (Reference 521).

Structures of the Yucatan Platform

At its nearest point, the Yucatan Platform province lies about 370 miles (600 kilometers) west-southwest of the Units 6 & 7 site. Bedrock structure of the Yucatan Platform is constrained by surface geologic mapping (compilation in Reference 492) and gravity and magnetic studies (Reference 522), which indicate the platform comprises denser basement rock with a cover of Cretaceous through Oligocene strata. The basement of the Yucatan Platform exhibits an undulating and irregular surface consisting of a variety of pre-Late Paleozoic igneous, metamorphic, and sedimentary terranes often overprinted with a Late Paleozoic metamorphic age. The metamorphic signature represents the assemblage of Pangea (Reference 522).

Alvarado-Omana (Reference 522) speculates that the undulating and irregular basement surface, modeled using gravity and magnetic data, could be due to either: (a) crustal thinning and stretching associated with North America-South America rifting between which the Yucatan block was situated in the Jurassic; or (b) density differences between northern and southern Yucatan Platform basement rock (0.05 g/cc greater in the northern portion). Alvarado-Omana (Reference 522) suggests that density differences could result from the possibility that the Yucatan block comprises a series of "micro-continental" blocks that surround the Yucatan Platform. A possible explanation for the density differences could be that the Jurassic rift basins of the northern Yucatan Platform (Reference 523) contain higher-density material than the cover of Cretaceous and younger strata overlying the basement of more southerly portions.

The northern Yucatan Platform region was uplifted, accommodated mostly by normal faulting along its northwestern margin during the Late Triassic, concurrent with opening of the Gulf of Mexico (References 522 and 524). This process created the Campeche Escarpment that delineates and extends along the northwestern margin of the platform. French and Schenk (Reference 492) mapped several normal faults along a small portion of the Campeche Escarpment, but little is known of their age; they could be gravitational due to the steepness of the escarpment. No seismicity from {the Phase 1 or Phase 2 earthquake catalogs} (Subsection 2.5.2.1) is associated or coincides with those faults. Uplift continued into the Middle Jurassic, followed by subsidence due to onlapping deposition of the Lower Cretaceous Carbonate Platform over the dense Paleozoic basement. SOF 2.5.1-1 SOF 2.5.1-2

Pindell et al. (Reference 523) propose the Yucatan Platform underwent two episodes of counter-clockwise rotation. The first episode involved 10 to 15° of rotation from Late Triassic through Late Jurassic, associated with North America-South America continental rifting. The second involved an additional 30 to 35° of rotation from Late Jurassic though earliest Cretaceous associated with later stages of oceanic spreading in the Gulf of Mexico. Rotations are constrained by alignment of the Jurassic rift basins of the northern Yucatan Platform with those of North America (Reference 523). These rotations are not, however, directly associated with deformation of the Yucatan Platform.

From Early Cretaceous through Late Cretaceous (Maastrichtian) time, the platform existed as a relatively passive margin (References 522, 525, and 523). Beginning in the Masstrichtian, the Caribbean Plate passed along the eastern margin of the Yucatan Platform. Regional stress fields transitioned from those related to oblique sinistral convergence from Late Cretaceous (Maastrichtian) through late Paleocene time, to oblique sinistral extension from late Paleocene through Middle Eocene time (Reference 525) (Figure 2.5.1-297). The active margin of the eastern Yucatan Platform represented the North America-Caribbean Plate boundary. Several normal faults are mapped by French and Schenk (Reference 492) parallel, and 50 to 75 miles (80 to 120 kilometers) west of the former plate boundary. These structures have been described as offshore extensions of the Pinar fault in Cuba (e.g., Reference 529). {No seismicity from the Phase 1 or Phase 2 earthquake catalogs (Subsection 2.5.2.1) are coincident SOF 2.5.1-1
or associated with those faults}. After passage of the Caribbean Plate, the eastern margin of the Yucatan Platform became passive as sinistral faulting associated SOF 2.5.1-2
with northeastern motion of the Caribbean Plate shifted to the Oriente fault and the adjacent Yucatan Basin sutured to the North America Plate.

At the extreme southeastern corner of the Yucatan Platform, offshore Belize, Lara (Reference 819) mapped a series of Cretaceous to Eocene left-lateral transtensional faults and a set of Pliocene high-angle normal faults using seismic reflection data. The earlier structures reflect the Cretaceous-Eocene strike-slip boundary as the Greater Antilles Arc moved past the southeastern Yucatan Platform. The youngest structures may be influenced by the Cayman trough rifting to the east (Reference 819).

Seismicity of the Yucatan Platform

{The Phase 2 earthquake catalog (Subsection 2.5.2.1.3) indicates that SOF 2.5.1-2
earthquakes in the Yucatan Platform are small to moderate in magnitude and concentrated towards the south near the Polochic fault} (Figure 2.5.1-202) {and to SOF 2.5.1-2
the southeast near the southwest extension of the Nortecubana fault} (Figure 2.5.1-267). The proximity of these earthquakes to these features suggests

possible association of seismicity with the active Polochic-Motagua fault system, and possible crustal weakness associated with the southwest extension of the Nortecubana fault. Aside from these two possible examples, the overall seismicity pattern within the Yucatan Platform shows no correlation with geologic or tectonic features (Subsection 2.5.2.3).

2.5.1.1.2.1.3 Geology of the Yucatan Basin

Physiography of the Yucatan Basin

The major physiographic features of the Yucatan Basin include the abyssal plain, occupying the western and northern half of the province, which gives way southward to faulted bank areas and culminates on the southern boundary of the province with the shallow water Cayman Ridge and its emergent Cayman Islands (Figure 2.5.1-210).

The Yucatan Basin lies between the Yucatan Peninsula and Cuba and the east-northeast-trending Cayman Ridge. On the west, the fault-controlled Yucatan Strait separates the Yucatan Platform from a narrow strip of carbonate platform at the western margin of the Yucatan Basin. To the north and northeast, the Yucatan Basin and its ridges dip beneath the Cuba margin along a sediment-filled trench (Reference 529). To the south, the Yucatan Basin is separated from the Cayman Trench by the Oriente fault system (Figures 2.5.1-202, and 2.5.1-210).

The Yucatan Basin itself is separated into a deeper (4000 to 4600 meters or 13,000 to 15,000 feet) northwestern part containing the Yucatan Plain and a shallower (2000 to 3500 meters or 6500 to 11,500 feet) southeastern part that is dominated by ridges (the Cayman Ridge on the south and the more subdued Camaguey Ridges to the northeast) that strike northeast across the basin. Linear, sediment-filled basins lie between the Cayman and Camaguey Ridges (Reference 526) (Figure 2.5.1-296).

The Cayman Ridge trends west-southwest from the Sierra Maestro of southern Cuba to within 100 kilometers (60 miles) of the base of the Honduras continental slope where it disappears beneath thick sediment cover in the Yucatan Basin. Over much of its length, a double ridge crest separates small perched basins, valleys, or flats (References 526 and 499). The Cayman Islands; Misteriosa, Pickle, and Rosario Banks; and some isolated algal reefs lie near or above sea level on top of the Cayman Ridge (References 527 and 528) (Figure 2.5.1-296).

Stratigraphy of the Yucatan Basin

Surficial pelagic-hemipelagic sediments of the Yucatan Basin consist of foraminifera- and pteropod-rich chalk marl oozes and marl clays. Chalk oozes predominate on the elevated southeastern portion of the basin. Marl oozes predominate within the turbidite-lutite sequences of the Yucatan Basin, reflecting influx of sediments from terrigenous sources. Turbidites consist of a heterogeneous series of terrigenous sands, muds, and carbonate sands (Reference 526).

The Belize Fan feeds terrigenous sands and muds into the southwest area of the Yucatan Basin abyssal plain. The primary sediment sources for the Belize Fan are the Polochic, Motagua, Chamelecon, and Ulua rivers that flow from the mountains of Guatemala and Honduras. The rivers converge at the head of the Belize and Motagua Fans. The Yucatan Basin Slope gradients reverse in its eastern extension, leading upslope toward the mouth of the Cauto River. The Cauto River drains much of the Sierra Madre Oriental of Cuba. A well-developed drainage network funnels pelagic carbonate sediments into the Yucatan Plain from the shallower portion of the Yucatan Basin. In addition, carbonates are also brought in from the continental and island slopes of Yucatan and Cuba via canyons (Reference 526).

Based on seismic reflection data, including extensive multi-channel data, Rosencrantz (Reference 529) concludes that the Yucatan Basin is underlain by crust of complicated internal structure, composed of oceanic crust of two different origins plus continental crust, distributed across the former North America-Caribbean Plate boundary between the Yucatan Platform and the Yucatan Basin. Rosencrantz (Reference 529) identifies three distinct crustal types or blocks. The first crustal type underlies the western flank of the basin and includes metasediments lithologically similar to Paleozoic continental rocks found at depth across the Yucatan Platform. This crustal type is postulated to represent the offshore continuation of the adjacent Yucatan Platform. The possible relationship between the crust of the western flank of the basin and that of the Yucatan Platform and the Florida and Bahama Platforms are described in Subsection 2.5.1.1.1.2.1.2. The second includes the topographically heterogeneous areas of the eastern two thirds of the basin (including the Cayman Rise, Cayman Ridge, and Camaguey Trench) and is dominated by a subsided volcanic rise or arc resting on probably oceanic crust of pre-Tertiary age. The eastern edge of the rise and adjacent basins dip northeast beneath the Cuban margin along the sediment filled Camaguey Trench. The third type of crust occupies a rectangular deep area within the western third of the basin. Available evidence indicates that this crust is oceanic and represents a large, mature pull-apart basin set within a wide paleo-transform zone between the western platform and the eastern oceanic basin (Reference 529). The oceanic crust was produced by back-arc spreading behind the Cuban Arc (References 210 and 526).

Seismic reflection profiles and regional gravity interpretations suggest that the crust beneath the deep north-central and western parts of the Yucatan Basin is oceanic, but that crust thickens southward to more than 20 kilometers (12 miles) beneath the Cayman Ridge (Reference 529). K/Ar cooling ages of volcanic, metavolcanic, and granodiorite rocks dredged from the southern wall of the Cayman Ridge indicate ages of 59 to 69 Ma. This suggests that the thicker crust represents a buried Late Cretaceous island arc resting on Late Cretaceous or older crust (Reference 528). Lewis et al. (References 810 and 811) analyzed Nd-Sr and Pb isotope ratios of arc-related calc-alkaline granitoids and volcanic rocks from the western part of the Cayman Ridge and indicate that these rocks were intruded into continental crust. This confirms that crustal rocks of the western Cayman Ridge are the rifted eastern extension of the continental Maya block of Belize, Mexico, and Guatemala, as has been suggested previously (Reference 815) (see related discussion in Subsection 2.5.1.1.2.2.2).

Inferred oceanic crust from the deep western part of the basin appears to be younger (Late Cretaceous to Eocene) on the basis of heat flow (Reference 530) and depth-to-basement measurements (References 526 and 222). Pindell et al. (Reference 525) use ages of pull-apart basin faults offsetting age-dated sediments in the surrounding region to estimate an age for the initiation of rifting as late Middle Eocene, or about 45 Ma, in this portion of the basin (Reference 529).

Based on multichannel seismic reflection lines across the basin, Rosencrants (Reference 529) finds that Yucatan Basin abyssal sediments are mostly undisturbed, indicating that the basin has been tectonically quiescent since spreading ceased in the Late Eocene (see Subsection 2.5.1.1.3 for geologic history). The basement relief at the southern portion of the Yucatan Basin has the appearance of tilted fault blocks, which suggests the possibility that distension, rifting, and foundering of preexisting crust occurred during the opening of the basin (Reference 526).

Structures of the Yucatan Basin

At its nearest point, the Yucatan Basin lies 260 miles (420 kilometers) southwest of the Units 6 & 7 site. Its convex-northwest margin represents a portion of the former sinistral transform and oblique-convergent margin of the Caribbean Plate. Its relatively linear southern margin is defined by the east-northeast striking Cayman Trough and sinistral strike-slip western Oriente fault system (Reference 492) (Figure 2.5.1-229).

Structure within the Yucatan Basin is limited to Eocene and older basement rocks that are overlain by relatively undeformed post-Eocene cover of oceanic sediments (References 530, 529, and 525). Deformation of sedimentary cover over basement rocks mostly is due to gravitational adjustments, such as slumping over the pervasively steep and irregular basement surface, and exhibits little to no deformation related to late Cenozoic tectonics of the current plate boundary (Reference 529).

The origin of basement structure in the Yucatan Basin is associated with Late Cretaceous (Maastrichtian) through Late Eocene east- and northeast-directed subduction of the proto-Caribbean ocean crust beneath the Caribbean Plate. During this time, the Caribbean Plate passed between the bottleneck formed between the Yucatan Platform on the North America Plate to the north, and the South America Plate (Figure 2.5.1-297). Beginning at 72 Ma, motion of the northwestern portion of the plate, the Escambray terrane, was directed northwest while the remainder of the plate was directed northeast. These motions imparted stresses, causing sinistral oblique subduction of the Yucatan Platform and proto-Caribbean oceanic crust beneath the Escambray terrane that persisted until 56 Ma. Beginning at 56 Ma, rollback of the proto-Caribbean crust caused counter-clockwise rotation of the Yucatan Platform and redirection of the Escambray terrane vector to the northeast, subparallel to the vector of the remainder of the Caribbean Plate (References 525 and 523). The redirection of the Escambray Terrace vector during the Eocene formed a pull-apart basin bound by sinistral normal faults that leaked new ocean crust and marked the North America-Caribbean Plate boundary. During this time, the La Trocha and Trans Basin faults developed within the Yucatan Basin and the Oriente fault developed along the southern margin of the basin to accommodate the differentially directed vectors between the Escambray terrane and the remainder of the Caribbean Plate (References 529 and 525) (Figure 2.5.1-297). A consequence of this model for the opening of the Yucatan basin is that the northeast-striking faults (such as the Pinar, La Trocha, and Nipe faults) would have initiated as mainly normal fault structures. However, available kinematic data on the Pinar, for example, indicate it is a left-lateral strike-slip structure (Reference 697), and therefore, support a different opening style (e.g., Reference 639).

The primary structures within the Yucatan Basin are the Trans Basin fault and faults associated with the pull-apart structure formed during the Late Cretaceous (Maastrichtian) through Middle Eocene opening of the Yucatan Basin. 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 Trans Basin fault is identified in four fault-normal seismic reflection profiles and diagrams from Rosencrantz (Reference 529). Rosencrantz (Reference 529) interprets about 50 kilometers (31 miles) of displacement along the fault, estimated from onshore geologic relations of the La Trocha fault and offshore offset of a graben by the Trans Basin fault. Displacement along these faults occurred during the latest Paleocene through Middle Eocene. Also during this time, the crustal block east of the sinistral Trans Basin fault was subducted beneath Cuba along the presently inactive Camaguey Trench (Reference 529). The Camaguey Trench delineates the boundary between the Greater Antilles deformed belt and Yucatan Basin provinces of French and Schenk (Reference 492), and terminates to the west at the La Trocha-Trans Basin fault. Subduction along the Camaguey Trench is thought to have been active either during the Cretaceous as a part of the Cuban Arc, or during the Eocene as a back thrust behind the Cuban Arc. Seismic reflection profiles and diagrams in Rosencrantz (Reference 529) indicate that the trench is presently buried by several kilometers of undeformed oceanic sediments. There is no stratigraphic or geomorphic evidence for any activity along the Trans Basin fault since the Middle Eocene. However, 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). {Five other earthquakes (M_w 3 to 4.6) from the Phase 2 earthquake catalog} (Subsection 2.5.2.1) lie within close proximity of the Trans Basin fault, suggesting it may have some seismogenic potential within the Yucatan Basin.

SOF 2.5.1-2

SOF 2.5.1-2

The pull-apart structure and associated faults (Figure 2.5.1-297) as the "Eocene Ocean" accommodated about 350 kilometers (217 miles) of cumulative oblique sinistral extension between the Caribbean and North America plates between the

Late Paleocene to Middle Eocene (References 529 and 525). {A cluster of 15 historical earthquakes (M_w 3.5 to 6.4) from the Phase 2 earthquake catalog (Subsection 2.5.2.1) occurs in the southwest corner of the Yucatan Basin}. The cluster is coincident with the Eocene pull-apart structure and associated faults, and likely represents seismogenic reactivation of the faults due to far-field stresses caused by the Oriente fault that lies 5 to 60 miles (8 to 100 kilometers) to the south. SOF 2.5.1-2

Seismicity of the Yucatan Basin

{The Phase 2 earthquake catalog (Subsection 2.5.2.1.3) indicates moderately abundant earthquakes within the Yucatan Basin} (Figure 2.5.1-267). The preponderance of these is concentrated at the margins of the basin near the Oriente fault near southwestern Cuba and near the west end of the Swan Islands fault zone. Additionally, the {Phase 2 earthquake catalog indicates moderately abundant earthquakes that range from M_w 3.1 to 7.5 in the eastern corner of the Yucatan Basin.} These events likely are associated with far-field stress in normal faults striking parallel to the Oriente fault, located approximately 15 to 80 miles (25 to 130 kilometers) south in the Cayman Trough (Reference 529). Several additional earthquakes occur in interior to the province, about 100 kilometers (60 miles) or more from known active faults. SOF 2.5.1-2 SOF 2.5.1-2

2.5.1.1.2.1.4 Geology of the Charleston, South Carolina, Seismic Zone

Physiography of the Charleston, South Carolina, Seismic Zone

The Charleston, South Carolina, seismic zone is located along the Atlantic coast of South Carolina, within the Coastal Plain geologic province. Elevations range from sea level in the southeast map area to 114 feet (35 meters) in the northwest, reflecting a gentle net regional slope to the southeast of about 2.8 feet/mile (5 0.53 meters/kilometer). Locally, steep bluffs along major rivers may expose a few feet of Tertiary sediment. Elsewhere, the Charleston region is covered by a ubiquitous blanket of lower Pleistocene to Holocene sand and clay that obscures the distributional pattern of underlying Tertiary stratigraphic units.

Landsat imagery and topographic maps of the South Carolina coastal plain indicate that the courses of the Santee, Black, Lynches, and Pee Dee rivers and the Caw Caw Swamp are noticeably curved toward the north-northeast along a 15-kilometer (9-mile) wide, 200-kilometer (125-mile) long zone from south-southwest of Summerville, South Carolina to just east of Florence, South Carolina (Reference 533) (Figure 2.5.1-298). Other river anomalies observed within the zone include incised channels, changes in river patterns, and convex-upward longitudinal profiles (References 533 and 534). While these anomalies may indicate a lithologic boundary formed by a paleo-shoreline, the trend of the zone of anomalies does not parallel the trends of other paleo-shorelines. Marple and Talwani (References 533 and 534) conclude that this zone is likely due to tectonic deformation.

Stratigraphy of the Charleston, South Carolina, Seismic Zone

The Coastal Plain sediments in Georgia and South Carolina mostly consist of unlithified sediments interbedded with lesser quantities of weakly lithified to indurated sedimentary rocks (Reference 775). Lithologies include stratified sand, clay, limestone, and gravel. These units dip gently seaward and range in age from Late Cretaceous to Recent. The sedimentary sequence thickens from 0 feet at the Fall Line to more than 3962 feet (1219 meters) at the coast (Reference 536). Regionally, rocks and sediments dip and thicken toward the southeast, but dips and thicknesses vary owing to the presence of a number of arches and embayments within the province (Figure 2.5.1-299).

The shallow subsurface Tertiary stratigraphy of the greater Charleston, South Carolina region reflects the tectonic development and setting of the region over the past 34 m.y. Upper Eocene and Oligocene stratigraphic horizons show a net regional dip toward the southwest or south, whereas Miocene and Pliocene horizons show a shift to net regional dips toward the southeast (Reference 775).

A number of localized areas show persistent net upward or downward motion attributed to Tertiary crustal adjustments (Reference 534).

Structures of the Charleston, South Carolina, Seismic Zone

The August 31, 1886, earthquake that occurred near Charleston, South Carolina, 500 miles (800 kilometers) north of the Units 6 & 7 site, is the largest historical earthquake in the eastern United States. The event produced MMI X shaking in the epicentral area (Figure 2.5.2-212) and was felt as far away as Chicago (Reference 538).

As a result of this earthquake and the relatively high seismic risk in the Charleston area, government agencies funded numerous investigations to identify the source of the earthquake and the recurrence history of large magnitude events in the region. Because no primary tectonic surface deformation was identified with the 1886 event, a combination of geology, geomorphology, and instrumental seismicity data have been used to suggest several different faults (East Coast fault system, Woodstock fault, and Ashley River fault) as the source for

Charleston seismicity. However, the source of the 1886 earthquake has not been definitively attributed to any particular fault.

Seismicity of the Charleston, South Carolina, Seismic Zone

{Seismicity data in the Charleston, South Carolina region include historical accounts of the large 1886 Charleston earthquake (Phase 1 earthquake catalog Emb 6.75),} instrumental records of low-magnitude events, and paleoliquefaction studies describing the occurrence of large prehistoric earthquakes in coastal South Carolina. SOF 2.5.1-1

Estimates of the magnitude of the 1886 Charleston earthquake generally are in the high-6 to mid-7 range. For example, Martin and Clough (Reference 537) base their M_w 7 to 7.5 estimate on a geotechnical assessment of liquefaction features produced by the 1886 earthquake. Johnston (Reference 538) estimated a M_w 7.3 ± 0.26 for the 1886 Charleston event, based on an isoseismal area regression accounting for eastern North America anelastic attenuation. More recently, Bakun and Hopper (Reference 539) indicate a best estimate of M_w 6.9, with a 95 percent confidence level corresponding to a range of M_w 6.4 to 7.1. Bakun et al. (Reference 758) indicate that the 1886 Charleston earthquake was felt as far south as Key West, Florida with Modified Mercalli Intensity (MMI) III. Additionally, five felt reports indicate MMI III to IV in the Tampa-St. Petersburg-Fort Meade, Florida area (Reference 758). One felt report from Fowey Rocks Lighthouse in Biscayne Bay, Florida indicates MMI IV for the 1886 Charleston earthquake.

Based on local seismic networks, three zones of elevated microseismic activity have been identified in the greater Charleston area. These include the Middleton Place-Summerville, Bowman, and Adams Run seismic zones. The Middleton Place-Summerville seismic zone is an area of elevated microseismic activity located approximately 12 miles (20 kilometers) northwest of Charleston (References 540, 541, 542, 543, and 544). Between 1980 and 1991, 58 events with duration magnitude (Md) 0.8 to 3.3 were recorded in a 7- by 9-mile (11- by 14 kilometer) area, with hypocentral depths ranging from approximately 1 to 7 miles (0.5 to 11 kilometers) (Reference 542). {Seven events from this zone are listed in the Phase 1 catalog, with Emb values ranging from 3.30 to 3.51.} The elevated seismic activity of the Middleton Place-Summerville seismic zone has been attributed to stress concentrations associated with the intersection of the postulated Ashley River and Woodstock faults (References 545, 542, 546, and 543). Some investigators speculate that the 1886 Charleston earthquake occurred within this zone (References 539, 546, and 544). The Bowman seismic zone is located approximately 50 miles (80 kilometers) northwest of Charleston, SOF 2.5.1-1

South Carolina, outside of the meizoseismal area of the 1886 Charleston earthquake. The Bowman seismic zone is identified on the basis of a series of local magnitude (M_L) 3 < M_L < 4 {(Emb 3.14 to 4.28 in the Phase 1 earthquake catalog)} earthquakes that occurred between 1971 and 1974 (References 540 and 547). The Adams Run seismic zone, located within the meizoseismal area of the 1886 Charleston earthquake, is identified on the basis of four magnitude <2.5 earthquakes (not listed in the Phase 1 earthquake catalog), three of which occurred in a two-day period in December 1977 (Reference 544). Bollinger et al. (Reference 540) downplay the significance of the Adams Run seismic zone, noting that, in spite of increased instrumentation, no additional events were detected after October 1979. SOF 2.5.1-1

Liquefaction features are recognized in the geologic record throughout coastal South Carolina and are attributed to both the 1886 Charleston and earlier moderate- to large-magnitude earthquakes that occurred in the region since mid-Holocene time (e.g., References 548, 549, 550, 551, and 552). Paleoliquefaction features predating the 1886 Charleston earthquake are found throughout coastal South Carolina. The spatial distribution and ages of paleoliquefaction features in coastal South Carolina constrain possible locations and recurrence rates for large earthquakes (References 548, 549, 550, 551, and 552). Talwani and Schaeffer (Reference 553) combined previously published data with their own studies of paleoliquefaction features in the South Carolina coastal region to derive possible earthquake recurrence histories for the region. Talwani and Schaeffer (Reference 553) describe two alternative paleo-earthquake scenarios that include both moderate (approximately M_w 6+) and large (approximately M_w 7+) earthquakes (Table 2.5.2-215), and they estimate a 500- to 1000-year recurrence of large earthquakes in the Charleston region since mid- to late-Holocene time, with a preferred estimate of approximately 550 years.

2.5.1.1.2.2 Geology of the Caribbean Plate Provinces

This subsection includes a description of the physiography, stratigraphy, structure, and seismicity of portions of the Caribbean Plate near its boundary with the North America Plate. Due to their remote distance from the Units 6 & 7 site, features of the Caribbean-South America Plate boundary are not discussed in this subsection.

2.5.1.1.2.2.1 Geology of the Cayman Trough

Physiography of the Cayman Trough

The Cayman Trough (Figures 2.5.1-210 and 2.5.1-202) is an elongated deep basin, oriented west-southwest to east-northeast, that extends 1600 kilometers (1000 miles) from the Windward Passage between Cuba and Hispaniola to the Gulf of Honduras. Images from the long-range side-scan sonar instrument Geological LOng-Range Inclined Asdic (GLORIA) elucidate the morphology of the walls and floor of the trough. The rectangular basin is bounded to the north and south by steep scarps that locally rise more than 5000 meters (16,400 feet) from the basin floor. These scarps are or have been active transform faults (Swan Islands fault zone to the north and the Oriente fault zone to the south) during the development of the basin. The greatest depth, 6800 meters (22,300 feet), occurs adjacent to the north wall between Grand Cayman Island and Cuba. The northern boundary of the basin, south of the Yucatan Basin and the Cayman Ridge, marks the boundary of the Caribbean and North America Plates. Note that the terminology "Cayman Ridge" refers to the line of islands and shoals that include the Cayman Island chain. This reflects normal usage in Caribbean literature but is distinct from the terminology used in French and Schenk (Reference 492), who use the term, contrary to other geologic literature, to designate the north portion of the northern Nicaraguan Rise.

The Cayman Trough has three morphologic areas. On the western third of the trough, a relatively flat abyssal plain lies at a depth of about 5000 meters (16,400 feet). The central third of the trough lies at a depth of about 5500 meters (18,000 feet) and includes an active spreading center characterized by north-south-trending ridges. The eastern third of the trough is an abyssal basin that lies at a depths of between 4000 and 6800 meters (13,100 to 22,300 feet) and exposes the tops of older southeast- to northwest-trending ridges. The change in ridge orientation between the eastern and central portions of the trough records a change in spreading direction. The history of relative motion recorded in the crust accreted at this spreading center both outlines the age and duration of tectonic events along the northern boundary of the Caribbean and provides a measure of constraint over the relative motions between the Caribbean Plate and surrounding plates (Reference 222).

The active spreading center in the central region represents younger rocks with older rocks to the east and west (Reference 554). This north-south spreading axis is very short, 150 kilometers (90 miles) long and 30 kilometers (19 miles) wide. The rift valley is deep (5500 meters [18,000 feet] average depth with a maximum depth of 6000 meters [20,000 feet]) and is flanked by rift mountains with peaks of 2500 meters (8200 feet) deep. The average strike of the spreading zone is about 080° (Reference 499). As the North America Plate moves westward relative to the Caribbean, a continual opening takes place at the spreading center, which is filled with upwelling mafic asthenospheric material and hardens to form new oceanic crust (References 555, 528, and 499). Ten to fifty meters (33 to 164 feet) of the spreading axis is characterized as a series of volcanic ridges, cones, and depressions in a 2 to 3 kilometers (1.2 to 1.9 miles) wide belt that parallels the valley walls (Reference 555). The rift valley walls rise abruptly from the edge of the rift valley and consist of a series of fault escarpments and ledges that form inward facing steps a few meters to tens of meters in relief. Subsequent erosion and the formation of talus ramps have modified the small-scale morphology to a minor extent (Reference 527).

Stratigraphy of the Cayman Trough

The composition and age of the rock units cropping out in the Cayman Trough are derived from 80 dredge hauls on Duke University's research vessel *Eastward* during 1971, 1972, and 1973 and 94 sampling stations from the research vessels *Knorr* in 1976 and *Oceanus* in 1977, in addition to geophysical data. In general, the Cayman Ridge and northern Nicaraguan Rise are composed of metamorphic, plutonic, volcanic, sedimentary, and carbonate rock units. The trench floor is composed of mafic and ultramafic rocks (References 528 and 555). The Cayman Trough has four distinctive morphotectonic regions: eastern Cayman Trough, Cayman Ridge, northern Nicaraguan Rise (Subsection 2.5.1.1.2.2.5.1), and the mid-Cayman spreading center.

The eastern Cayman Trough covers the area south of the Sierra Maestra (Cuba) and consists of granodiorites, tonalites, and basalts that exhibit various degrees of alteration and metamorphism. Limestone, large manganese nodules, thick manganese plates, and coral were sampled at shallower depths between the Sierra Maestra and Jamaica (Reference 528).

The diverse rocks along the Cayman Ridge (Figure 2.5.1-202) are located in the area west of the Sierra Maestra. In the deepest part of the ridge, metamorphic and plutonic rocks with lesser amounts of volcaniclastics, volcanics, and late Cretaceous and late Paleocene shallow-water carbonates crop out (>2500 meters or >8200 feet). Along the western end of the ridge, amphibolites, gneisses, and micaceous schists were retrieved from the dredge samples. However, the predominant rock type recovered was a medium to coarse-grained hypautomorphic-granular granodiorite. Greenschist grade metamorphism and cataclastic textures occur frequently in the plutonic rocks; these are similar to those found south of the Sierra Maestra (Reference 528). Extrusive rocks range from basalt to aplitic rhyolite, but the majority are andesites or dacites. The colors of the volcanic rocks are purple to reddish due to enrichment of oxidized mafic and opaque minerals. The pyroclastics exhibit virtoclastic textures with various degrees of alteration and devitrification. Some of the tuffs are intercalated with microfossil bearing carbonates and clays. The sedimentary rocks appear as outcrops along the ridge and consist of volcanic breccia, conglomerate, arenites, and argillite that are composed mostly of igneous fragments with small amounts of mineral, clastic, metamorphic, and biogenic clasts in clay matrices. Also present are nonvolcanic argillite, graywacke, arkose, and conglomerate. Lastly, the carbonate constituents range in age from Miocene to Pleistocene and are generally micritic, planktonic oozes with some reef limestones with abundant shallow-water biologic material such as coquina, sponges, coral, algal balls, sea biscuits, echinoids, and mollusk shells (Reference 528).

The mid-Cayman spreading center has a crustal sequence identical to the mid-oceanic ridge (Reference 528). Dredging samples consisted of serpentinite (with minerals of, orthopyroxene, clinopyroxene, and spinel) and probably pseudomorphs after olivine. This is indicative of mineral assemblages that are stable in the mantle at depths of 25 to 70 kilometers (15 to 45 miles). The samples indicate that they were crystallized from a melt in the crust or very shallow mantle (Reference 558). The Oriente fault yielded dredge samples consisting primarily of serpentinite and serpentinized peridotite with minor quantities of graywacke and basalt. Serpentinized peridotite and coarse gabbro were dredged from the walls of the mid-Cayman spreading center. Dolerite and basalt were retrieved on outcrops higher along the escarpments. Lesser amounts of metavolcanics, metasediments, marble, and limestone were sampled from the dredge hauls. The amount of carbonate dredged from the mid-Cayman spreading center was slight and difficult to identify as in situ on the top of the ridges. Most are micritic limestones with pelagic forams and minor angular fragments of plagioclase, clinopyroxene, chlorite, iddingsite, amphibole, and epidote. It is possible that these limestones formed at depth within the trench as seen from a lack of shallow-water fossils and granitic detritus (Reference 528).

Structures of the Cayman Trough

The Cayman Trough comprises a central north-northwest-trending spreading axis, with strike-slip faults extending both east and west from its southern terminus and a strike-slip fault extending east from its northern terminus (Figure 2.5.1-202). Extending east from the northern end of the spreading axis is the left-lateral

Oriente fault, which connects with the Septentrional fault on the island of Hispaniola. From the southern end of the spreading axis, the Swan Islands fault extends to the west, eventually linking with the Motagua fault in Guatemala and Honduras.

To the east of the southern end of the spreading axis, the Walton, Duanvale, and Enriquillo-Plantain Garden faults extend eastward through Jamaica to Hispaniola. The submarine portions of these structures were mapped with the aid of the SeaMARC II sidescan instrument (Reference 559). The spreading axis itself is offset by a short discontinuity. Seismicity indicates this is a left-lateral strike-slip fault (Reference 499). The Oriente fault is described in detail in Subsections 2.5.1.1.1.3.2.4 and 2.5.1.1.2.3.1.2.

The Swan Islands transform includes continuous bathymetric lineaments defined by small scarps, furrows, sag structures, or en echelon folds and fissures offshore (Reference 559). The Swan Islands are formed by a right-step in the left-lateral fault, which creates a restraining bend, and the islands rise about 5000 meters (16,400 feet) relative to the seafloor in the adjacent portions of the trough. The overlapping segments of the fault, known as the East and West Swan Islands faults, overlap west of the Swan Islands and come to within 12 kilometers (7.5 miles) of each other (Reference 559). Analyses of magnetic anomalies in the seafloor indicate that this fault has been active since sometime between 50 and 30 Ma (Reference 499). Detailed information regarding this structure, which is an active tectonic fault and a seismic source zone, is found in Subsection 2.5.1.1.2.3.1.1.

The Walton fault extends for about 185 miles (300 kilometers) eastward from the southern end of the mid-Cayman spreading center to northwestern Jamaica (Reference 766). Slip is transferred from the Walton fault across the island of Jamaica through a broad restraining bend that includes the east-west striking Duanvale, Rio Minho-Crawle River, South Coast, and Plantain Garden faults (Reference 503). The geometry of the Walton-Duanvale fault is more complicated than the Swan Island transform, with pull-apart and pop-up structures intersecting its sinuous trace (Reference 559). The Walton-Duanvale fault probably developed in the late Miocene (Reference 559). The topography of Jamaica results from the complicated interaction of the Walton-Duanvale fault system and the Enriquillo-Plantain Garden fault system (Figure 2.5.1-300). This entire system is described in more detail in Subsection 2.5.1.1.2.3.2.3.

Seismicity of the Cayman Trough

The Cayman Trough includes major active plate boundary structures, including the spreading axis and the Swan Islands, Enriquillo-Plantain Garden, Walton-Duanvale, and Oriente faults. The Phase 2 earthquake catalog (Subsection 2.5.2.1.3) indicates abundant large earthquakes in this area (Figure 2.5.1-267). These earthquakes are concentrated along these major active plate boundary structures and seismicity mapping of the region clearly identifies the gross fault structure of the Cayman Trough (e.g., Reference 813) (Figure 2.5.1-267). Subsection 2.5.1.1.2.3.1 provides additional discussion regarding the active tectonic structures of the Cayman Trough and associated instrumental and historical seismicity.

2.5.1.1.2.2.2 Geology of the Southeastern Greater Antilles

The Greater Antilles are a group of Caribbean islands comprised of Jamaica, Cuba, Hispaniola, Puerto Rico, and the Cayman Islands. Due to its location relative to the Units 6 & 7 site, Subsections 2.5.1.1.1.1.3 and 2.5.1.1.1.2.3 include descriptions of Cuba in some detail. This subsection describes the physiography, stratigraphy, structures, and seismicity of the islands of Jamaica, Hispaniola, and Puerto Rico. The Cayman Islands are discussed in Subsection 2.5.1.1.2.1.3 as part of the Cayman Ridge of the Yucatan Basin.

Mattson (Reference 804) and Pindell and Barrett (Reference 219) propose that Cretaceous igneous rocks of the Greater Antilles islands of Cuba, the Cayman Ridge, Hispaniola, and Puerto Rico originated in an intra-oceanic island arc, with northeast-dipping subduction, bounding one edge of a proto-Caribbean Sea (Figure 2.5.1-347, part B). In these models, attempted subduction of a Pacific-derived oceanic plateau (the Caribbean ocean plateau) caused the Greater Antilles Arc to reverse its polarity to south-southwest-dipping subduction. The arc then migrated to the north-northeast, consuming the Jurassic to Early Cretaceous proto-Caribbean ocean crust. Based on lithologic types and metamorphic rock ages in Cuba, Dominican Republic, and Puerto Rico, Mattson (Reference 804) suggests that the arc polarity reversal occurred during the latest Early Cretaceous (120-130 Ma) and that renewed subduction began during the early Late Cretaceous (110 Ma) and ended by middle Late Cretaceous (85 Ma). Mattson (Reference 804) notes that volcanism ceased by 85 Ma. Pindell and Barrett (Reference 219) note that obducted ophiolites (the Bermeja Complex of Puerto Rico) were accreted to the south side of the island before about 95 Ma (the middle Late Cretaceous or Campanian time), suggesting north-dipping subduction. Pindell and Barrett (Reference 219) also note that after about 80 Ma (middle Late Cretaceous or Santonian to Campanian time) ophiolitic complexes were emplaced on the north side of the arc, suggesting south-dipping subduction. Draper et al. (Reference 808) cite new structural data from central Hispaniola, suggesting that a mid-Cretaceous orogenic event resulted in the obduction of peridotites onto the early Great Antilles Arc in the late Early Cretaceous (Aptian-Albian). Draper et al. (Reference 808) and Draper and Barros (Reference 834) also note that this event is synchronous with chemical changes of the arc magmas in Hispaniola, Puerto Rico, and central Cuba, and thus, both may be related to the postulated Greater Antilles Arc polarity reversal.

The geologic evidence used in these early models to support Cretaceous subduction polarity reversal is the present-day out crop of older (Jurassic-Early Cretaceous [?]) high pressure/low temperature metamorphic rocks along the southern flank of arc rocks in Cuba and Puerto Rico and younger (Late Cretaceous-early Tertiary [?]) high pressure/low temperature metamorphic rocks along the northern flank of arc rocks in Cuba and Hispaniola (Reference 833). Nearly 30 years after Mattson's work (Reference 804), the basic model for the development of the Greater Antilles Arc has been tested and is still the most accepted model of early development of the Greater Antilles Arc and the Caribbean Plate (Reference 807).

The Cretaceous-Eocene island arc rocks of the northeastern Caribbean can be subdivided into a basal Late Jurassic (?) to Early Cretaceous primitive island arc (PIA) suite and an overlying Late Cretaceous-Oligocene calc-alkaline (CA) rock suite (Reference 568) (Figure 2.5.1-301). Pindell and Barrett (Reference 219) consider intermediate and calc-alkaline plutons, lavas, and tuffs as evidence of subduction. They find that the period over which each arc was volcanically or magmatically active correlates approximately with the period of active subduction. Calc-alkaline arc activity in the northeastern Caribbean terminated in Eocene-Oligocene time by collision of the arc with the Bahama carbonate platform (Reference 219).

Although the local stratigraphy and structure of arc rocks of the islands of Greater Antilles is complex, a striking correlation exists between Late Cretaceous-Eocene volcanic arc-related lithologies and intercalated siliciclastic and carbonate deposits. The Cretaceous-Paleogene histories of island arc development in Cuba, the Cayman Ridge, Hispaniola, and Puerto Rico are similar, suggesting that these islands belonged originally to the same arc system. According to Pindell and Barret (Reference 219), westernmost and north-central Cuba may be continental and unrelated to the Greater Antilles Arc and the island of Jamaica, part of the Greater Antilles island group, may be part of a different volcanic arc (the Chortis arc of Meschede and Frisch [Reference 856] or the Nicaragua-Jamaica Arc of Pindell and Barrett [Reference 219]). Pindell and Barrett (Reference 219) assert that the Nicaragua-Jamaica Arc included pre-Mesozoic continental crust in Jamaica and the northern Nicaraguan Rise, those areas may be genetically related to the Chortis arc of southern Guatemala, Honduras, northern Nicaragua and propose that the western Nicaraguan Rise. In contrast, Mann et al. (Reference 814) propose that the crust underlying the northern Nicaraguan Rise and Jamaica is not continental but of volcanic island arc origin.

2.5.1.1.2.2.2.1 Geology of Jamaica

Physiography of Jamaica

Jamaica is the third largest of the Greater Antillean islands and lies at the edge of the seismically active plate boundary between the North America and Caribbean Plates (References 560 and 493). The island is approximately 130 kilometers (80 miles) long and 80 kilometers (50 miles) wide, with a total area of 10,991 kilometers^2. It is the emergent part of the eastern apex of the Nicaraguan Rise and is separated from the North America Plate by the Cayman Trough. Over 60 percent of the surface outcrop is limestone that has been extensively karstified (Reference 217).

The physiography of Jamaica resembles the other islands of the Greater Antilles, with its mountains, limestone plateaus, and steep seaward slopes rising abruptly from a coastal plain that in most places is extremely narrow. The Blue Mountains (maximum elevation 7388 feet [2250 meters]) begin near the east end of the island and parallel the northeast coast for about a third of its length. The Blue Mountains represent the eroded core of an ancient volcanic arc, once much more extensive. Over the western two-thirds of the island and partly encircling the Blue Mountains is a plateau of white limestone that arches gently down to the north and south. Another ancient volcanic core exposed by erosion of this plateau forms several small chains (maximum elevation 3165 feet or 965 meters) with deeply cut flanks that parallel the axis of the Blue Mountains (Reference 217).

The tropical to subtropical climate of Jamaica results in the deep weathering of volcanic sediments that underlie the Blue Mountains. This weathering forms deep residuals soils that are highly susceptible to both rainfall and earthquake-induced landslides.

Stratigraphy of Jamaica

Jamaica is composed of Cretaceous and Tertiary rocks (Figures 2.5.1-302 and 2.5.1-303) exposed in blocks and belts across the island. The blocks of Jamaica are Cretaceous in age. Fault-bounded belts of younger (Tertiary) rocks flank and separate the blocks (Reference 805) (see the Structures subsection for Jamaica). Pliocene and Quaternary rocks, found mostly around the coast, consist of patch reef (carbonate) sediments with some subaerial to submarine fanglomerates. Late Pleistocene through Holocene sediments are neritic and form a series of raised marine terraces (Reference 217).

Three main structural blocks and three belts (morphotectonic units) have been identified in Jamaica (Reference 217). The blocks, from west to east, are the Hanover, Clarendon, and Blue Mountain blocks. These three blocks are separated by two northwest-trending graben structures; the Montpelier-Newmarket belt separates the Hanover and Clarendon blocks, and the Wagwater belt separates the Clarendon and Blue Mountain blocks. The North Coast belt is an east-west-trending unit that abuts the northern edge of the central Clarendon block.

The Hanover, Clarendon, and the Blue Mountain blocks consist of Early to Late Cretaceous (Albian to Maastrichtian) volcanic, volcaniclastic, and plutonic assemblages with some minor limestones. The stratigraphy of these older rocks is different for each block due to lateral variations in rock types deposited in small basins of the Cretaceous island-arc system.

The Hanover block contains only Late Cretaceous rocks exposed in four inliers: the Lucea, Jerusalem Mountain, Green Island, and Grange inliers. An inlier is an area or group of older rocks surrounded by young rocks (Reference 202). The Lucea inlier contains a 4000-meter (13,100-foot) thick sequence of shales, sandstones, and minor limestones ranging from late Santonian to early Campanian in age. An important feature in these rocks is a submarine canyon complex consisting of conglomerate channel fill that cuts across and disturbs the underlying shales and sands (Reference 217). Other structural units of the Lucea inlier contain sequences of clastic deposits and minor limestones, including channelized sands of Santonian age (Reference 217). The Green Island, Grange, and Jerusalem Mountain inliers contain lithologies similar to the Lucea inlier but are younger. Lithologies include a Late Cretaceous (Maastrichtian) arenaceous red bed sequence with rudist limestones and red fluvial sandstones and conglomerates (Reference 217).