migration of salt along normal faults in the Carolina Trough (Figure 2.4.6-202). It appears that oversteepening of the sea floor due to salt movement, aggravated by any earthquakes in the region, however small, could lead to repeated slope failures and landslides. See Subsections 2.5.1.1.5 and 2.4.6 for further discussion of potential landslide and tsunami hazards to the Units 6 & 7 site.

2.5.1.1.1.1.2 Bahama Platform

From the Late Jurassic to Early Cretaceous, the Bahama Platform was contiguous with the Florida Platform, the Yucatan Platform, and the carbonate platform of the Gulf of Mexico (Reference 307). Together, the complex was part of one of the most extensive carbonate systems in Earth's geologic history. The carbonate platform stretched nearly 7000 kilometers (4400 miles) from the north-central Gulf of Mexico along the eastern North American continental margin to Canada (Reference 327). Carbonate production on the Bahamas-Grand Banks megaplatform began to shut down in the mid- to Late Cretaceous (Reference 327) (Subsection 2.5.1.1.1.1.1.2).

Located immediately east and south of the Florida Platform, the Bahama Platform is a broad, shallow marine platform with shallow banks (small portions of which are emergent as the Bahamas Islands) and intervening deep-water channels with depths of up to 13,100 feet (4000 meters) (Reference 307). The Bahama Bank, consisting of the Great and Little Bahama Banks, is separated from the Florida Peninsula by the Straits of Florida. The Bahama Bank mostly comprises shallow continental shelf and lagoon sediments. The windward side comprises a small percentage of active reefs. The reef pinnacles are found on the outer margin of the shelf. The sediment surface consists of grass flats of carbonate sands with relict sand bodies and oolite shoals (Reference 282).

The geomorphology of the Bahama Platform is controlled by the progradation of reefs, the brecciated fore-reef escarpments, and the accumulation of back-reef carbonate sediments reworked by currents, waves, and winds. A minor component of platform sediments is terrigenous sands transported from Africa by the prevailing trade winds (Reference 328).

Anselmetti et al. (Reference 228) analyze high-resolution seismic data collected across the Great Bahama Bank margin and the adjacent Straits of Florida to determine that the deposition of strata in this transect over the past 23 m.y. was and is controlled by two sedimentation mechanisms: (a) west-dipping layers of the platform margin, which are a product of sea-level-controlled, platform-derived downslope sedimentation; and (b) east- or north-dipping drift deposits in the basinal areas, which were deposited by ocean currents. These two sediment systems are active simultaneously and interfinger at the toe-of-slope. The Neogene slope sediments consist of peri-platform oozes intercalated with turbidites, whereas the basinal drift deposits consist of more homogeneous, fine-grained carbonates that were deposited without major hiatuses by the Florida Current starting at approximately 12.4 Ma. Glacial sea-level fluctuations, which controlled the carbonate production on Great Bahama Bank by repeated exposure of the platform top, controlled lithologic alternations and hiatuses in sedimentation across the transect.

Droxler and Schlager (Reference 329) analyze the sedimentation rates during glacial and interglacial periods. Based on radiometric and faunal assemblage age dating for stratigraphic sequences, Droxler and Schlager (Reference 329) find the mean of bulk sedimentation rates at the Great Bahama Bank is four to six times higher in interglacial periods than during glacial periods; average accumulation rates of recognizable turbidites are higher during interglacial than glacial periods by a factor of 21 to 45, and interglacial turbidite frequency is higher by a factor of 6 to 14 during glacial periods. Sediment composition indicates that increased interglacial sedimentation rates are due to higher accumulation of platform-derived material. Additional data from other Bahamian basins as well as published material from the Caribbean strongly suggest that highstand shedding is a general trend in pure carbonate depositional systems. Carbonate platforms without a siliciclastic component export more material during highstands of sea level when the platform tops are flooded and produce sediment. The response of carbonate platforms to Quaternary sea-level cycles is directly opposite of that of siliciclastic ocean margins, where sediment is stored on the inner shelf during highstands and passed on to continental rises and abyssal plains during lowstands of sea level (Reference 329).

Carbonate production on the Bahama Platform is controlled largely by sea-level conditions. Sediment production and off-bank transport is highest during sea-level highstands when the platform is flooded (References 330, 331, and 332). During these times, more sediment is produced than can be accumulated on the platform top, and a large amount of sediment is transported off-bank onto the slopes (References 330, 333, 863, and 334). Light dependency forces the carbonate-secreting organisms to maintain the depositional systems close to sea level, resulting in a nearly flat sediment surface across the entire platform. As a result, falling sea level exposes the platform and restricts sediment production to the fringes of the platform. With renewed flooding of the platform, sediment production and off bank transport resumes, depositing a highstand wedge on the leeward slope of the western Great Bahama Bank (Reference 334).

2.5.1.1.1.1.3 Cuba

Unlike the Bahama Platform, the physiography of Cuba includes mountainous terrain. The archipelago of Cuba is formed of about 1600 islands, the largest of which, Cuba, lies approximately 150 miles (240 kilometers) south of the Units 6 & 7 site. The Windward Passage separates Cuba from Jamaica, the Bahamas, and Haiti. Cuba is about 1200 kilometers (745 miles) east to west and between 40 and 290 kilometers (25 and 180 miles) north to south. The island covers 107,500 kilometers^2 (44,000 miles^2) and is mountainous for 20 percent of its land surface. Three different mountain ranges have been identified: the highest (up to 2000 meters or 6600 feet) in the Sierra Maestra of southeastern Cuba; the central low ranges of Escambray Mountains (Sierras Cienfuegos and Sancti Spiritus), and in the west, the Pinar del Rio range (Sierra de los Organos) (Figure 2.5.1-227). The other 80 percent of Cuba's land surface consists of more gently rolling hills and extensive lowlands, with deep red sandy clays and fertile alluvial soils in the flood plains (Reference 335). About two-thirds of the island consists of limestone and karstic features are well developed, particularly in the eastern section (Reference 336).

Although rivers are plentiful, the island's narrow, elongated form means that much of the fresh water runs off quickly seawards, with little retention other than where captured by human activities. The longest is the Cauto River at 370 kilometers (230 miles), followed by the Sagua la Grande River at 163 kilometers (101 miles) and Zaza River at 155 kilometers (96 miles) (Figure 2.5.1-227). The east coast is subject to hurricanes from August to October, and droughts are also common (Reference 336).

2.5.1.1.1.2 Regional Stratigraphy within the Site Region

The stratigraphy described in this subsection has been developed from the analysis of surface and subsurface geologic and geophysical investigations performed at the site and reported in peer-reviewed publications. The stratigraphy of southern Florida is characterized by a thick sequence of Jurassic to Holocene sediments that lie unconformably on Jurassic basement volcanic rocks. Although most of the units in the sedimentary sequence are carbonates, deposition of Appalachian derived siliciclastic sediments occurred during the Miocene and Pliocene. The oldest stratum exposed at the surface in the southern Florida region is the Miocene-Pliocene Peace River Formation that crops out in Hardee and DeSoto counties (Reference 283).

An important aspect of describing stratigraphy is identifying the depth to the basement. Basement may be defined as structural, stratigraphic, seismic, or petrologic. Recent literature has generally accepted the pre-Cretaceous surface as an appropriate upper limit of the basement stratigraphy of the Gulf of Mexico and North America-Caribbean Plate boundary (References 212 and 337). In this context, "basement" refers to stratigraphic basement below a regionally recognizable and tectonically significant unconformity. The basement unconformity separates pre- to syn-rift rocks formed during the breakup of Pangea from overlying rocks. The information presented in this subsection refers to the basement surface as pre-Middle Jurassic. This age designation more accurately constrains the Mesozoic post-rift unconformity that can be correlated across most of in the subsurface of Florida and across the Gulf of Mexico, Yucatan and Bahama Platforms, and Caribbean region.

2.5.1.1.1.2.1 Stratigraphy of the Florida Peninsula and Platform

This subsection describes the stratigraphy of the Florida Peninsula and the remainder of the submerged Florida Platform.

2.5.1.1.1.2.1.1 Stratigraphy of the Florida Peninsula

Two basement lithologic regions are recognized in Florida: a central and northern suite of Proterozoic rocks collectively known as the Suwannee terrane and a southern early Middle Jurassic volcanic province (References 338 and 339) (Figure 2.5.1-205).

The depth to metamorphic or crystalline basement beneath the Florida Peninsula and Platform is variable, from depths of 5 to 7 miles (8 to 11 kilometers) beneath the North Atlantic Ocean shorelines (Reference 282). Basement rocks are overlain by up to 15,000 feet (4570 meters) of relatively flat-lying Mesozoic evaporate and carbonate units (Figure 2.5.1-228), which are in turn overlain by up to 6000 feet (1830 meters) of Cenozoic carbonate and siliciclastic sediments (References 339, 338, and 340). The basement is found at depths of about 15.5 miles (25 kilometers) beneath the southern Florida shoreline, within the South Florida Basin. There, basement rocks are overlain by up to 25,000 feet (7600 meters) of relatively flat-lying Mesozoic evaporate and carbonate units, which are in turn overlain by up to 5250 feet (1600 meters) of Cenozoic carbonate and siliciclastic sediments (Reference 341).

Proterozoic Stratigraphy of the Florida Peninsula

The Suwannee terrane (Figures 2.5.1-205 and 2.5.1-228) comprises the following:

- Low-grade, felsic metavolcanics of the Osceola volcanic complex
- The undeformed Osceola Granite
- A suite of high-grade metamorphic rocks, such as gneiss and amphibolite, belonging to the St. Lucie complex
- A succession of generally undeformed Paleozoic sedimentary rocks

The Osceola Volcanic Complex

The Osceola volcanic complex (Figures 2.5.1-205 and 2.5.1-228) is a group of calc-alkaline, felsic, low-grade metaigneous rocks (Reference 338). Lithologic variations within the complex include felsic vitric tuff, felsic ash-flow tuff, and tuffaceous arkose with subordinate andesite and basalt. The rocks are generally undeformed but almost always display low-grade metamorphic assemblages (Reference 342). There is no consensus in the published literature on the age of the rocks belonging to the Osceola volcanic complex.

Dallmeyer (Reference 338) correlates rocks of this volcanic complex with a West African calc-alkaline metaigneous sequence dated at 650 Ma. Lithologic comparisons were used to propose that the north Florida volcanic suite is directly correlative with Late Proterozoic calc-alkaline volcanic rocks of the Niokolo-Koba Group in Senegal, West Africa, which, in turn, were proposed to be coeval with granites dated by $^{40}Ar/^{39}Ar$ and $^{87}Rb/^{86}Sr$ at 650 to 700 Ma (late Proterozoic) (Reference 343).

Chowns and Williams (Reference 344) suggest a Late Proterozoic to early Paleozoic age for the rock based on core recovered from a well drilled in central Florida where the felsic igneous complex appears to be unconformably overlain by Lower Ordovician sandstone. Whole rock K-Ar ages for this igneous complex range from about 165 to 480 Ma. Unpublished whole rock $^{40}Ar/^{39}Ar$ data reported by Horton et al. (Reference 342) on a suite of seven volcanic samples indicate that all of the samples have a noticeably discordant age spectra. A slate sample from 11,600 feet (3500 meters) displays an internally discordant $^{40}Ar/^{39}Ar$ age spectrum, defining a total-gas age of about 341 Ma. Similarly, a felsic metavolcanic rock recovered from a depth of 12,350 feet (3800 meters) displays an internally discordant age spectrum; however, intermediate and high temperature increments correspond to a plateau age of about 375 Ma (Reference 342).

Heatherington and Mueller (Reference 343) report on the age of a suite of volcanic rocks; basaltic andesites to rhyolites, from northeastern and north central Florida. These rocks from Putnam and Flagler counties yielded $^{40}Ar/^{39}Ar$ measurements corresponding to approximately 410 to 420 Ma, while whole rock $^{87}Rb/^{86}Sr$ data suggest a composite isochron corresponding to an age of about 480 ± 60 Ma. Heatherington and Mueller (Reference 343) report that, while these are the only dates available for these rocks, they should be viewed as "lower limits" only. This limitation appears to be due to: the complexity of the $^{40}Ar/^{39}Ar$ data, the possibility that the whole-rock $^{87}Rb/^{86}Sr$ data may represent a mixing array, and that both the $^{40}Ar/^{39}Ar$ and $^{87}Rb/^{86}Sr$ systems are easily reset in these types of rocks by low-grade thermal and hydrothermal events.

The Osceola Granite

The Osceola Granite (Figures 2.5.1-205 and 2.5.1-228) comprises undeformed diorite to batholithic granodiorite (Reference 345). This rock has a granitic texture with coarse pink sodic plagioclase feldspar, abundant quartz, albite-oligoclase, and some potash feldspar, ilmenite, and apatite (Reference 340). Dallmeyer et al. (Reference 337) describe the pluton as heterogeneous and predominantly comprising biotite granodiorite, leucocratic biotite quartz monzonite, and biotite granite. According to Horton et al. (Reference 342), most of the samples examined by Dallmeyer et al. (Reference 337) were predominantly composed of oligoclase, quartz, perthitic alkali feldspar, and biotite. Depth to the top of this granite is approximately 8000 feet (2400 meters) in Osceola County (Reference 339).

Several dates are reported for the Osceola Granite. Biotite samples collected from two wells in Osceola and Orange counties yielded $^{40}Ar/^{39}Ar$ dates of 527 and 535 Ma (Reference 337). Dallmeyer et al. (Reference 337) suggest that these ages closely date emplacement of the pluton in view of its high-level petrographic character and apparently rapid postmagmatic cooling. $^{87}Rb/^{86}Sr$ analytical results from several density fractions of feldspar collected from a well in Osceola County reflect a crystallization age for the granite of about 530 Ma (Reference 346). Mueller et al. (Reference 347) report different ages obtained from whole-rock samples taken from two wells in Osceola County, suggesting that the Late Proterozoic to Early Cambrian Osceola Granite was derived from two or more older sources with different ages, at least one of which was Archean.

Reconnaissance single-grain ion-probe analyses of zircons from the Osceola Granite corroborate both the $^{40}Ar/^{39}Ar$ cooling age of approximately 530 Ma determined by Dallmeyer et al. (Reference 337) and the Archean component suggested by Mueller et al. (Reference 347). According to Heatherington and Mueller (Reference 343), several grains produced $^{206}Pb/^{238}U$ dates of about 550 to 600 Ma consistent with the $^{40}Ar/^{39}Ar$ date of 530 Ma as a cooling age.

St. Lucie Metamorphic Complex

The St. Lucie metamorphic complex (Figures 2.5.1-205 and 2.5.1-228) is immediately south of, and associated with, the Osceola Granite. It is a suite of high-grade metamorphic rocks and variably deformed igneous rocks. Predominant rock types include amphibolite, biotite-muscovite schist, chlorite schist and gneiss, and quartz diorite. The complex has a distinctive aeromagnetic signature with marked northwest-trending magnetic lineations that may reflect structural strike (Reference 342). Depth to the amphibolite in St. Lucie County is approximately 12,500 feet (3800 meters) (Reference 338).

Core recovered from wells drilled in the St. Lucie metamorphic complex in St. Lucie and Marion counties are predominantly amphibolites with schist and layers of quartz diorite (Reference 346). Radiometric dates include K/Ar dates of 503 and 470 Ma for hornblende from amphibolite recovered from a well drilled in St. Lucie County (Reference 346) and a reportedly more reliable $^{40}Ar/^{39}Ar$ date of 513 ± 9 Ma for a hornblende concentrate from amphibolite recovered from another well in St. Lucie County (Reference 338). On the basis of this later date, Dallmeyer (Reference 338) suggests that the St. Lucie amphibolite is correlative with amphibolites from the northern Rokelide orogen in Sierra Leone, West Africa, which have similar cooling ages.

Paleozoic Stratigraphy of the Florida Peninsula

The Paleozoic sedimentary suite is composed of a succession of undeformed, Lower Ordovician quartzitic sandstones and Middle Devonian black shales and siltstones overlying the Peninsular Arch (Reference 339) (Figures 2.5.1-205 and 2.5.1-228). Muscovite within the sandstone records an $^{40}Ar/^{39}Ar$ age of 504 Ma (Reference 338).

The base of the subsection, the Lower Ordovician littoral quartz sandstone (Reference 342), consists of white to reddish quartz sandstone with *Skolithos* burrows and interbedded micaceous shales. This portion of the subsection is the most widely distributed and possibly the thickest of all the Paleozoic sedimentary units. The sandstone is Early Ordovician in age and is defined on the basis of Arenig age graptolites and inarticulate brachiopods (References 207 and 348).

Overlying the sandstone is Ordovician to Middle Devonian shale with locally significant horizons of siltstone and sandstone (Reference 342). The dark-gray to black shales are interbedded with gray fine-grained micaceous sandstone and locally medium- to coarse-grained quartz sandstone. Based on paleontologic data, the shales are divided into three sections. The lowest section consists of Middle to Upper Ordovician fauna including trilobites, inarticulate brachiopods, conulariids, conodonts, and chitinozoans. The middle section consists of Late Silurian to Early Devonian shale with bivalves, gastropods, orthocone cephalopods, tentaculitids, brachiopods, crinoids, eurypterids, ostracods, and chitinozoans. The upper section consists of shales and sandstones containing Middle Devonian land plants, bivalves, ostracods, and marine microfossils (Reference 207). According to Thomas et al. (Reference 207), the contacts between several of the units are undefined and the section might be continuous. However, there is a possible discontinuity based on the absence of Early Silurian faunas. The thickness of the sedimentary units is uncertain, but based on gravity modeling and seismic profiles the thickness of the entire section ranges from 8202 feet (2500 meters) in parts of north-central Florida, to 32,808 feet (10,000 meters) in the Panhandle (References 207 and 342).

A genetic relationship between the southern Florida basement (Figure 2.5.1-204) and West African rock sequences has been suggested by many investigators (References 339, 338, 349, and 350) based on the following:

- A correlation between lithology and the radiometric age of calc-alkaline felsic igneous complex rocks in central Florida and West Africa (Reference 338). There is a correlation between the Osceola Volcanic Complex and West Africa calc-alkaline, metamorphosed igneous sequence (i.e., Niokola-Koba Group) along western portions of the Mauritanide, Bassaride, and northernmost Rokelide orogens (Reference 337). The isotopic ages of the sequence are about 650 and 700 Ma (Reference 342).

- A correlation between radiometric ages and petrography of the Osceola Granite with post-tectonic granite plutons in Guinea West Africa (Reference 338). The inferred correlation proposed by Dallmeyer et al. (Reference 337) for the Osceola Granite is with the Coya Granite in West Africa (northern Rokelide orogen in Guinea). The Osceola and Coya granites both have crystallization ages of about 530 Ma and display similar petrographic characteristics (Reference 342).

- A correlation between the stratigraphic, geochronologic, and geochemical data of the southern Florida tholeiitic volcanic sequence and Liberian tholeiites indicates that both may have had the same parental magma (Reference 339). Hornblende $^{40}Ar/^{39}Ar$ cooling ages of 510 to 515 Ma from the St. Lucie Metamorphic complex are similar to the Rokelide orogen where hornblende K-Ar and $^{40}Ar/^{39}Ar$ dates are approximately between 485 and 530 Ma (Reference 342).

- A correlation of the Paleozoic sedimentary sequence overlying the Peninsular Arch with the lithology, radiometric ages, paleontology, and paleomagnetic data from rocks in Senegal and Guinea (Reference 338). The correlation between the subsurface Paleozoic sedimentary sequences in the North Florida Basin with sequences of similar age in the Bové Basin of Senegal and Guinea is suggested by similarities in fauna and stratigraphic succession (Reference 344). In addition, an $^{40}Ar/^{39}Ar$ 505 Ma date of detrital muscovite from subsurface Ordovician sandstone in Marion County, Florida, suggests a metamorphic source similar in age to the rocks of the Bassaride and Rokelide orogens that yield $^{40}Ar/^{39}Ar$ muscovite ages of about 500 to 510 Ma (Reference 206). Opdyke et al. (Reference 351) report 1650 to 1800 Ma U-Pb ages for detrital zircons from Ordovician-Silurian age sandstone in Alachua County, Florida, which suggests a source similar in age to the basement of the West African craton.

The lithologic and geochronologic characteristics described above suggest that these Florida basement provinces originated in West Africa and represent a fragment of Gondwana that accreted to Laurentia during the late Paleozoic formation of Pangea (References 339, 338, and 349). The Floridian piece of Africa remained attached to North America when Pangea broke apart during the opening of the Atlantic Ocean in the Jurassic (Reference 338). This fragment of the African Plate provided the base for the development of a carbonate platform that included the Florida Platform (Reference 349) (Subsection 2.5.1.1.2.1).

Jurassic Stratigraphy of the Florida Peninsula

The Florida carbonate platform began to develop following the establishment of a continental base in North America. Knowledge of the Mesozoic sequence is principally derived from limited oil exploration borings and geophysical data reported in the literature (References 352, 353, 354, 355, and 356).

The Peninsular Arch and other structural/topographic high points (Figure 2.5.1-229) controlled the type and distribution of carbonate depositional facies of Jurassic and Cretaceous sediments including reef complexes that onlapped and wedged or pinched out against these bathymetric highs. A major barrier reef complex of continual reef growth existed in southern Florida from the Cretaceous to Holocene. The presence of nearly continuous carbonate-evaporite cyclical deposition from the Jurassic to the present indicates that sedimentation in the southern Florida Basin kept pace with subsidence (Reference 355). Several wells have been drilled in the southern Florida Basin through carbonate and evaporite sequences to depths as much as 5300 feet (1615 meters) below the Punta Gorda Anhydrite (Figure 2.5.1-228). The deepest well penetrated igneous basement rocks at a total depth of 18,670 feet (Reference 353).

The Upper Jurassic and Lower Cretaceous Wood River Formation (Figure 2.5.1-228) is the stratigraphically lowest sedimentary unit in southern Florida and rests unconformably on rhyolite porphyry dated at 189 Ma (Reference 354). A 100- to 150-foot (46-meter) thick clastic unit forms the basal part of the Wood River Formation and consists of dark-red shale, sandy dolomite, and fine- to coarse-grained arkosic sandstone and calcareous sandstone. These basal clastic units may represent fan, fan-delta, and fluvial-lacustrine or marine deposits. Overlying these clastic rocks is a thick sequence of anhydrite, dolomite, and limestone with occasional interbedded salt stringers, indicating marine transgression. Marine beds are predominant in the formation, and the depositional environment, especially in the southern part of the depositional area, probably favored reef growth (Reference 354). The dolomite is microcrystalline and brown with relict oolitic texture (Reference 356). Interbedded anhydrite, salt stringers, and micritic limestones act as impermeable layers within the more porous dolomite (Reference 355). The thickness of the Wood River Formation ranges from 1700 to 2100 feet (520 to 640 meters) and is generally encountered at depths exceeding 15,000 feet (4572 meters) (Reference 353).

Cretaceous Stratigraphy of the Florida Peninsula

A major barrier reef complex of continual reef growth existed in southern Florida from the Cretaceous to the Holocene (Reference 355). From the Late Jurassic (161 Ma) through the Early Cretaceous (99 Ma), the continental margin was occupied by a carbonate complex that restricted marine circulation in some areas. In the southeast, this barrier caused the deposition of lagoonal carbonates and anhydrites that formed the Bone Island and Pumpkin Bay Formations and the Glades, Ocean Reef, Big Cypress, and Naples Bay Groups (Figures 2.5.1-228 and 2.5.1-230). Carbonate-evaporite deposition in the south ended at the close of the Early Cretaceous and was followed by the deposition of chalk and chalky limestone of the Late Cretaceous Pine Key Formation (Figure 2.5.1-228). By the middle of the Late Cretaceous, the Rebecca Shoal barrier reef had appeared on the upthrown northern side of the straits. This barrier reef expanded to encircle the Florida Peninsula completely. Winston (Reference 357) indicates that following this encirclement, the Paleocene (65 to 56 Ma) Cedar Keys Formation (Figure 2.5.1-231) lagoonal dolomite-anhydrite appears to have been deposited within this enclosed environment.

The Lower Cretaceous Bone Island Formation conformably overlies the Upper Jurassic Wood River Formation (Figure 2.5.1-228). The Lower Cretaceous Bone Island Formation is a sparsely oolitic brown limestone with occasional similarly textured dolomites and anhydrites (Reference 353). Winston (Reference 356) and Applegate et al. (Reference 353) indicate the Bone Island Formation is capped by a regionally persistent 200-foot (61-meter) thick anhydrite layer and contains a 100-foot (30.5-meter) thick lens of dolomite in the type section (well). The Bone Island Formation is approximately 1300 to 2000 feet (400 to 600 meters) thick in southern Florida (References 353 and 356).

The Lower Cretaceous Pumpkin Bay Formation conformably overlies the Cretaceous Bone Island Formation (Figure 2.5.1-228). The Pumpkin Bay Formation is composed of limestone, except at its northern limit, where dolomite is the dominant lithology. A 350-foot thick dolomite zone occurs in the middle and upper parts of the formation and exhibits pinpoint intercrystalline to vuggy porosity (Reference 355). The limestone is brown and sparsely oolitic with occasional oolitic textured dolomite and two thick (200 feet or 61 meters) anhydrite lenses (Reference 356). Pollastro and Viger (Reference 354) describe organic-rich beds in the upper Pumpkin Bay Formation. Anhydrite and dolomite are predominant in the lower part of the formation (Reference 353). Within the Florida Peninsula, the Pumpkin Bay Formation is as much as 1200 feet (600 meters) thick and thickens westward into the southern Florida Basin depocenter. Onshore, the Pumpkin Bay Formation is found at depths from approximately 12,500 to more than 15,000 feet (3810 to more than 4570 meters) (Reference 354).

The Lower Cretaceous Glades Group conformably overlies the Pumpkin Bay Formation (Figure 2.5.1-228). The Glades Group consists of the Lehigh Acres Formation and Punta Gorda Anhydrite and exhibits a continuous lagoonal carbonate depositional environment. The Lehigh Acres Formation conformably overlies the Cretaceous Pumpkin Bay Formation. The Lehigh Acres Formation is divided into the basal West Felda Shale Member, the Twelve Mile Member, and the uppermost Able Member. The members represent a backreef depositional cycle of limestone, dolomite, and anhydrite with a total thickness that varies from 530 to over 700 feet (References 353 and 356). The West Felda Shale Member consists of dark gray, micaceous, calcareous shale with thin interbeds of brown, micritic limestone up to 200 feet thick. The overlying Twelve Mile Member is composed of relatively thin limestone beds within the main thick, vugular, porous dolomite unit. The Able Member consists of a regionally persistent white to gray anhydrite interbedded with limestone and occasional dolomite beds (References 352 and 353). The Lower Cretaceous Punta Gorda Anhydrite of the Glades Group conformably overlies the Cretaceous Lehigh Acres Formation. Punta Gorda Anhydrite layers have been used as marker beds throughout the Gulf of Mexico and are divided into nine individual anhydrite beds traceable from southern Mississippi to southern Florida (Reference 352). Applegate et al. (Reference 353) describe the Punta Gorda Anhydrite as a series of anhydrite layers approximately 800 feet (244 meters) thick and indicate that it has been found at an elevation of -12,000 feet (-3660 meters) in Collier County. It serves as a regional impermeable seal for hydrocarbon deposits both above and below (Reference 353). Winston (Reference 356) also indicates the presence of salt stringers in the upper Punta Gorda Anhydrite.

The Punta Gorda Anhydrite beds appear to thicken and interfinger with carbonates of the Lower Cretaceous shelf edge reef (Figure 2.5.1-228). Paleontologic data indicate that these interbedded carbonates were deposited in water depths that ranged up to 300 feet (91 meters). Carbonates and anhydrites were deposited simultaneously with carbonate patch reefs developing on crests of paleo highs while evaporites precipitated out of a hyper-saline solution on the flanks. Areas where poor anhydrite bed development occurs indicate areas of patch reefs. Some anhydrite beds are regional whereas others are more restricted. Isopach maps show that these beds were deposited with the long axis of the southern Florida Basin parallel to the reef trend. Anhydrite deposition occurred where evaporation of restricted highstand waters was behind reefs that rimmed the shelf edge (Reference 352). The presence of micritic, calcareous mudstone immediately above the anhydrite provides evidence of the termination of marine regression (Reference 296).

The Lower Cretaceous Ocean Reef Group conformably overlies the Glades Group (Figure 2.5.1-228). The Ocean Reef Group consists of the Sunniland, Lake Trafford, and Rattlesnake Hammock Formations. The units of the Ocean Reef Group are typically composed of evaporites and carbonates formed during transgressive-regressive cycles (Reference 360). The units consist of limestones, anhydrites, and dolomites that have been subdivided into multiple formations and groups based on regionally persistent anhydrites that form the uppermost lithologic unit of each formation (Reference 356). Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present, especially in the anhydrite and limestone intervals. The limestones range from white to gray to tan to dark brown and are usually micritic, chalky, and calcarenitic, with skeletal fragments of gastropods, algae, and other fossils. The anhydrite is nodular, microcrystalline, or crystalline and is commonly bedded. Dolomite crystals are euhedral to sucrosic and occur in approximately 30 percent of each formation (Reference 360).

The Sunniland Formation conformably overlies the Punta Gorda Anhydrite (Figure 2.5.1-228). The Sunniland Formation is the basal unit of the Ocean Reef Group. The formation is relatively uniform in thickness within the region and consists of limestone, dolomite, and anhydrite composed of reefs, shoals, carbonate mounds, bioherms, and related features (Reference 354). These shelf carbonates were deposited in beach and shoal-type environments along a high energy, reef-forming band between the shallow-water, low-energy chalky beds and the quiet, deep-water dark micrites to the southwest. Almost all of the effective porosity is in this northwest-southeast band where reef buildup occurred. Secondary dolomitization, which appears to be important in the higher porosity, decreases abruptly perpendicular from this band both to the northeast and the southwest (References 361 and 362). The upper Sunniland Formation represents a shoaling-upward depositional cycle that extends throughout onshore and offshore southern Florida. This slowly oscillating transgression-regression cycle continues to the top of the Sunniland Formation, where it gives way to a major marine regression with the deposition of the Lake Trafford Formation (Reference 359).

The lower Sunniland Formation is composed of brown and medium-dark-gray micritic and argillaceous limestones that are commonly algal laminated. The dark carbonate facies varies in thickness up to 150 feet and thins toward the eastern and southern margins of the southern Florida Basin (Reference 355). The dark carbonate unit called the "rubble zone" in the lower Sunniland Formation is burrowed, fractured, and stylolitized. The lower zone is enclosed by impermeable, micritic, tidal-flat, calcareous mudstones above and sealed below by the Punta Gorda Anhydrite (Reference 363). At the base of the Sunniland Formation, at the top of the Punta Gorda Anhydrite, is evidence of a slow marine transgression and the termination of a major regression (Reference 359).

The upper Sunniland Formation consists of isolated fossil-shell, skeletal-petal, porous, and permeable grainstone mounds enclosed by impermeable lagoonal mudstones, wackestones, nodular anhydrite beds, and micritic carbonates-some of which have been dolomitized (Reference 354). This facies may represent storm deposition as shoals in a regionally restricted, back-reef lagoonal area in a warm, shallow marine-shelf setting (References 361 and 364). Biotic abundance and content of the fragmented biotic material suggests that the debris mound facies were deposited on micritic tidal mud flats during a sea level rise (Reference 365). During a later regression, the upper portions of these porous shoal mounds were sub-aerially exposed, leached, and dolomitized during a low sea-level stand, further increasing the porosity of the upper Sunniland Formation carbonates. Individual mounds are between 40 and 100 feet thick (Reference 363). These highly porous bioclastic mounds accumulated along the southeastern coast of the Florida Peninsula on subtle topographic/bathymetric highs that were probably related to underlying basement structure (Reference 363). Pollastro (Reference 363) also describes an anhydrite-cemented nonporous sabkha-like facies near the southern boundary of the upper Sunniland Formation that formed in supratidal arid conditions on restricted coastal plains above high tide level (Reference 354).

Pollastro et al. (Reference 366) indicate that the depth to the top of the Sunniland Formation in southern Florida is approximately 10,000 feet and increases to greater than 12,000 feet in the Florida Basin to the southwest. The thickness of the Sunniland Formation in southern Florida is approximately 200 to 300 feet and increases toward the south (Reference 355).

The Lake Trafford Formation conformably overlies the Sunniland Formation (Figure 2.5.1-228). A major regression in the continuing oscillating transgression occurred with the deposition of the Lake Trafford Formation (Reference 359). The Lake Trafford Formation consists of a limestone-dolomite unit with a thin (<100 feet) anhydrite lens. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Lake Trafford Formation is approximately 150 feet thick in southern Florida (Reference 356).

The Rattlesnake Hammock Formation conformably overlies the Lake Trafford Formation (Figure 2.5.1-228). The Rattlesnake Hammock Formation consists of a 200-foot thick anhydrite cap underlain by cyclic deposits of limestone, anhydrite, dolomite, anhydrite, and limestone units successively. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Rattlesnake Hammock Formation is approximately 600 feet thick in southern Florida (Reference 356).

The Lower Cretaceous Big Cypress Group conformably overlies the Rattlesnake Hammock Formation of the Ocean Reef Group (Figure 2.5.1-228). The Big Cypress Group consists of the Marco Junction, Gordon Pass, and Dollar Bay Formations. The units of the Big Cypress Group are typically composed of evaporites and carbonates formed during transgressive-regressive cycles (Reference 360). The units consist of limestones, anhydrites, and dolomites that have been subdivided into multiple formations and groups based on regionally persistent anhydrites that form the uppermost lithologic unit of each formation (Reference 356). Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present, especially in the anhydrite and limestone intervals. The limestones range from white to gray to tan to dark brown and are usually micritic, chalky, and calcarenitic, with skeletal particles of gastropods, algae, and other fossils. The anhydrite is nodular, microcrystalline, or crystalline and is usually bedded. The dolomite crystals are euhedral to sucrosic and occur in approximately 30 percent of each formation (Reference 360).

The Lower Cretaceous Marco Junction Formation conformably overlies the Rattlesnake Hammock Formation (Figure 2.5.1-228). The Marco Junction Formation consists of a relatively thin (<100 feet) anhydrite cap underlain by a sequence of limestones and dolomites and a second thin anhydrite lens. The Marco Junction Formation is approximately 350 feet thick in southern Florida (Reference 356).

The Gordon Pass Formation conformably overlies the Marco Junction Formation (Figure 2.5.1-228). The Gordon Pass Formation consists of a thick (>100 feet) anhydrite cap underlain by a sequence of limestones and dolomites and a second thin anhydrite lens. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Gordon Pass Formation is approximately 475 feet thick in southern Florida (Reference 356).

The Dollar Bay Formation is the uppermost unit of the Big Cypress Group; it conformably overlies the Gordon Pass Formation (Figure 2.5.1-228). The Dollar Bay Formation commonly consists of evaporite-carbonate beds of limestone, dolomite, and anhydrite formed during a transgressive-regressive cycle (Reference 354). The Dollar Bay Formation consists of reefs, shoals, carbonate mounds, bioherms, and related features, forming organic-rich calcareous units inter-bedded with the carbonates (Reference 355). The limestone, dolomite, and anhydrite units occur in a series of cycles that typically begin and end with anhydrite. Porous carbonate units were deposited as tidal shoal deposits and patch reefs in a tidal flat, lagoonal, restricted-marine setting and in a sub-tidal platform, open-marine setting (Reference 354). Environments from shallow shelf to euxinic are present (Reference 367).

The Dollar Bay Formation consists of a 55-foot thick dark brown, fine crystalline dolomite with intercrystalline porosity that is typically found at the base of the formation. Above this lies a sedimentary cycle averaging 325 feet thick consisting characteristically of chalky dolomite and limestone interspersed with beds of fine-grained calcarenite (Reference 367). Leached limestone units (Reference 354) formed from isolated patch reefs (Reference 360) are present in the middle part of the Dollar Bay Formation. A porous dolomite unit forms the upper part of the formation (References 354 and 360). These units are capped with an impermeable tidal flat deposit of micritic, argillaceous lime mudstone and an uppermost anhydrite unit (Reference 354). The Dollar Bay Formation occurs at depths of more than 10,000 feet (3050 meters) and averages 450 feet (140 meters) thick but ranges up to as much as 620 feet (190 meters) thick in some parts of the southern Florida Basin (Reference 354). All contacts above, below, and within the Dollar Bay Formation are conformable (Reference 367).

The Lower Cretaceous Naples Bay Group conformably overlies the Big Cypress Group (Figure 2.5.1-228). The Naples Bay Group consists of the Panther Camp, Rookery Bay, and Corkscrew Swamp Formations. The units of the Naples Bay Group are typically composed of evaporites and carbonates formed during transgressive-regressive cycles (Reference 360). The units consist of limestones, anhydrites, and dolomites that have been subdivided into multiple formations and groups based on regionally persistent anhydrites that form the uppermost lithologic unit of each formation (Reference 356). Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present, especially in the anhydrite and limestone intervals. The limestones range from white to gray to tan to dark brown and are usually micritic, chalky, and calcarenitic, with skeletal particles of gastropods, algae, and other fossils. The anhydrite is nodular, microcrystalline, or crystalline and is usually bedded. The dolomite crystals are euhedral to sucrosic and occur in approximately 30 percent of each formation (Reference 360).

The Panther Camp Formation conformably overlies the Dollar Bay Formation (Figure 2.5.1-228). The Panther Camp Formation consists of a thin (<100 feet) cap of anhydrite underlain by two limestone-dolomite units separated by an anhydrite layer. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Panther Camp Formation is approximately 350 feet thick in southern Florida (Reference 356).

The Rookery Bay Formation of the Naples Bay Group conformably overlies the Panther Camp Formation (Figure 2.5.1-228). The Rookery Bay Formation consists of a thin (<100 feet) cap of anhydrite underlain by two limestone-dolomite units separated by a thin anhydrite layer. This, in turn, is underlain by a dolomite unit and a limestone unit. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Rookery Bay Formation is approximately 500 feet thick in southern Florida (Reference 356).

The Corkscrew Swamp Formation of the Naples Bay Group conformably overlies the Rookery Bay Formation (Figure 2.5.1-228). The Corkscrew Swamp Formation consists of a thin (<100 feet) cap of anhydrite underlain by a dolomite unit and two limestone units separated by a second 100-foot thick anhydrite layer. Calcareous shales, mudstones, salt, and lignitic carbonaceous materials are also present. The Corkscrew Swamp Formation is approximately 450 feet thick in southern Florida (Reference 356).

The Upper Cretaceous Pine Key Formation conformably overlies the Corkscrew Swamp Formation of the Naples Bay Group and is the uppermost Mesozoic formation in southern Florida (Figure 2.5.1-228). Its lower contact is conformable in southern and eastern Florida, but unconformable to the west (Reference 368). The Pine Key Formation is essentially made up of two facies: (a) a white chalk and chalky limestone formed in a lagoonal environment that interfingers with and is replaced by (b) the lower tongues of a regional barrier reef complex composed of tan, cream, light gray, and brown very fine microcrystalline to coarse crystalline euhedral and anhedral dolomite (References 369, 357, and 370). The reef facies is characterized by vugs and reports of cavities and wall collapse zones (References 371, 357, and 370). Neither evaporites nor dolomites are present within the lagoonal facies of the Pine Key Formation indicating that the Rebecca Shoals barrier-reef complex did not completely encircle Florida or otherwise restrict circulation during the Late Cretaceous (Reference 370). In the South Florida back-reef basin, deposition of the lagoonal chalk facies of the Pine Key Formation persisted until the barrier reef had completely encircled the Florida Peninsula during the Paleocene (Reference 357). The Pine Key Formation is as much as 3000 feet thick in southern Florida at a depth of approximately 5500 to 6000 feet (References 356 and 369).

Cenozoic Stratigraphy of the Florida Peninsula

The early part of the Cenozoic consists of a depositional shallow marine environment of carbonate rocks (limestone and dolostone with some evaporites). These carbonate rocks include the Cedar Keys Formation, Oldsmar Formation, Avon Park Formation, Ocala Limestone, Suwannee Limestone, and part of the basal Arcadia Formation (Figure 2.5.1-231). The occurrence of gypsum and anhydrite during the Cenozoic indicates that seawater circulation in the shallow marine environment was periodically restricted (Reference 287). During the Cenozoic (last 65 m.y.), sea level fluctuated ±100 feet above and below the present-day sea level (Reference 287).

The oldest Cenozoic sediment that crops out in the site region is the Miocene-Pliocene Peace River Formation, exposed in Hardee and DeSoto counties (Figure 2.5.1-201). All deeper Cenozoic units occur only in the subsurface. The Cenozoic sedimentary section in southern Florida averages approximately 5000 to 6000 feet thick and consists of a sequence of carbonate deposition interrupted by Appalachian derived siliciclastic sediments during the Miocene and Pliocene (References 373, 374, 375, 376, 377, 378, 356, and 379). The regional Cenozoic stratigraphic section is shown in Figure 2.5.1-231. Figures 2.5.1-232, 2.5.1-233, 2.5.1-234, 2.5.1-235, and 2.5.1-236 provide geologic cross sections illustrating the regional Cenozoic stratigraphy.

Paleocene Stratigraphy of the Florida Peninsula

By the Paleogene, the Appalachian Mountains had been gradually lowered by erosion. This not only reduced the supply of siliciclastic material, but also resulted in a lower stream gradient that limited the transport of siliciclastic sediments to the Florida Platform. In addition, the currents in the Suwannee Channel (also known as the "Gulf Trough" or "Suwannee Straits") (Figures 2.5.1-218 and 2.5.1-229) acted as a barrier to siliciclastic transport. These currents protected the carbonate depositional environment of the Florida Platform from the influx of siliciclastic sediments resulting in predominantly carbonate deposition during the Paleogene (References 338 and 349).

The oldest Cenozoic formation on the Florida Platform is the Paleocene Cedar Keys Formation that conformably overlies the Late Cretaceous Pine Key Formation (Figure 2.5.1-231). The Cedar Keys Formation is a marine lagoonal facies that occurs within the confines of the Rebecca Shoal barrier reef (Reference 369). In southern Florida, the Cedar Keys Formation consists primarily of gray dolomite, gypsum, and anhydrite with a minor percentage of limestone. The upper part of the Cedar Keys Formation consists of coarsely crystalline, porous dolomite. The lower part of the Cedar Keys Formation contains more finely crystalline dolomite interbedded with anhydrite (Reference 369). The configuration of the Paleocene sediments in Peninsular Florida reflects depositional controls inherited from pre-existing Mesozoic structures such as the

Peninsular Arch and the southern Florida Basin. The upper unit of porous dolomite in the Cedar Keys Formation forms the base of the Floridan aquifer system (Subsection 2.4.12) throughout southern Florida (Reference 349), where it is found at elevations ranging from -3000 to -4000 feet (-900 to -1200 meters) (Reference 389). The Cedar Keys Formation varies from approximately 500 feet up to 2000 feet (150 meters up to 600 meters) thick in southern Florida (References 356 and 375).

Eocene Stratigraphy of the Florida Peninsula

The Eocene Oldsmar Formation within southern Florida conformably overlies the Paleocene Cedar Keys Formation (Figure 2.5.1-231). The Oldsmar Formation primarily consists of a sequence of white, cream to gray, micritic to chalky limestones interbedded with tan to light-brown microcrystalline, vuggy dolomite. Dolomitization is usually more extensive in the lower part of the formation that is also noticeably unfossiliferous (References 390, 376, and 349). Gypsum and thin beds of anhydrite occur in some places. According to Winston (Reference 379), the top of the Oldsmar Formation in southern Florida is not identifiable or distinguishable on the basis of lithologic and faunal criteria. However, in southern Florida, the top of the uppermost thick dolomite unit is marked by glauconitic limestone (Reference 376). The "Boulder Zone," a regional hydrostratigraphic unit recognized in the subsurface of South Florida (Subsection 2.4.12), forms part of the lower Oldsmar Formation and characteristically contains fractured dolomite (Reference 376). The Oldsmar Formation occurs in the subsurface at elevations ranging from -1950 to -2250 feet (-590 to -690 meters) (Reference 375). It ranges from 500 to as much as 1500 feet (150 to as much as 460 meters) thick in southern Florida (Reference 376). Observations recorded during the construction of the Class V exploratory well EW-1 at the Turkey Point Units 6 & 7 site provide a site-specific measurement for depth to the top of the Oldsmar formation of approximately 2580 feet below ground surface (bgs). All depths for well EW-1 are reported as below pad level, which represents the depth below the top of the 64-inch-diameter pit pipe. The pit pipe was surveyed and found to be at elevation 7.18 feet North American Vertical Datum of 1988 (NAVD 88), which is approximately 0.4 feet above the final ground surface (6.8 feet NAVD 88) at the exploratory well (Reference 970). LDP-CS535 LDP-CS564

The Eocene Avon Park Formation overlies the Oldsmar Formation (Figure 2.5.1-231). A regional unconformity in southern Florida has been proposed at the top of the Oldsmar Formation/base of the Avon Park Formation (Reference 375). The Avon Park Formation consists of cream to light brown or tan, poorly indurated to well-indurated, variably fossiliferous, marine limestone (grainstone, packstone, and wackestone, with rare mudstone). These limestones are interbedded with light brown to orange-brown to dark brown or black, very poorly indurated to well indurated to dense, sucrosic to very fine to medium crystalline, fossiliferous (molds and casts), vuggy dolomites. Fine- to medium-grained calcarenite that is moderately to well sorted is intermittently present. Portions of the middle Avon Park Formation are very fine-grained with low permeability and act as confining beds separating the Avon Park Formation into upper and lower (formerly Lake City) parts (Reference 349). The fossils present include mollusks, foraminifera, echinoids, algae, and carbonized plant remains (References 377 and 376). The top of the Avon Park Formation is marked in some places by light brown, finely crystalline to fossiliferous dolomitic limestone or dolomite, thinly interbedded with limestone. Thick intervals containing mostly dolomite, but in some places interbedded with limestone, are commonly present in the middle to lower part of the Avon Park Formation in southern Florida. High permeability due to fracturing is common, particularly in dolomite units. Gypsum and anhydrite also occur in the lower part of this formation in southwestern Florida, either as bedded deposits or more commonly as intergranular or pore-filling material in the carbonate rocks. An upper marker horizon separates the more thinly bedded strata of the upper Avon Park Formation from more thickly bedded and massive units of the lower Avon Park Formation (Reference 376).

The shallow marine limestones and dolomites of the Avon Park Formation were deposited primarily on the inner part of a broad, flat-lying carbonate ramp that sloped gently toward the Gulf of Mexico during the Eocene (Reference 391). Carbonates of the Avon Park Formation are the oldest sediments exposed in the state and crop out in a limited area on the crest of the Ocala Platform in the central peninsula (Reference 377). The Avon Park Formation varies from 400 feet up to 1200 feet thick in southern Florida (References 375 and 356) and occurs at elevations ranging from -1000 to -1300 feet (Reference 375). Observations recorded during the construction of the Class V exploratory well EW-1 at the Turkey Point Units 6 & 7 site provide a site-specific measurement for the Avon Park formation from a depth of 1255 to 2580 feet bgs (1255 to 2580 feet below pad level). LDP-CS535

The Eocene Ocala Limestone overlies the Eocene Avon Park Formation (Figure 2.5.1-231). A regional unconformity in southern Florida has been proposed at the top of the Avon Park Formation/base of the Ocala Limestone (Reference 375). The Ocala Limestone consists of white to cream, micritic or chalky marine limestones, calcarenitic limestone, coquinoid limestone, and occasional dolomites (References 376 and 392). Generally the Ocala Limestone is soft and porous, but in places it is hard and dense because of cementation of the particles by crystalline calcite. The deposit is unique in that it is composed of almost pure calcium carbonate from shells and micritic chalky particles (Reference 392). It can be subdivided into lower and upper facies on the basis of lithology. The lower unit is composed of a white- to cream-colored, fine- to medium-grained, poorly to moderately indurated, very fossiliferous limestone (grainstone and packstone). The lower facies may not be present throughout the areal extent of the Ocala Limestone and may be partially to completely dolomitized in some regions. The upper facies is a white, poorly to well indurated, poorly sorted, very fossiliferous limestone (grainstone, packstone, and wackestone). Silicified limestone is common in the upper facies. Fossils present in the Ocala Limestone include abundant large and smaller foraminifera, echinoids, bryozoans, and mollusks. Where the Ocala Limestone is at or near the surface, it exhibits extensive karstification (see discussion of hydrologic features related to karstification processes in Subsection 2.5.1.1.1.1.1.1) (Reference 377). The limestone is characterized by abundant large benthic foraminifera, which have been used by various workers to distinguish the Ocala Limestone from the overlying Suwannee Limestone and the underlying Avon Park Formation (Reference 376).

The fine-grained carbonates of the Ocala Limestone (Figure 2.5.1-231) were deposited on the middle to outer-ramp setting at water depths generally below storm wavebase (Reference 391). The Ocala Limestone occurs at the surface in a few locations, but appears to be absent even in the subsurface of the southernmost part of southeastern Florida (most of Miami-Dade County and southeastern Broward County). In the remainder of southern Florida, the thickness of the Ocala Limestone varies from 200 to 400 feet (61 to 122 meters) (References 376 and 356) and occurs at elevations ranging from -980 to -1100 feet (-300 to -335 meters) (Reference 375).

Oligocene Stratigraphy of the Florida Peninsula

A significant increase of siliciclastic sediments occurred during the Oligocene, possibly due to renewed uplift of the Appalachian Mountains. The Suwannee Channel (also known as the Suwannee Straits) was filled with a flood of siliciclastic sediments as a possible result of longshore transport and currents. As a result of filling the Suwannee Channel, the carbonate depositional environment was replaced with sands, silts, and clays (Reference 349). The siliciclastic sediments appear in the early Miocene in northern Florida; however, in southern Florida, carbonates continued to be deposited until at least mid-Miocene. The siliciclastics spread southward along the east coast of Florida due to active transport conditions along the Atlantic coastline (Reference 287). The siliciclastic depositional environment moved further south due to longshore transport and currents until almost the entire Florida Platform was covered with sands and clays. The incursion of siliciclastics diminished during the later Pleistocene (Reference 349).

Karst features began to form at least as early as the latest Oligocene as determined from the occurrence of terrestrial vertebrate faunas (Reference 349). Karst features such as sinkholes, dissolution valleys, and collapse depressions formed when groundwater flowed through Florida's Eocene, Oligocene, and Miocene limestones and dissolved these carbonate sediments (Reference 287).

The Early Oligocene Suwannee Limestone overlies the Eocene Ocala Limestone (Figure 2.5.1-231). A regional unconformity in southern Florida has been described at the top of the Ocala Limestone/base of the Suwannee Limestone (References 375 and 393). The Suwannee Limestone consists of a white to cream, poorly to well indurated, fossiliferous, vuggy to moldic marine limestone (grainstone and packstone) with minor amounts of quartz sand and rare-to-absent phosphate mineral grains. The dolomitized parts of the Suwannee Limestone are gray, tan, light brown to moderate brown, moderately to well indurated, finely to coarsely crystalline, dolomite with limited occurrences of fossiliferous (molds and casts) beds. Silicified limestone and chert are common (References 392 and 377). Up to seven lithofacies have been identified in the Suwannee Limestone based on biotic content and texture (Reference 373). Characteristic porosity and permeability in the Suwannee Limestone is interparticle to moldic or vuggy (Reference 376). Mollusks, foraminifers, corals, and echinoids are present in the Suwannee Limestone (Reference 392).

During deposition of the early Oligocene Suwannee Limestone, a series of clean siliciclastic shoreline deposits began to prograde onto the southern Florida Platform that extended along the present west coast of Florida; however, these siliciclastic sediments did not affect the continued deposition of carbonate sediments in an open circulation shelf setting (Reference 394). The Suwannee Limestone represents the continued deposition in shallow marine conditions during the early Oligocene (Reference 391). The Suwannee Limestone exhibits numerous cycles of limestone capped by brecciated karst suggesting subaerial exposure; each cycle is overlain by a landward shift in sedimentary facies (marine flooding) (Reference 373). Various publications contain opposing interpretations concerning the presence or absence of the Suwannee Limestone in southeastern Florida. The Suwannee Limestone may be absent from the eastern side of the

Peninsular Arch (Figures 2.5.1-229, 2.5.1-232, and 2.5.1-234) due to erosion, nondeposition, or both (References 232, 267, and 377). In southern Florida, the thickness of the Suwannee Limestone varies from 200 feet to as much as 600 feet in Lee and western Collier counties (References 356 and 376) and occurs at elevations ranging from -900 to -1300 feet (Reference 375).

The Oligocene-Miocene-Pliocene Hawthorn Group unconformably overlies the Oligocene Suwannee Limestone (Figure 2.5.1-231). The Hawthorn Group consists of an interbedded sequence of widely varying lithologies and components that include limestone, mudstone, dolomite, dolomitic silt, shells, quartz sand, clay, abundant phosphate grains, and mixtures of these materials. The characteristics that distinguish the Hawthorn Group from underlying units are (a) high and variable siliciclastic and phosphatic content; (b) color, which can be green, olive-gray, or light gray; and (c) a distinguishing gamma-ray log response. Intervals high in phosphate sand or gravel content are present and have high gamma-ray log activity, with peaks of 100 to 200 API gamma ray units or more (Reference 376). In southern peninsular Florida, the Hawthorn Group consists of the basal Oligocene-Miocene Arcadia Formation, including the Tampa Member and the uppermost Miocene-Pliocene Peace River Formation with its Bone Valley Member (Reference 377). Zones of dissolution of Oligocene rocks indicate that post-Oligocene erosion was extensive (Reference 375). The complete Hawthorn Group varies from 500 to 800 feet thick in southern Florida (References 373 and 394).

A regional unconformity in southern Florida has been proposed at the top of the Suwannee Limestone/base of the Arcadia Formation of the Hawthorn Group (References 373 and 394). Zones of dissolution of Oligocene rocks indicate that post-Oligocene erosion was extensive (Reference 375). The Arcadia Formation is predominantly a carbonate unit with a variable siliciclastic component, including thin beds of quartz sands. The Arcadia Formation (with the exception of the Tampa Member) is composed of yellowish gray to light olive gray to light brown, micro to finely crystalline, variably sandy, clayey, and phosphatic, fossiliferous limestones and dolomites. Thin beds of sand and clay are common. The sands are yellowish gray, very fine- to medium-grained, poorly to moderately indurated, clayey, dolomitic, and phosphatic. The clays are yellowish gray to light olive gray, poorly to moderately indurated, sandy, silty, phosphatic, and dolomitic. Molds and casts of mollusks are common in the dolomites (Reference 377). Sediments within the Arcadia Formation show an upward and geographically northward (Reference 395) change from predominantly carbonate with some quartz sand to an equal mix of siliciclastics and carbonates (Reference 394). The Tampa

Member occurs near the base of the Arcadia Formation and is predominantly a white to yellowish gray fossiliferous marine limestone (mudstone, wackestone, and packstone) with subordinate dolomite, sand, clay, and phosphate. The Tampa Member is usually a hard, massive crystalline rock, and in some areas it contains small moldic cavities. Mollusks and corals, foraminifera, and algae are common in the Tampa Member.

Subsurface data show the Arcadia Formation as a gently sloping carbonate ramp upon which was deposited multiple high frequency, fining/coarsening upward, eustatically-driven siliciclastic sequences. Fossil evidence suggests a shift from tropical to subtropical oceanic conditions during Arcadian deposition (Reference 373). The Tampa Member and the lower part of the Arcadia Formation form the upper part of the Floridan aquifer system (Subsection 2.4.12) in parts of southern Florida (References 377 and 392). The thickness of the Arcadia Formation in southern Florida varies from 100 to 700 feet and occurs at elevations ranging from -300 to -650 feet (-91 to -200 meters) (References 373 and 394).

Miocene Stratigraphy of the Florida Peninsula

During the Miocene, siliciclastics covered the Florida Platform providing a semipermeable barrier that reduced dissolution of the underlying carbonates. However, erosion of these siliciclastics during the early Pleistocene renewed the dissolution of the underlying limestones formations. This dissolution led to increased karst and an enhanced secondary porosity of the sediments of the Floridan aquifer system.

During the early Miocene a strong southward flood of terrigenous coarse clastics, presumably from the southern Appalachian Mountains, prograded over most of the Florida Platform (References 368 and 393) (Figure 2.5.1-237). The Hawthorn Group of shallow marine to non-marine coastal and deltaic sandstones and mudstones prograded out over the older carbonate platform during the late Oligocene to Pliocene (Reference 391). By the end of the Oligocene, the influx of siliciclastic sediments, principally from the Appalachians, increased in volume and fines content. Carbonate production was significantly reduced in the east; however, the slow rate of sediment influx and lack of significant clay content allowed continued carbonate growth to continue into the mid-Miocene in the central portion of the Florida Platform (Reference 394). This drowning/burial by siliciclastics is not the only interpretation for the reduction of the carbonate-producing organisms. McNeill et al. (Reference 395) suggest sea level rise, environmental deterioration, and the influence of local ocean currents as viable alternatives (see discussion of carbonate platforms: growth, shut downs and crashes in Subsection 2.5.1.1.1.1.1.2).

The middle Miocene-early Pliocene Peace River Formation of the Hawthorn Group unconformably overlies the Oligocene-Miocene Arcadia Formation (Figure 2.5.1-231). The base of the Peace River Formation is a regional unconformity that is identified by a thin, black phosphorite layer that appears to be the source of a strong gamma log response (Reference 395) (Figure 2.5.1-234). The Peace River Formation is composed of interbedded sands, clays, and carbonates. The sands are generally light gray to olive gray, poorly consolidated, clayey, variably dolomitic, very fine- to medium-grained, and phosphatic. The clays are yellowish gray to olive gray, poorly to moderately consolidated, sandy, silty, phosphatic, and dolomitic. The carbonates are usually light gray to yellowish gray, poorly to well indurated, variably sandy, clayey, and phosphatic dolomites. Two distinct lithologies are present in the subsurface in southern Florida: a lower diatomaceous mudstone unit and an upper unit of mud-rich, very fine quartz sandstone. Fossil mollusks occur as reworked casts, molds, and limited original shell material. The Bone Valley Member of the Peace River Formation crops out in a limited area on the southern part of the Ocala Platform in Hillsborough, Polk, and Hardee counties. Where it is present, the Bone Valley Member is a poorly consolidated clastic unit consisting of sand-sized and larger phosphate grains in a matrix of quartz sand, silt, and clay. The lithology is highly variable, ranging from sandy, silty, phosphatic clays, and relatively pure clays to clayey, phosphatic sands to sandy, clayey phosphorites. Colors range from white, light brown, and yellowish gray to olive gray and blue green. Vertebrate fossils occur in many of the beds within the Bone Valley Member. Shark's teeth are often abundant (Reference 377). The Peace River Formation may be, in part, correlative to the proposed Long Key formation (Reference 373).

Cunningham et al. (Reference 396), McNeill et al. (Reference 395), and Ward et al. (Reference 391) suggest that the Peace River Formation represents the southward transport and deposition of continental siliciclastics in a fluvial-deltaic system, which eroded and prograded out over the older carbonate platform environment. Well data show intervals of quartz sand localized as a wide north-south pathway from the central part of the peninsula to the middle Florida Keys (Reference 393) (Figure 2.5.1-237). This pathway is interpreted as a record of a strong, southward-moving shoreline and channeled deposition or a regional prograding spit (Reference 393). The ultimate source of these siliciclastics is considered to be the distant Appalachian highlands (References 395, 393, and 368). The Peace River Formation is widespread in southern Florida. It is part of the intermediate confining unit between the surficial and Floridan aquifer systems (References 376 and 377) (Subsection 2.4.12). The thickness of the Peace River Formation in southern Florida varies from 100 to 650 feet and occurs at elevations ranging from -100 to -250 feet (-30.5 to -76 meters) (References 373 and 394).

Pliocene Stratigraphy of the Florida Peninsula

The Pliocene Tamiami Formation unconformably overlies the Miocene-Pliocene Peace River Formation of the Hawthorn Group and interfingers with the contemporaneous Cypresshead Formation (Figure 2.5.1-231). The Tamiami Formation in southern Florida is a poorly defined lithostratigraphic unit containing a wide range of mixed carbonate-siliciclastic lithologies that include: (a) light gray to tan, unconsolidated, fine- to coarse-grained, fossiliferous sand; (b) light gray to green, poorly consolidated, fossiliferous sandy clay to clayey sand; (c) light gray, poorly consolidated, very fine- to medium-grained, calcareous, fossiliferous sand; (d) white to light gray, poorly consolidated, sandy, fossiliferous limestone; and (e) white to light gray, moderately to well indurated, sandy, fossiliferous limestone (Reference 377). Phosphatic sand- to gravel-sized grains are present in small quantities within virtually all the lithologies. Fossils present in the Tamiami Formation occur as molds, casts, and original material. The fossils present include barnacles, mollusks, corals, echinoids, foraminifera, and calcareous nannoplankton (Reference 377). The occurrence of limestone lenses in the Tamiami Formation appears to be related to fluctuations of the water table accompanied by cementation with calcium carbonate. The faunal assemblage of the Tamiami Formation commonly contains a variety of mollusks (Reference 397). The lower unit of the Tamiami Formation includes greenish sandy, clayey silt beds of low permeability that vary in thickness and extent and conform with the surface of the underlying Hawthorne Formation. The argillaceous content of the lower Tamiami and underlying Peace River strata is expressed in well logs regionally and at the Turkey Point site by an increase in activity on the gamma ray log (References 391 and 708). The complex mix of permeable and impermeable lithologies makes the Tamiami Formation part of both the surficial aquifer system and the intermediate confining unit between the surficial and Floridan aquifer systems (References 376, 377, and 862) (Subsection 2.4.12). The Tamiami Formation may be, in part, correlative to the proposed Long Key formation (Reference 373).

Cunningham et al. (Reference 396) suggest that the presence of minor carbonate in the Tamiami Formation reflects a shift from the progradation of siliciclastics to aggradation of a vertical mix of carbonates and siliciclastics. The top of the Tamiami Formation is an undulating surface that varies as much as 25 feet (7.6

meters) in elevation within a distance of 8 miles (13 kilometers) (Reference 397). This unevenness indicates that the upper part has been subjected to erosion. The deposition of the Caloosahatchee Formation on top of and along the flanks of erosional remnants indicates that the Tamiami Formation was dissected prior to Pliocene deposition and again during the Pleistocene. Apparently the deeper valleys were developed during the Pleistocene (Reference 397) in response to lower sea levels caused by glaciation. The Tamiami Formation occurs at or near the land surface in Charlotte, Lee, Hendry, Collier, and Monroe counties (Reference 377). In Collier and Lee counties, Schroeder and Klein (Reference 397) found the Tamiami Formation to be approximately 50 feet (15 meters) thick, while in Miami-Dade County various reports (References 397 and 398) indicate it ranges in thickness from 25 to 220 feet (7.6 to 67 meters).

The Pliocene Cypresshead Formation unconformably overlies the Miocene-Pliocene Peace River Formation of the Hawthorn Group and interfingers with the contemporaneous Tamiami Formation (Figure 2.5.1-231). The Cypresshead Formation consists of reddish brown to reddish orange, unconsolidated to poorly consolidated, fine- to very coarse-grained, clean to clayey sands. Cross-bedded sands are common within the Cypresshead Formation. Discoid quartzite pebbles and mica are often present. Clay beds are scattered and not really extensive. Original fossil material is not present in the sediments although poorly preserved molds and casts of mollusks and burrow structures are occasionally present. The Cypresshead Formation is at or near the surface from northern Nassau County southward to Highlands County forming the peninsular highlands (Lakeland, Lake Henry, Winter Haven, and Lake Wales Ridges) and appears to be present in the subsurface southward and to underlie the Florida Keys (Figure 2.5.1-217). The Cypresshead Formation formed in a shallow marine, near-shore environment and consists of deltaic and prodeltaic sediments (Reference 377). The Cypresshead Formation may be in part correlative to the proposed Long Key formation (Reference 373). The Cypresshead Formation is approximately 50 to 60 feet thick in Polk County (Reference 399).

The Pliocene-Pleistocene shell beds have attracted much attention due to the abundance and preservation of the fossils but the biostratigraphy and lithostratigraphy of the units has not been well defined. The "formations" previously recognized within the latest Tertiary-Quaternary section of southern Florida include the Late Pliocene-Early Pleistocene Caloosahatchee Formation and the Late Pleistocene Fort Thompson Formation (Figure 2.5.1-231). Lithologically these sediments are complex, varying from unconsolidated, variably calcareous and fossiliferous quartz sands to well indurated, sandy, fossiliferous limestones (both marine and freshwater). Clayey sands and sandy clays are present. These sediments form part of the surficial aquifer system (Reference 377) (Subsection 2.4.12). The identification of these units is problematic unless the significant molluscan species are recognized (Reference 377); over 680 species are presently recognized (Reference 397). Often the collection of representative faunal samples is not extensive enough to properly discern the biostratigraphic identification of the formation. In an attempt to alleviate the inherent problems in the recognition of lithostratigraphic units, Scott (Reference 349) suggests grouping the latest Pliocene through late Pleistocene Caloosahatchee Formation and Fort Thompson Formation into a single lithostratigraphic unit. This unit may be in part correlative to a proposed Long Key formation (Reference 373) (Figure 2.5.1-231). In mapping these shelly sands and carbonates, a generalized grouping termed the Tertiary-Quaternary shell-bearing units was used by Scott (Reference 377) in the preparation of the Geologic Map of Florida. A more detailed description of the units identified as the Caloosahatchee and Fort Thompson Formations follows.

The Pliocene-Pleistocene shell-bearing sediments, also known as the Caloosahatchee Formation, unconformably overlie the Pliocene Tamiami Formation (Reference 397) (Figure 2.5.1-231). The Caloosahatchee Formation consists of fossiliferous quartz sand with variable amounts of carbonate matrix interbedded with variably sandy, shelly limestones. Freshwater limestones are commonly present within the Caloosahatchee Formation (Figure 2.5.1-231). Fresh unweathered exposures are generally pale cream-colored to light gray, although green clay marls have been included in the formation. Green silty sands or sandy silts in the Caloosahatchee Formation appear to be restricted to the flanks of the hills of the Tamiami Formation. The greenish clastics are considered redeposited green clay marls of the Tamiami Formation (Reference 397). Mollusks are typically the predominant fossils, along with corals, bryozoans, echinoids, and vertebrates (Reference 392). The sand and shell variations of the Caloosahatchee Formation can be separated from the Pleistocene marine formations by identification of the mollusk faunas (Reference 397).

Sediments identified as part of the Caloosahatchee Formation occur from Tampa south to Lee County and to the east coast (Reference 349). The Caloosahatchee Formation is present in southern Florida as discontinuous erosion remnants. The most continuous exposures occur as thin beds along the Caloosahatchee River and other rivers along the southwest Florida coast (Reference 397). The Caloosahatchee Formation has not been identified on the southeast Florida mainland (Reference 393). The Caloosahatchee Formation is at least 10 feet thick along the Caloosahatchee River and may be as much as 20 feet thick near Lake Hicpochee (Reference 397).

The Pliocene-Pleistocene shell-bearing sediments, also known as the Fort Thompson Formation, appear to conformably overlie the Pliocene Tamiami Formation but lie unconformably on the Caloosahatchee Formation (Reference 397) (Figure 2.5.1-231). The discontinuity surfaces within the Fort Thompson Formation can include dense, well-indurated laminated crusts (Reference 400). Both Sonenshein (Reference 401) and Wilcox et al. (Reference 402) split the Fort Thompson Formation into an upper and lower unit based on lithologic and core data. The Fort Thompson Formation is typically composed of interbedded marine limestone, minor gastropod-rich freshwater limestone, shell marl, sandy limestone, and sand (References 403, 397, and 349). The shell beds are variably sandy and slightly indurated to unindurated. The sandy limestones were deposited under both freshwater and marine conditions. The sand present in the Fort Thompson Formation is fine- to medium-grained quartz sand with abundant mollusk shells and minor but variable clay content (Reference 349). Descriptions of core indicate that the Fort Thompson Formation is a vuggy, solution-riddled, well to poorly indurated, dense to friable limestone. Numerous vertical features in the formation are characteristic of shallow solution pipes or vugs. The features commonly penetrate through more than one horizon and may be conduits for vertical water flow through the formation (Reference 403).

The depositional environment of the Fort Thompson Formation can be related to late Quaternary sea level fluctuations (References 397 and 400). This formation is composed of a group of high-frequency depositional cycles within a progradational environment building on the Tamiami clastic ramp (Reference 404). According to Cunningham et al. (Reference 405), the depositional environments for the Fort Thompson Formation include (a) platform margin to outer platform, (b) open marine, restricted, and brackish platform interiors, and (c) freshwater terrestrial. The Fort Thompson Formation covers the greatest geographical area of all Quaternary formations in southern Florida (Reference 397). The thickness of the Fort Thompson Formation varies from approximately 40 to 80 feet in Miami-Dade, Broward, and Palm Beach counties, where it constitutes the highly productive zone of the Biscayne aquifer (References 400 and 397) (Subsection 2.4.12). In southern Florida the thickness of the Fort Thompson Formation ranges from approximately 50 to 100 feet (References 403 and 398).

Pleistocene Stratigraphy of the Florida Peninsula

During the Pleistocene, glaciation and fluctuating sea levels occurred worldwide (Figure 2.5.1-212) (Subsection 2.5.1.1.1.1.1.1). Growth of continental glaciers resulted in a drop in sea level as water was retained in the ice sheets. As a result, Florida's land area increased significantly (Figure 2.5.1-219). Based on sea levels during peak glacial periods, Florida's Gulf of Mexico coastline was probably situated some 100 miles (161 kilometers) west of its current position. Warmer interglacial intervals resulted in the glacial melting and a rise in sea level that flooded Florida's land area. At the peak interglacial intervals, sea level stood approximately 100 feet (30 meters) above the current sea level (Reference 287). During this time wave action and currents eroded the existing landforms that became filled with quartz sands originating from the erosion of the Appalachian Mountains and other upland areas. Due to a rise in sea level during the Pleistocene, nutrient rich waters flooded the southern portion of the Florida Peninsula and broken shell fragments along with chemically precipitated particles became the main source of carbonate sediments (Reference 287).

The Pleistocene Anastasia Formation overlies the Pliocene-Pleistocene shell-bearing formations and transitions into the contemporaneous Key Largo Limestone and Miami Limestone (Figure 2.5.1-231). The Anastasia Formation is composed of interbedded sands and coquinoid limestones. The most recognized facies of the Anastasia Formation sediments is an orange-brown, unindurated to moderately indurated coquina of whole and fragmented mollusk shells in a matrix of sand commonly cemented by sparry calcite. Sands occur as light gray to tan and orange-brown, unconsolidated to moderately indurated, unfossiliferous to very fossiliferous beds. The Anastasia Formation forms part of the surficial aquifer system (Reference 377) (Subsection 2.4.12).

The Anastasia Formation includes the coquina, sand, sandy limestone, and shelly marl of Pleistocene age that lies along both the east and west coasts of Florida (Figure 2.5.1-231). The typical coquina of the Anastasia Formation in the type locality does not occur in the western part of southern Florida. Sand, shell beds, marl, and calcareous sandstone are the most common materials. In southern Florida, molluscan faunas establish a Pleistocene age for the Anastasia Formation (Reference 397).

The Atlantic Coastal Ridge (Figure 2.5.1-217) is underlain by the Anastasia Formation from St. Johns County southward to Palm Beach County. The Anastasia Formation generally is recognized near the coast but extends inland as much as 20 miles (32 kilometers) in St. Lucie and Martin counties. To the south of

Palm Beach County, the Anastasia Formation grades laterally into the Miami Limestone and is not present in southern Miami-Dade County (Reference 377). Thin marine sandstones of the Anastasia Formation are also present along the southwest coast and extend as a tongue into Collier and Hendry counties (Reference 397). The thickness of the Anastasia Formation varies up to a maximum of 140 feet in southern Florida (Reference 398).

The Pleistocene Key Largo Limestone overlies the Pliocene-Pleistocene shell-bearing sediments and transitions into the contemporaneous Anastasia Formation and Miami Limestone (Figure 2.5.1-231). The Key Largo Limestone is a white to light gray, moderately to well indurated, fossiliferous, coralline marine limestone composed of coral heads encased in a calcarenitic matrix (Reference 377). Some of these corals have been partially dissolved by groundwater, and the spaces remaining have been filled with crystalline calcite (Reference 392). Little to no siliciclastic sediment is found in these sediments. Fossils present include corals, mollusks, and bryozoans. The Key Largo Limestone is highly porous and permeable and is part of the Biscayne aquifer of the surficial aquifer system (Reference 377).

The Key Largo Limestone is a fossil coral reef that is believed to have formed in a complex of shallow-water shelf-margin reefs and associated deposits along a topographic break during the last interglacial period (Reference 406). The Key Largo Limestone is exposed at the surface in the Florida Keys from Soldier Key on the northeast to Newfound Harbor Key near Big Pine Key on the southwest and from Big Pine Key to the mainland. On the mainland and in the southern Florida Keys from Big Pine Key to the Marquesas Keys, the Key Largo Limestone is replaced by the Miami Limestone (Reference 377). The thickness of the Key Largo Limestone varies widely and is more than 180 feet in southern Florida (Reference 406).

The Pleistocene Miami Limestone overlies the Pliocene-Pleistocene shell-bearing sediments and transitions into the contemporaneous Key Largo Limestone and Anastasia Formation (Figure 2.5.1-231). The Miami Limestone (formerly the Miami Oolite) is a Pleistocene marine limestone. Johnson (Reference 407) has identified six lithofacies in the Miami Limestone: ooid calcarenite, oomoldic-recrystallized, calcirudite, breccia, sandy, and microsparry-coralline. The oolitic facies is the most common and consists of white to orange gray, oolitic limestone with scattered concentrations of fossils. Fossils present include mollusks, bryozoans, and corals; molds and casts of fossils are common (Reference 392).

The Miami Limestone occurs at or near the surface in southeastern peninsular Florida from Palm Beach County to Miami-Dade and Monroe counties. It forms the Atlantic Coastal Ridge and extends beneath the Everglades (Figure 2.5.1-217) where it is commonly covered by thin sediment. The Miami Limestone occurs on the mainland and in the southern Florida Keys from Big Pine Key to the Marquesas Keys. From Big Pine Key to the mainland, the Miami Limestone is replaced by the Key Largo Limestone. To the north, in Palm Beach County, the Miami Limestone grades laterally northward into the Anastasia Formation (Reference 377). The depositional environment of the Miami Limestone can be related to late Quaternary sea level fluctuations (Reference 400). This formation is composed of a group of high-frequency depositional cycles within an aggradational environment (Reference 404). According to Cunningham et al. (Reference 405), the depositional environments for the Miami Limestone include both open marine platform interior and freshwater terrestrial. The highly porous and permeable Miami Limestone forms much of the Biscayne aquifer of the surficial aquifer system (Reference 377) (Subsection 2.4.12). The thickness of the Miami Limestone varies from 10 to 40 feet in southeastern Florida (References 406, 398, and 766). Undifferentiated Quaternary sediments overlie the Pliocene-Pleistocene shell-bearing sediments and the Pleistocene Anastasia Formation, Key Largo Limestone, and Miami Limestone. These undifferentiated sediments consist of siliciclastics, organics, and freshwater carbonates that vary in thickness. The siliciclastics are light gray, tan, brown to black, unconsolidated to poorly consolidated, clean to clayey, silty, unfossiliferous, variably organic-bearing sands to blue green to olive green, poorly to moderately consolidated, sandy, silty clays. Organics occur as plant debris, roots, disseminated organic matrix, and beds of peat. Freshwater carbonates, often referred to as "marls" are scattered over much of the region. In southern Florida, freshwater carbonates are nearly ubiquitous in the Everglades. These sediments are buff colored to tan, unconsolidated to poorly consolidated, fossiliferous carbonate muds. Sand, silt, and clay may be present in limited quantities. These carbonates often contain organics. The dominant fossils in the freshwater carbonates are mollusks (Reference 377).

Where these sediments exceed 20 feet in thickness, Scott (Reference 377) maps them as discrete units. Those sediments occurring in flood plains are termed alluvial and flood plain deposits. Sediments exhibiting the surficial expression of beach ridges and dunes are shown separately. Terrace sands are not identified individually. The subdivisions of the undifferentiated Quaternary sediments are not lithostratigraphic units but are used to facilitate a better understanding of the geology (Reference 377).

Holocene Stratigraphy of the Florida Peninsula

Much of Florida is covered by a blanket of Pliocene to Quaternary undifferentiated siliciclastic sediments that range in thickness from less than 1 foot (<0.3 meter) to greater than 100 feet (30 meters). The Holocene sediments in Florida occur near the present coastline at elevations generally less than 5 feet (1.5 meters). These sediments include quartz sands, carbonate sands, and muds with organic materials (Reference 377).

Because of the scouring effect of hurricanes in southern Florida (References 756, 865, and 866), Holocene sediment sequences are preserved only in protected depositional environments. Much of the recent work on these deposits has focused on low energy, low relief areas sheltered by barrier islands, such as the mangrove-capped oyster bars that separate Florida Bay from open marine influences (Reference 755). The following description of Holocene stratigraphy of southern Florida, indicating a general history of sea-level transgression, regression, transgression during the Holocene (References 749 and 757), is based on: deposits preserved in Blackwater Bay on the southwest Gulf coast of Florida (Reference 750); deposits preserved in Sarasota Bay and Little Sarasota Bay on the west-central Gulf coast of Florida (Reference 753); deposits preserved in Whitewater Bay near Cape Sable, on the southern tip of Florida (Reference 800); and the hurricane-disrupted deposits of Biscayne Bay, on the southeastern coast of Florida (Reference 754).

Based on six core samples retrieved from Blackwater Bay, Lowrey (Reference 750) notes that this portion of the southwest Florida shoreline has experienced three major phases of relative sea-level change during the Holocene eustatic rise. Using vibracore samples, Lowrey (Reference 750) developed a stratigraphic sequence that is consistent across the entire bay. Pliocene limestone bedrock (described in References 751 and 752), at the base of cores 6 and 1, is overlain by units A (oldest) to D (youngest). These units were classified as sediment type A (quartz packstone or a clayey quartz sand), sediment type B (quartz grainstone), sediment type C (*Rhizophora*, red mangrove, peat), and sediment type D (shelly quartz packstone to wackestone). The base of the peat in core 1 was dated at 4170 + 40 years before present using radiocarbon techniques, and the upper surface of the peat in core 6 was dated at 1090 + 40 years before present.

Vertical and lateral relationships of units A to D in the cores suggest that Blackwater Bay has undergone three phases of local sea-level change during the eustatic Holocene transgression. Each sedimentary sequence represents a time transgressive unit, as changes in sea level caused migration of depositional environments. Sediment types A and B formed during the early transgressive phase, as interpreted by Parkinson (References 751 and 752), as shoreline approached the study site. The occurrence of sediment type C represents the shoreline intersection with the site, followed by a stabilization and possible regression of the shoreline at approximately 4100 years before present with the accumulation of thick peat sequences. The facies change to sediment type D at a uniform elevation indicates a significant event at approximately 1000 to 1090 years before present, possibly a storm or series of storms, inundated the mangroves in all cores, reinitiating a relative sea-level rise and a return to deeper water conditions.

Davis et al. (Reference 753) conducted studies of the Holocene stratigraphy of Sarasota Bay and Little Sarasota Bay, coastal bays located landward of a Holocene barrier/inlet complex on the west-central, microtidal Gulf Coast of Florida. In addition to evidence for cyclic sea-level change, the sand and shell gravel deposits sampled in cores from both bays were deposited by at least four storms. Three storm units from Sarasota Bay have been radiocarbon dated at 2270, 1320, and 240 years before present. Historically documented severe hurricanes influenced this coast in 1848 and 1921. Hurricanes interrupted the normal, low energy, slow deposition in the bays and caused inlets to open and close (Reference 753).

Vlaswinkel and Wanless (Reference 800) find that, under conditions of sea-level rise, natural and cut tidal channels contribute to a larger tidal flow and thus bring increased volumes of sediment-laden tidal water into estuaries and coastal lakes (e.g., Lake Ingraham and adjacent southern lakes). Rapidly forming flood tidal mud deltas are filling these lakes and bays (e.g., Whitewater Bay near Cape Sable) at rates of 1 to 20 centimeters per year. Organic content of these carbonate sediments is up to 40 percent (in contrast to 2 to 10 percent in most of the Florida Bay mud banks). This rapid pulse of coastal sedimentation in response to small sea-level changes and coastal instability may be more common in building a stratigraphic record than presently appreciated (References 756 and 800).

According to Wanless et al. (Reference 756), the Pleistocene and Holocene coastal dune ridges found around the Gulf of Mexico and Atlantic Ocean coasts of Florida are stabilized mostly by vegetation and do not appear to be producing layered sequences because the sand, as it gradually accumulates, is bioturbated by root processes. Some of these ridges are formed during and just following major storm events as large volumes of sediment are scoured and recycled.

Wanless et al. (Reference 756) identify rapid pulses of growth during times of rising sea level as large volumes of coastal and shelf sediment became exposed and unstable. Waves and currents rapidly erode and deposit these sediments inland from the coast producing pulses of dune-ridge growth. These thickly layered sequences are then followed by a time of vegetative stabilization, bioturbation of the upper portion, and minor trapping of sand that is blown or washed in. This process is occurring along sections of the southwest Florida coast today. Probably with the help of the 23-centimeter relative rise of sea level during the past 70 years, the marl (firm carbonate mud) and organic peat of the southwest coast of Florida is rapidly eroding (200 to 400 meters since the earliest 1928 aerial photographs) and large volumes of sediment are being redistributed (Reference 756).

Hurricanes complicate the preservation of Pleistocene and Holocene deposits on the east and west coasts of the Florida Peninsula by eroding these deposits and redepositing them elsewhere. As an example, Hurricane Andrew impacted the shallow marine environments of south Florida in August, 1992 (References 754, 865, and 866). Tedesco and Wanless (Reference 754) maintained an extensive set of pre-storm data and monitor a broad spectrum of environments on both Florida coasts since immediately after the storm. They report that the most pronounced long-term change occurred on the high energy shallow marine carbonate banks forming the seaward margin of Biscayne Bay. These banks experienced accelerated surge currents at areas of shoaling or confinement. Seagrass blowouts covered a broad expanse of the seaward bank margin and up to 1 meter of initial erosion of muddy substrates resulted. A bankward thinning wedge of skeletal sand and gravel, which originated from erosional areas, was deposited on the banks. Destabilized areas exposed to lower energy storm events have continued to be reworked. The overwash lobes of skeletal sand and gravel have prograded bankward more than 60 meters (200 feet). Sediment for lobe progradation came initially from seaward erosional areas, but now originates from portions of the overwash lobe itself. Skeletal sand and gravel reflecting the initial storm deposit has been eroded and reincorporated into an evolving, migrating sediment wedge up to 15 centimeters (6 inches) thick. New fauna has been incorporated into the deposit. This beach-building process appears to be continuing (Reference 756).

2.5.1.1.1.2.1.2 Stratigraphy of the Florida Platform

The Florida Platform is a broad low-relief marine platform ranging in elevation from -656 feet to the shoreline (-200 to 0 meters). It includes the shallow portion of the continental shelf currently underwater, stretching from the Florida Escarpment to Florida's Gulf coast, roughly 300 miles (480 kilometers) across from west to east (Figure 2.5.1-214). Geophysical data indicate that the platform is underlain by continental crust at the axis of the peninsula to thinned continental crust at its periphery. The crust beneath southern Florida may be more mafic or transitional (Reference 409). The structure and tectonic evolution of the Florida Platform are described in detail as part of the larger Florida Platform, including the modern peninsular Florida and its surrounding areas of continental shelf and slope (Subsection 2.5.1.1.3), which are located immediately west of the Florida Platform. The Florida Escarpment represents the transition to the Gulf of Mexico, the deep-water basin that opened in the middle Jurassic (Reference 410).

The structural relationships between the large, separated areas of carbonate platform in the Gulf of Mexico, the Bahamas, the Blake Plateau, and elsewhere in the Caribbean are not clear. The following discussion is pertinent to the continuity of basement and overlying stratigraphy between these carbonate platforms, as described in Subsections 2.5.1.1.1.2.1.2, 2.5.1.1.1.2.2, 2.5.1.1.2.1.2, and 2.5.1.1.2.1.3. Two different hypotheses have been proposed for the character and continuity of the basement rocks between the Florida and Bahama Platform. These hypotheses probably also apply to the relationship between those two platform areas and the Yucatan Platform. Mullins and Lynts (Reference 411) postulate that the Bahama Bank formed during the Jurassic on top of a rift-generated horst-and-graben topography (known as the "graben hypothesis"). According to this hypothesis, the seaways now separating the banks originally formed as structural lows and that the Florida-Bahamas megabank was situated on structural highs. During long-term subsidence following initial rifting, carbonate-derived sedimentation kept pace across the megabank topographic highs, forming up to 14 kilometers (9 miles) of shallow-water limestones. The basins also accumulated great thicknesses of both shallow and deep-water carbonate sediments but lagged behind the banks, thereby amplifying the original depositional relief.

An alternate hypothesis is proposed by Sheridan et al. (Reference 307), who postulate that a large, continuous megabank, extending from the Florida Escarpment to the Blake-Bahamas Escarpment, had formed by the Late Jurassic on a basement not segmented by horsts and grabens (Sheridan et al.'s hypothesis is known as the "megabank hypothesis"). The continuous platform may have had deep-water reentrants (Reference 501), but most of the area from the Florida Platform to the Blake-Bahamas Escarpment was covered by shallow-water carbonate depositional environments that persisted until the mid-Cretaceous. Deep sea drilling has confirmed that, prior to the mid-Cretaceous, shallow-water limestones were deposited in the Straits of Florida, in contradiction to the graben hypothesis.

Beginning in the mid-Late Cretaceous, the Cuban and Antillean orogenies produced left-lateral shearing between the North America and Caribbean plates. Faults and folds developed, preferentially aligned with the margins of the carbonate banks, including the eastern margin of the Florida Platform. As a result, the megabank broke up into a number of banks and basins in the Florida-Bahamas region. On the basis of undeformed sediments visible on seismic reflection surveys, Hine (Reference 309) concludes that the eastern margin of the Florida Platform detached from the Bahama Platform and the Straits of Florida formed during the mid-Late Cretaceous. Hines (Reference 309) notes the continuity of flat-lying, shallow water limestones across the Florida to Bahama Platforms in the mid-Late Cretaceous, indicating the initiation of Florida Current activity at a mid-Late Cretaceous (Coniacian) unconformity in what would become the Straits of Florida. Later (post-Coniacian) strata are thinner in the Straits of Florida than on the west Florida and Bahama Platforms. It is likely that the Straits of Florida (and perhaps other channels across the Bahama Platform) are the result of new current circulation patterns that may have been caused by tectonic events such as the emergence of the Isthmus of Panama (as discussed in Subsection 2.5.1.1).

Persistent structural controls on carbonate sedimentation across the larger Florida Platform are discussed in Subsection 2.5.1.1.1.3.2.1. Stratigraphic relationships indicate, for example, that the Peninsular Arch has been a structural high since Late Jurassic time and possibly as early as mid-Paleozoic time, while the Sarasota Arch has been a structural high since late Paleozoic time and possibly as long as early Paleozoic (Reference 413). According to Winston (Reference 413), the Florida arches were formed not by uplift, but by subsiding more slowly than contiguous basin areas. The depositional basins identified across the Florida Peninsula and Florida Platform have been structural lows since the Late Cretaceous (Coniacian) time and may be downwarping even today (Reference 413). This differential subsidence has limited the continuity of carbonate and evaporite deposition since the Late Jurassic. These structural controls have been the main determinant as to the lateral continuity and thickness of the shallow carbonate and evaporate units across peninsular Florida and the Florida Platform.

The Middle Jurassic through Paleogene carbonate strata of the Florida Platform is essentially the same, albeit thicker, as the units described for the Florida Peninsula. As the Pangea supercontinent began to break apart in the Early

Jurassic (about 175 Ma), the rocks along the rifted margins were faulted into large blocks that began to subside. The resulting basins began to fill with sediments eroded from the blocks and from the adjacent continents. As these basins subsided below sea level, they were invaded by seawater whose restricted circulation and high evaporation rates caused deposition of thick evaporitic deposits in some areas (References 414, 415, 416, 417, 418, and 886).

The oldest Cenozoic formation on the Florida Platform is the Paleocene Cedar Keys Formation that conformably overlies the Late Cretaceous Pine Key Formation (Figure 2.5.1-231) (References 357 and 369). The Cedar Keys Formation is a lagoonal facies that occurs within the confines of the Rebecca Shoal barrier reef (Reference 369). In southern Florida, the Cedar Keys Formation consists primarily of gray dolomite, gypsum, and anhydrite with a minor percentage of limestone. The upper part of the Cedar Keys Formation consists of coarsely crystalline, porous dolomite. The lower part of the Cedar Keys Formation contains more finely crystalline dolomite interbedded with anhydrite (Reference 369). Based on structural/stratigraphic analyses of borehole data, the configuration of the Paleocene sediments in peninsular Florida reflects depositional controls inherited from preexisting Mesozoic structures such as the Peninsular Arch and the southern Florida Basin (References 389 and 419). The upper unit of porous dolomite in the Cedar Keys Formation forms the base of the Floridan aquifer system (Subsection 2.4.12) throughout southern Florida (Reference 349), where it is found at elevations ranging from -3,000 to -4,000 feet (~-914 to -1220 meters) (Reference 389). The Cedar Keys Formation varies from approximately 500 feet up to 2000 feet (~152 to 610 meters) thick in southern Florida (References 356 and 375).

2.5.1.1.1.2.1.3 Stratigraphy of the Atlantic Offshore Continental Shelf and Slope

The southern portion of the Atlantic margin from Florida and the Bahamas northward to the Newfoundland Fracture Zone represents a fully developed, passive margin with a sedimentary record spanning the mid-Jurassic to Recent (Reference 327). The strata rest on Triassic-Early Jurassic rift basins. The Atlantic margin includes a generally broad continental shelf underlain by extended continental crust transitioning to thick oceanic crust, including the Blake Plateau and the Bahama Platform. The basins of the Atlantic margin display the two-phase architecture characteristic of extension (passive) continental margins. Rift basins, formed by the brittle failure during the initial phase of crustal stretching, are followed by a broad seaward-thickening sediment wedge deposited during the phase of flexural subsidence that accompanies regional cooling and subsidence as the rifted margins move away from the oceanic spreading center. The sediment piles characteristically onlap the continental margin over periods of tens of millions of years as the thinned continental crust gradually subsides (Reference 327).

Rifting was accompanied by the extensive volcanic activity of the central Atlantic magmatic province or CAMP (Subsection 2.5.1.1). Basaltic dikes, sills, and flows formed during a 25 m.y. period spanning the Triassic-Jurassic boundary over vast areas of the Pangean suture between the proto-North America, South America, and African cratons. The rift basins include the South Georgia Rift, the Suwannee Basin, and others buried beneath Coastal Plain and continental shelf sedimentary cover (Reference 421) (Figure 2.5.1-229). Further subsidence of the rifted margin included development of shallow seas and the deposition of extensive evaporites, present under the South Georgia Basin, the Carolina Trough, the Blake Plateau Basin, and the Bahama Platform (Reference 327).

The transition from rifting to drifting in the middle Atlantic margin from northern Florida to Newfoundland began in the Middle Jurassic (Reference 421). Near the Blake Plateau, the transition from rifting to drifting appears to have occurred slightly later in the Middle Jurassic (e.g., Reference 341). The sedimentary succession in the Atlantic marginal basins is about 9 kilometers (5 miles) thick and consists of a variegated clastic succession of conglomerate, felsic and lithic arenite, siltstone, shale and mudstone, with interbedded basaltic lava flows. Evaporites, eolian sands, coal, and kerogen-rich beds are locally important. Siliceous tufas formed locally from hydrothermal systems associated with the lava fields. Fossil remains include fish, algae, zooplankton, spores, and pollen; the organic remains occurring in sufficient abundance in some cases to quality the fine-grained deposits as oil shales. Varved deposits attest to cyclic climatic conditions (Reference 327).

Sedimentary cover across Florida's Atlantic Continental Shelf and Slope began in post-Albian (post-Early Cretaceous) time when the area became a marine province. Siliciclastic sediments shed from the southern Appalachians, moved by rivers running north-south across the peninsula, accumulated on the level carbonate platform of Florida's Atlantic margin. Regional unconformities at the tops of the Albian, Santonian, Maastrichtian, Paleocene, and Oligocene units as well as one between Turonian and the Santonian have been mapped. Two styles of sedimentary accumulation have been active: (a) platform upbuilding and (b) platform outbuilding or progradation of the shelf. In post-Albian time, the area became a marine province, and sediment accumulated on a level platform. During the Santonian-Coniacian a shelf prograded seaward across this platform, but during the Campanian, Maastrichtian, and Paleocene deposition on a level plateau resumed (Reference 234).

The persistence of Gulf Stream erosion during the Cenozoic, in conjunction with crustal subsidence, transformed the distal edge of this continental margin sector into a deep-water, sediment-starved environment, the Blake Plateau (Reference 234). The Blake Plateau comprises an 8- to 12-kilometer (5- to 7.5-mile) thick sequence of Jurassic and lower Cretaceous limestones that are capped by less than 1 kilometer (0.6 mile) of Upper Cretaceous and Cenozoic deposits (Reference 422). The limestone platform extends beneath the emergent Florida Peninsula and continues west beneath the Florida Platform. The carbonates apparently also extend, uninterrupted, beneath the Bahama and Yucatan Platforms.

The Continental Offshore Stratigraphic Test Well (COST GE-1) was drilled in the center of the Southeast Georgia Embayment and penetrated more than 4 kilometers (2.5 miles) of marine and continental sedimentary strata, terminating in Paleozoic metamorphic rocks (Reference 423). Based on well data and seismic reflection profile data, Paull and Dillon (Reference 487) summarize the stratigraphy of the Atlantic Continental Shelf and Slope across the Florida-Hatteras Shelf and the Blake Plateau. Lower Cretaceous sediments were continental at the end of the Cretaceous, the entire area was a broad, level, submerged carbonate platform. The Mesozoic-Cenozoic boundary is marked by a small but not particularly distinct unconformity. A sequence of Paleocene strata about 100 meters (330 feet) thick overlies the Cretaceous units. The top of the Paleocene section is irregularly eroded and has relief of as much as 100 meters. The erosion is related to the initiation of the Gulf Stream. The late Paleocene unconformity is buried by a large seaward progradational wedge of Eocene to Oligocene age. The Eocene sections consist primarily of limestone and marl that grade northward into sandy limestone. Progradation was terminated by erosion at the end of the Oligocene. The Late Oligocene erosional surface was buried by another progradation of shelf and slope during Miocene to Holocene time. Tertiary accumulations under the shelf are much thicker than on the Blake Plateau.

2.5.1.1.1.2.2 Stratigraphy of the Bahama Platform

The stratigraphy of the Bahama Platform is based on large quantities of seismic reflection data as well as core recovered from numerous DSDP and ODP drilling sites (e.g., Reference 787) (Figure 2.5.1-211) (Table 2.5.1-201). A limited number of deep drill holes are located on the Bahama Platform. Petroleum exploration holes reached depths of 5700 meters (16,400 feet), bottoming in the Upper

Jurassic carbonates and evaporites. DSDP and ODP holes reached depths greater than 3000 meters (9800 feet).

The northwestern portion of the Bahama Platform is a passive continental margin that was not significantly affected by the tectonism that sutured Cuba and the Yucatan Basin during the Late Cretaceous though Eocene (Reference 220). Based on numerous reprocessed seismic surveys (Reference 424), the basement of the carbonate platforms of the Atlantic margin and Gulf of Mexico comprises highly rifted transitional continental crust consisting of probable Paleozoic crystalline metamorphics overlain by late Paleozoic sediments, intruded by Early to Middle Jurassic volcanics. The surface topography of the acoustic basement, as deduced from seismic reflection data, indicates a landscape of ancient horsts and grabens. The acoustic basement beneath the Bahama Platform is estimated to be between 7.5 to 8.7 miles (12 to 14 kilometers) (Reference 425) thick and is overlain by laterally continuous sedimentary units with large impedance variations, such as alternations of volcaniclastics, evaporites, and limestones (Reference 426) (Figure 2.5.1-244). The pre-rift sediments, where present, have been rotated with the underlying fault blocks. The sediments are often missing on high-standing fault blocks.

According to Case et al. (Reference 427), the Florida and Bahama Platforms are one continuous tectonic entity, that is, there is no single tectonic discontinuity or boundary identified that separates the two. The basement beneath the Florida Platform and the relationship between the Florida and Bahama Platforms (and possibly also the Yucatan Platform) are described in Subsection 2.5.1.1.1.2.1.2. The Bahama Platform is built upon the same rifted fragments of continental or transitional crust as the Florida Platform. However, gravity and magnetic data indicate that the crust of the Bahamas is more variable, with the southeastern portion of the platform beyond the site region potentially consisting of thick oceanic crust that was formed during Jurassic volcanism (Reference 428). The Middle Jurassic was a period of widespread production of the thickened oceanic crust, some of which floors the Caribbean basins and surrounding regions (Reference 250). The thickened oceanic crust is believed to be related to anomalously high heat flow due to Pangean rifting, related to emplacement of the ECMIP in Subsection 2.5.1.1.

Mesozoic rifting of the Atlantic Ocean and the Gulf of Mexico resulted in modification of continental crust along both margins and the creation of new oceanic crust farther offshore. The crust beneath the Bahama Platform (and within the site region) is characterized by several studies as having similar characteristics to the crustal types within the Gulf of Mexico. The Gulf of Mexico and the site region are also similarly characterized as seismically quiescent. Studies that characterize similar crust between these two regions include:

- Sawyer et al. (Reference 410) divide basement rock in the Gulf of Mexico region into four main types on the basis of the manner in which crust was created or modified by Mesozoic rifting: oceanic, thin transitional, thick transitional, and continental crust (Figure 2.5.1-238).

- Ewing (Reference 430) includes Florida as part of the Gulf of Mexico.

- Crustal-scale cross sections by Salvador (References 368 and 839) depict thick transitional crust beneath the Florida Peninsula and Shelf (Figures 2.5.1-239, 2.5.1-240, 2.5.1-241, and 2.5.1-242).

- {The Phase 1 and 2 earthquake catalogs (Subsections 2.5.2.1.2 and 2.5.1.2.3, respectively) indicate sparse seismicity throughout the Florida and the Bahama Platform, in contrast with the island arc terranes of Cuba that show abundant seismicity (Figure 2.5.2-201).} SOF 2.5.1-1 SOF 2.5.1-2

The deepest wells in the Bahamas have encountered a basement of arkosic rhyolitic volcaniclastic deposits overlain by Upper Jurassic limestones, dolomites, and evaporites (Reference 307) (Figure 2.5.1-243). The overlying stratigraphic section is more than 3 miles (5 kilometers) thick and indicates that shallow shelf and platform carbonate deposition continued essentially uninterrupted to the present time and was primarily controlled by eustatic sea level changes (Reference 211) (Figure 2.5.1-208). The Great Isaac I Well (Figure 2.5.1-243) reached volcaniclastic sediments beneath the Jurassic carbonates. Sheridan et al. (Reference 307) suggest that the larger, western platform near Andros Island and Grand Bahama is underlain by transitional continental-oceanic crust formed during an aborted rifting phase in the Mid-Jurassic. Later seismic reflection survey results show that the area is underlain by anomalously thick oceanic crust that extends from the Georges Bank to the tip of Florida (see discussion of the ECMIP in Subsection 2.5.1.1).

The Great Isaac I well, located southwest of the Little Bahama Bank, penetrated 7000 feet (2100 meters) into the carbonates without reaching crystalline basement (Reference 432) (Figure 2.5.1-243). However, the core revealed shallow-water carbonate-evaporite deposits (mid-Cretaceous and older) overlain by deep-water deposits with upward-increasing neritic debris (Late Cretaceous-Tertiary) and capped by bank-margin deposits (Plio-Pleistocene). This succession is interpreted by Schlager et al. (Reference 432) as a restricted carbonate platform that was drowned in the late Albian or Cenomanian (~100 m.y.) and subsided to over 2000 feet (600 meters) water depth (see discussion of carbonate platforms in Subsection 2.5.1.1.1.2.1.2). The drowned carbonate platform was subsequently reintegrated into the Great Bahama Bank by westward progradation of the platform (Reference 432) and tectonic uplift (Reference 327). The tectonism was associated with the collision of the Greater Antilles Arc with the North America Plate, starting in the mid-Late Cretaceous and continuing through Eocene.

Multichannel seismic line MC92 was run across the northern Straits of Florida to tie to the Key Largo well, KL, and the Great Isaac Island well, GI-1. The seismic-stratigraphic evidence seen in line MC92 indicates that the Straits of Florida first began to develop as a deepwater area during the Cenomanian (lower Upper Cretaceous). Before this, Albian (upper Lower Cretaceous) and older sedimentary units were deposited on a shallow-water bank, which was continuous from southern Florida to the Great Bahama Bank (References 307 and 424). LDP-CS536

Sheridan et al. (References 307 and 424) interpreted the seismic reflectors at the top of the upper Oligocene-Holocene (HOLO.-UP. OLIG.) as an asymmetric ridge. However, according to Eberli et al. (Reference 983), this feature may also be interpreted as a possible clinoform. As defined by Miall (Reference 985), a clinoform is a sloping dipping surface that is commonly associated with strata prograding into deepwater. SEPM (Reference 986) describe sigmoid clinoforms (s-shaped reflection patterns) to be interpreted as strata with thin, gently dipping upper and lower segments, and thicker, more steeply dipping middle segments. Twenty degrees is the angle of repose for carbonate sediments (Reference 983). In general, sigmoid clinoforms tend to have low depositional dips or angles for the upper segments, typically less than 1 degree, and are parallel with the upper surface of the facies unit with no strata termination with the bounding surfaces (Reference 986). According to Eberli et al. (Reference 983), the sigmoid clinoforms that formed in the northern Straits of Florida nearly match the third order sea level fluctuations on the global cycle chart. SEPM (Reference 987) defines a third order sea level fluctuation or sequence as a depositional sequence that has a duration in the order of 1 million to 10 million years with a relative sea level amplitude of 50 to 100 meters (164 to 328 feet) and a relative sea level rise/fall rate of 1 to 10 centimeters (0.4 to 3.9 inches) per 1000 years (Reference 987).

Bergman (Reference 906) and Anselmetti et al. (Reference 228) interpret the progradation of sediments that form the clinoforms in the Straits of Florida to be caused by a sea level drop. The drop in sea level occurred approximately during the middle Miocene. Eberli et al. (Reference 983) interpret the data and the results of modeling studies to indicate that progradation occurred in pulses during rises in sea level subsequent to drops in sea level. More sediment is produced on the bank surface than can be accommodated and, thus, excess sediment is transported down the leeward slope and deposited as apron sediments and turbidites (Reference 983). In addition to eustatic changes in sea level, a western boundary paleo-Florida Current had developed and the Straits of Florida became the major pathway for the Florida-Gulf Stream surface current system by the middle Miocene (References 228 and 906). LDP-CS536

Since the apparent slump is interpreted as a progradational depositional feature, it does not bear upon the tsunami hazard in the site region. Based on more recent data presented in Mulder et al. (Reference 984), the turbidite deposits might have resulted from a slope failure on the western margin of the Great Bahamas Bank. For Probable Maximum Tsunami purposes, a potential landslide-induced tsunami is discussed in Subsection 2.4.6.

Lower Cretaceous stratigraphy includes dolomite and layers of anhydrite. The upper Cretaceous sedimentary sequence is predominantly shallow water limestones, but deepwater oozes, chalks, and cherts of Late Cretaceous to Tertiary age occur in the Providence Channel (Figure 2.5.1-208). The finding of deep-water sediments in the Providence Channel indicates that deep-water channels and troughs of the Bahama Platform were in existence at that time (Reference 307).

A review of paleogeography developed by Salvador (Reference 368) from a combination of seismic profiles and drilling data indicates that shallow shelf and platform carbonate deposition on the Bahama Platform continued essentially uninterrupted from the Early Cretaceous until the present. The carbonate shelves and platforms were often fringed along their basinal margins by high-energy shoals, rudist-dominated reefal buildups, and barrier islands interrupted by tidal channels and passes. Banks, patch reefs, and occasional evaporites were often formed in intra-shelf basins and back-reef lagoons. Unlike Florida, there was no deposition of siliciclastics to interrupt carbonate deposition (References 211 and 368).

Based on their similar depositional environments and marine geomorphology, Hoffmeister et al. (Reference 384) state that the geologic features of Florida and the Bahama Platforms are mirror images of each other. Mesozoic sediments are largely shallow water carbonates with some evaporites.

Drilling at DSDP Site 627 (Figure 2.5.1-211) recovered mid-Cretaceous (Albian) through Quaternary sediments. A short section of Upper Pleistocene (160 centimeters [5.3 feet] in Core 627A-1H) is separated from the lower Pleistocene by an unconformity. The underlying section suggests relatively continuous sedimentation from late Miocene through early Pleistocene time. A possible hiatus separates this section from the underlying uppermost lower Miocene to middle Miocene. A substantial unconformity separates Neogene sediments from siliceous sediments deposited during the early to middle Eocene. Below this lies a thin section of Paleocene sediments. The range of ages and the thinness of the section suggest that sedimentation during this time may have been either punctuated or condensed (Reference 436).

The Cenozoic section is separated from the Mesozoic section by a substantial hiatus that includes the earliest Paleocene and all of the Late Cretaceous (Maastrichtian). The underlying upper Campanian section consists of purely pelagic sediment with open-ocean micro faunas and micro floras. This relatively thick Campanian section is underlain by a sequence of lower to middle Cenomanian hemipelagic marls. The microfaunas indicate that the top of this Cenomanian section represents an outer-shelf environment, whereas the base is an inner shelf. The underlying sequence of shallow-water-platform dolostones and evaporites is Albian and most probably late Albian in age. These stratigraphic relationships in the mid-Cretaceous suggest that little time elapsed between deposition of the shallow-water-platform sediments and subsequent deposition of the hemipelagic sequence (Reference 436).

Cenozoic sediments are dominated by low magnesium carbonates with varying amounts of aragonite and dolomite. Based on deep drilling and seismic reflection data, the base of Cenozoic sediments ranges in depth from approximately 3200 feet (975 meters) (References 385 and 437) to 8000 feet (2438 meters) (Reference 387). The Great Bahama Bank is considered to be an excellent indicator of sea-level changes in the Atlantic Ocean. Eberli et al. (Reference 385) report that deep core borings on the Great Bahama Bank indicate that the frequency and amplitude of sea-level changes have had a significant effect on the progradation, thickness, and diagenesis of the platform strata (Figures 2.5.1-244 and 2.5.1-245).

A combination of seismic, magnetic, and gravity profiles and drilling data provide information about the Quaternary subsurface stratigraphy of the Bahamas. Carew and Mylroie (Reference 438) draw the following conclusions about the Quaternary stratigraphy (Figure 2.5.1-246):

- A transition from Pliocene skeletal and reefal facies to Quaternary oolites and eolianites is located at the margins of the Great Bahama Bank.
- Shallow coring has indicated that Pleistocene-Holocene sediments are about 79 feet (24 meters) thick on the Little Bahama Bank and as much as 131 feet (40 meters) thick on Great Bahama Bank.
- The thickness of the Quaternary sediments does not vary systematically across the Bahamas.

Pleistocene stratigraphic units exposed on the Bahama Bank include the Owl's Hole, Grotto Beach, and Rice Bay Formations (Figure 2.5.1-246). The Pleistocene Owl's Hole Formation consists of eolianite deposits overlain by terra-rosa paleosol that are, in turn, overlain by either a highly oolitic eolianite deposit capped by a second terra-rosa paleosol or by subtidal deposits. The Owl's Hole eolianites consist of fossiliferous and peloidal grainstones and oolitic rocks. The oolitic rocks are micritized at the exposed surface but portions remain weakly cemented. The top of the unit is a hard, red micritic terra-rosa paleosol overlain by younger oolitic eolianites (Reference 438).

The Pleistocene Grotto Beach Formation consists of eolianite and beach-face to subtidal marine limestones subdivided into the French Bay and Cockburn Town Members. The Grotto Beach Formation is capped by a terra-rosa paleosol except where it has been eroded. The formation is characterized by well-developed ooids. The regressive stage and subtidal facies eolianites are predominantly peloidal or bioclastic and also contain ooids. The transgressive stage eolianites, a beach facies, are represented by the French Bay Member, consisting of fine to medium oosparites (oolitic grainstones), while the subtidal and stillstand through regressive stage beach and eolian deposits are represented by the Cockburn Town Member of the Grotto Beach Formation (Reference 438).

The Holocene Rice Bay Formation consists of all the rocks overlying the paleosol that caps the Grotto Beach Formation. In some places it is subdivided into the North Point and Hanna Bay Members (Figure 2.5.1-246). The Rice Bay Formation consists of eolianites and beach facies rocks that have been deposited during the transgressive and stillstand stages of the current sea level highstand. The rocks of the Rice Bay Formation are characterized by a low abundance of ooids, the small size of the ooids, the dominance of peloids and bioclasts, limited diagenetic micritization, and low magnesium calcite cement. The transgressive stage of eolianites is represented by the North Point Member. The rocks are mostly peloidal and cemented (by either water from the vadose zone or by marine water).

The stillstand stage beach and eolian facies of the Rice Bay Formation consist of the Hanna Bay Member. This member consists of peloidal/bioclastic grainstones with low-magnesium calcite cement. Lithification of rocks from this member occurred while at the current sea level (Reference 438).

2.5.1.1.1.2.3 Stratigraphy of Cuba

Cuba comprises several lithostratigraphic components including the following (Figure 2.5.1-247):

- The Socorro Complex, Grenvillian basement rocks in central Cuba
- North American-derived passive margin strata of Jurassic to Eocene age
- Jurassic to Cretaceous metamorphic terranes (the Escambray, Pinos, and Guaniguanico terranes)
- An allochthonous Cretaceous volcanic arc and associated ophiolites and mafic metamorphic rocks
- An in situ Tertiary volcanic arc at the southeastern edge of Cuba
- Undeformed upper Eocene to Recent cover

The Socorro Complex

Renne et al. (Reference 689) document the presence of Grenvillian basement rocks in central Cuba (Socorro Complex, 0.904 Ga, Fig. 1) that they propose formed part of a continuous band of Grenville rocks extending between southwestern North America, Central America (Chortis block) and northwestern South America (Reference 442).

North American-Derived Passive Margin Strata

The northeastern edge of Cuba, onshore and offshore, includes an approximately 16,000-foot (4900-meter) thick carbonate platform, carbonate slope, and deep-water basin in a northwest-trending exposure (Reference 439) (Figures 2.5.1-247 and 2.5.1-248). These sections range in age from upper Jurassic to lower-Middle Eocene. The platform section is located farther northeast, while the deep-water basin is exposed farthest to the southwest (Figure 2.5.1-248). The platform facies commonly includes an Late Triassic to Early Cretaceous, approximately 6600 to 13,100 feet (approximately 2000 to 4000 meters) thick, siliciclastic-evaporite-carbonate section. The Late Cretaceous platform section is more variable, but mostly includes shallow-water limestone, dolomite, and minor chert (Reference 440). The slope facies is represented by the

Camajuani belt, and includes uppermost Jurassic to Late Cretaceous deep-water limestone, chert, and calcareous clastic beds. The Placetas belt, to the southwest, is the most variable and represents a deep-water basin depositional environment. The stratigraphic section includes a Late Jurassic to Late Cretaceous deep-water limestone, chert, and clastics overlain by a Late Cretaceous calcareous megaturbidite, overlain by deep-water limestones (Reference 440). A comparison with wells drilled in Florida and in the Bahamas indicates that the Cuban passive margin strata are similar to the North American passive margin stratigraphic sequence (Reference 441). In addition, the transition from carbonate platform to slope deposits likely reflects the southern boundary of the Cretaceous Florida-Bahama carbonate platform.

The Late Cretaceous (Maastrichtian) to upper Eocene sections of the passive margin terrane display a characteristic transition from exclusively carbonate to terrigenous clastic deposition. This transition is variable across the island of Cuba and reflects the diachronous approach of the Greater Antilles volcanic arc (Figure 2.5.1-250). The southwestern portions of the passive-margin sequence are relatively more deformed and have the thickest syn-orogenic Paleocene to Eocene foreland basin deposits. To the northeast, the carbonate platform sections display less deformation and a thin clastic cap (Reference 440).

Metamorphic Southwestern Terranes

Three main exposures of Jurassic to Cretaceous metasedimentary rocks are collectively known as the southwestern terranes. The southwestern sedimentary terranes are characterized by a thick section of continentally derived clastics of Middle Jurassic age. From west to east these terranes are the Guaniguanico, the Pinos, and the Escambray (Figures 2.5.1-251 and 2.5.1-247). The terranes were originally Laurentian rocks that may have originated from the Yucatan Peninsula as the Greater Antilles Arc pushed eastward past the Yucatan block (References 442, 443, and 444).

In western Cuba the base of the Guaniguanico terrane is the San Cayetano clastic sequence that is as old as Early Jurassic. This unit, consisting of sandstones and conglomerates, was deposited over a rifting basement that is probably composed of continental crust (Reference 439). The provenance of the San Cayetano has been used to determine the paleo-position of Cuba before Early to Middle Jurassic rifting of Pangea. Detrital mica ages indicate that the southern Yucatan is the source for this unit (Reference 442), whereas detrital zircons indicate a northern South American or Yucatan provenance (Reference 445). Hence, this suggests that the Guaniguanico was also allochthonous. The terrane also includes an Late Jurassic thick basalt sequence with major and trace element geochemistry consistent with continental rifting (Reference 443). The overlying Jurassic to -Cretaceous sequence includes shallow and deep-water carbonates. An hiatus in deposition is present in the uppermost Cretaceous to earliest Paleocene before deposition transitions to Paleocene to lower Eocene foreland strata deposited in a piggyback basin. There, late Campanian (Late Cretaceous) strata (77 to 79 Ma) record the first fine-grained input from the approaching Greater Antilles Arc to reach the southern North American margin, indicating that the arc was approaching the Florida and Bahama Platforms at that time. The collision occurred later, however, because syn-orogenic strata of western Cuba contain nanofossils of late Paleocene to early Eocene age (Reference 220).

South of the main island of Cuba, the Pinos terrane is exposed on a small, circular island (Isla de la Juventud) (Figures 2.5.1-247 and 2.5.1-251). This terrane also includes Jurassic-Cretaceous metasiliciclastics, with marbles and amphibolites near the top of the section. The terrane was subjected to Late Cretaceous metamorphism (References 440 and 446).

The Escambray terrane, or massif, is exposed in south-central Cuba, outside the site region (Figures 2.5.1-247 and 2.5.1-251). It consists of two metamorphic domes separated by a Paleogene sedimentary cover. It is composed of Jurassic to Cretaceous age siliciclastic metasedimentary rocks and minor marbles, metabasic rocks, and serpentinites. The Escambray terrane is divided into a lower unit of greenschist grade pelites and carbonates, overlain by a middle unit of blueschist-facies metasediments with ultramafic boudins, which are in turn overlain by an upper unit of metasedimentary sequences with eclogite lenses in a serpentinite matrix. These rocks have $^{40}Ar/^{39}Ar$ and $^{87}Rb/^{86}Sr$ ages that reflect cooling from high temperatures at 70 Ma (Reference 218).

Cretaceous Volcanic Arc

The Cretaceous volcanic arc unit includes ophiolites, subduction-related metamorphic rocks, early tholeiitic island arc rocks, calc-alkaline volcanic and intrusive igneous rocks, and Paleocene to Eocene arc-derived strata (References 443 and 220) (Figure 2.5.1-247). These rocks are the result of the Greater Antilles Arc, produced during the subduction of the North America Plate. The volcanic arc rocks are in fault contact with the underlying passive margin strata and are deformed into a synclinorium along the length of Cuba (Reference 439) (Figures 2.5.1-247 and 2.5.1-252). The fault at the base of the Cretaceous arc section is the north-vergent Domingo thrust fault (Figure 2.5.1-247). Paleomagnetic data indicate that these units have poles that are discordant from North America in the mid-Cretaceous, indicating the arc was transported from southwest to northeast during the Cretaceous to Eocene (References 447 and 448). The Cretaceous arc terrane is sometimes known as the Zaza tectonic terrane and is allochthonous to the passive margin sequence (Figure 2.5.1-248).

Generally exposed directly above the Domingo thrust (Figure 2.5.1-247), the northern ophiolites include sheared serpentinites, interlayered gabbros, and metamorphosed volcanic and sedimentary rocks (such as basalt, chert, limestone, and shale) (Reference 440). Some of these deposits have been identified as back-arc basin related (References 440 and 443). Eclogites from this unit underwent high-pressure (>15 kbar from thermobarometry) metamorphism and $^{40}Ar/^{39}Ar$ amphibole and $^{87}Rb/^{86}Sr$ ages indicate they were emplaced in the early Late Cretaceous (Reference 449).

The arc includes the Mabujina complex, an amphibolite interpreted as a pre-Cretaceous arc basement, Aptian to Campanian tholeiitic to calc-alkaline extrusives and volcaniclastics, and intruding bodies of arc-related granodiorite (Reference 440). The earlier extrusives and volcaniclastics (pre-Albian) are tholeiitic basalts and rhyolites, while the post-Albian volcanic rocks are calc-alkaline andesites (Reference 216). The latest Cretaceous section may be dominated by high-alkaline compositions (Reference 443). $^{40}Ar/^{39}Ar$ mica ages from rhyolites, granodiorites, and other arc products indicate that the Cretaceous arc was uplifted and cooled between 75 and 70 Ma (Reference 770).

Tertiary Volcanic Arc

Paleocene to Eocene arc rocks are found primarily in southeasternmost Cuba, in the Oriente province (Figures 2.5.1-251 and 2.5.1-247). The southern portion of this arc exposure is dominated by calc-alkaline extrusives, while the northern portion consists of pyroclastics and sedimentary sequences that are more consistent with a back-arc depositional setting. Thin tuffaceous layers found in central and northern Cuban sedimentary successions indicate the distal influence of this younger arc (Reference 440).

Upper Eocene and Younger Strata

The complex folding and thrust-related deformation present in all of the older units in Cuba is not present in the unconformably overlying upper Eocene to recent sedimentary strata that drape the island. These post-orogenic sediments consist of Late Eocene argillaceous limestones overlain by a thick sequence of Oligocene through Pliocene limestones (Reference 439) (Figures 2.5.1-248 and 2.5.1-252). Iturralde-Vinent (Reference 451) identifies an unconformity that is followed by deposition of Paleocene submarine debris flows and Eocene calcareous shaly flysch. The Eocene-Oligocene contact is at a depth of approximately 4500 feet (1370 meters). The Oligocene unit consists of up to 600 feet (183 meters) of deep-water chalk and limestone that grades laterally into an arenaceous and shaly limestone deposited in marine water of intermediate depth. This is overlain by 400 to 1000 feet (120 to 300 meters) of Miocene sediments consisting of deep-water marl, siltstone, and shaly limestone that grade into arenaceous and calcareous sediments with intercalated, fossiliferous sandy limestone deposited in a neritic environment (Reference 382). Late Tertiary deposits occur in the northern coastal area and dip gently toward the north.

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Along Cuba's north coast in the site region, the marine terraces that dip gently seaward (to the north) consist primarily of Miocene through Pleistocene age limestones (References 923 and 924) and extend laterally along the north coast (Reference 848) except where rivers have eroded gaps in the terraces (Reference 926). The terraces are wide, with gentle slopes, the karst processes are more pronounced (i.e., the formation of caves and caverns and sinkholes), and notches (a cut along the base of a sea cliff near the high water mark that forms by undercutting the sea cliff due to wave erosion and/or chemical solution) are pronounced (Reference 921). The Miocene rocks that the marine terrace deposits formed are divided into the Cojimar Formation marls and the Güines Formation carbonates (chalks, argillaceous bioclastic limestones, and reef limestones) that outcrop from Havana to Matanzas. The Cojimar Formation marls represent a middle Miocene deep open shelf that is overlain unconformably by the Güines Formation. The Güines Formation represents a carbonate platform that covered almost the entire Greater Antilles from the second half of the middle Miocene up to the late Miocene. Late Miocene-Pliocene deposits are only locally developed at the Morro Castle of Havana (the Morro limestones) and near Matanzas City at El Abra de Yumurí (El Abra Formation). The El Abra Formation is a fluvio-marine unit. Pleistocene carbonates of the Jaimanitas Formation (coral reef limestones and calcarenites) are exposed along the coastal plain of Havana and Matanzas (References 383 and 919) and along much of the north coast of Cuba (Reference 925).

Terraces in Cuba near Matanzas are classified as erosional, depositional/ cumulative and constructional (References 920 and 923). Erosional terraces on Cuba's northern coastline are located east of Boca de Juruco, province of Havana and in the vicinity of the Bay of Matanzas (Reference 923). Cumulative terraces are described as: (a) having a sandy beach with an inner edge of 1 to 1.5 meters (3.3 to 4.9 feet) above sea level, and (b) storm bank with heights of 2 to 3 meters (6.6 to 9.8 feet) above sea level. Cumulative terraces occur on the northern coastline of Cuba, east of Havana. Constructional coral reef terraces are located on the north coast west of Havana to Mariel and the suburbs of Havana and Santa Fe Jaimanitas (References 920 and 923). PTN RAI 02.05.01-22

Four marine terraces near Havana occur at elevations 200, 100, 10–15 and 4–5 feet (61, 31, 3.1–4.6 and 1.2–1.5 meters) above mean sea level (References 383, 917, 918, and 926). Near Matanzas, six terraces have been observed at elevations 400, 300, 200, 140, 30, and 5–6 feet (122, 91, 61, 43, 9, and 1.5–1.8 meters) above sea level (References 917, 918, and 926). At Matanzas Bay, Ducloz (Reference 915), Shanzer et al. (Reference 923), and Penalver Hernandez et al. (Reference 921) observed four terraces at the following approximate elevations 25–51 meters (82–167 feet (Rayonera), 15–33 meters (49–108 feet) (Yucayo), +/-16 meters (+/- 52 feet) (Puerto), and +/-8 meters (+/-26 feet) (Terraza de Seboruco) (Table 2.5.1-208). The Rayonera terrace is strongly karstic. The presence of sinkholes and caves indicate that the outer edge of the terrace has a height of 39 meters (128 feet), whereas the inner edge is approximately 51 meters (167 feet) giving this surface a topographic slope of approximately 3 to 4 degrees towards the coast. The rocks of this terrace are Pliocene-Pleistocene in age. As noted by its name, the Yucayo terrace is "narrow." It has an average height of 30 meters (98 feet) near the Bay of Matanzas. The terrace is cut off from the sea by a vertical cliff that is approximately 6 to 14 meters (20 to 46 feet) high. Sea caves are present and are indicative of coastal erosion. The Pliocene-Pleistocene rocks of this terrace are algal conchiferas, with hard, massive, and recrystallized limestone reefs. The Pliocene-Pleistocene Puerto terrace is similar to the Yucayo and Rayonera terraces. All three are characterized by the development of karst, sinkholes and a very sharp weathering surface known "diente de perros" (dog's teeth) (References 915 and 921). The Terraza de Seboruco, the youngest of these terraces is located west of Matanzas Bay. It rises just a few meters (2 to 3 meters) (6.6 to 9.8 feet) above mean sea level with paleolagoonal facies extending inland 1 or more kilometers. Near Havana and Matanzas, the elevation of the Terraza de Seboruco ranges from 2 to 3 meters (6.6 to 9.8 feet) above mean sea level to 4 to 5 meters (13 to 16 feet) above mean sea level, respectively. The terrace is described as porous or cavernous fossilized limestone from the Pleistocene Jaimanitas Formation with a weathering surface of "diente de perros" (References 915 and 925). LDP-CS564

The terraces and sea cliffs form a stair-step sequence, which suggests that reef deposition was followed by high sea level stands that cut the bench-like features in the sea cliffs (Reference 912). Several alternate processes can explain or partially explain the stair-step morphology and bench-like features that were described by Agassiz (Reference 912), Spencer (Reference 924), and Ducloz (Reference 915). The alternate hypotheses for what might have contributed to terrace formation as discussed in FSAR subsections are eustatic changes in sea level (Subsection 2.5.1.1.1.1.1.1), changes in ocean circulation pattern (Subsection 2.5.1.1), rise and fall in sea level as a direct result of melting and formation of the continental glaciers (Subsection 2.5.1.1.1.1.1.1), and tectonic activity (Subsections 2.5.1 and 2.5.1.1.3.3). PTN RAI 02.05.01-22 LDP-CS564

U-Th dates were obtained on corals (two very large *Montastrea* sp. and one *Acropora* palmate) from the Terraza de Seboruco at the Cantera Playa Baracoa quarry and in the Santa Cruz del Norte canal. When corrected from the initial Uranium age dates, the ages of the samples correspond to the Marine Isotope Stage 5e sea level high stand at approximately 120–130 ka (Reference 925). Toscano et al. (Reference 925) observe that similar age terraces throughout "stable" portions of the Caribbean area are at similar elevations, which is evidence for the absence of active uplift near Matanzas in the past 120–130 ka. Therefore, based on the U-Th dates, the Terraza de Seboruco is correlative to the Cockburntown reef (Bahamas) (Reference 914), Barbados III (Barbados) (Reference 916), and Key Largo Limestone (Florida) (References 913 and 922). LDP-CS564

2.5.1.1.1.3 Regional Tectonics within the Site Region

This subsection describes the principal tectonic structures and features in the southeastern U.S. that are located at least partially within the site region, including descriptions of the regional gravity and magnetic fields. Additionally, because Cuba is located partially within the site region, this subsection describes the principal tectonic structures and features of Cuba.

2.5.1.1.1.3.1 Gravity and Magnetic Fields

Gravity and magnetic data for the site region are described in this subsection, with a focus on anomalous features in the gravity and magnetic fields. Data for the gravity and magnetic fields for the site region were obtained from the National Geophysical Data Center. The gravity (Reference 452) and magnetic data (Reference 453) were originally produced for the Decade of North America Project (DNAG).

The original DNAG gravity data were presented on a 6-kilometer grid (and subsequently regridded by the National Geophysical Data Center to a 2.5-minute grid spacing [Reference 454]), which represented free-air gravity anomalies over the ocean and Bouguer anomalies on land. Terrain corrections were only computed and applied in high relief areas of the continent. Large portions of the site region are located offshore and, as a result, this subsection describes both free-air and Bouguer anomalies for the offshore and onshore portions of the site region.

The original DNAG magnetic data were presented on 1.2-mile grid spacing based on a spherical North American Transverse Mercator projection. These data were subsequently also regridded on a 2.5-minute grid spacing by the National Geophysical Data Center. These data sets were selected because they extend farther and give better coverage offshore in southern portions of the site region.

Magnetic highs located near the eastern portion of the Bahamas Platform (including the Little Bahamas Bank) represent both positive and negative magnetic anomalies related to structural controls from post Lower Cretaceous folding or faulting in the basement rocks of the Bahama Platform (Subsection 2.5.1.1.1.3.2.2). The density contrasts below the sea floor as seen from the Bouguer gravity anomaly map and profile (Figures 2.5.1-254 and 2.5.1-255) in this area show that the intraplatform straits (and channels) and basins correlate with the present day platform topography (Figure 2.5.1-254). In general, the straits and basins are areas of negative anomaly while the platforms are generally areas of positive anomaly. The negative anomalies coincide with areas of structural lows, probably downfaulted, and their negative signature stems from a combination of downfaulting of relatively light material and infilling of the resulting lows with low density sediments (Reference 971). LDP-CS536 LDP-CS564

The Blake-Bahamas Platform is related to, and limited by, a regional structural feature, the crustal transition zone, in which Jurassic volcaniclastics are tilted in fault blocks (References 307, 424, and 971). The transitional crust has a smooth, circular magnetic anomaly pattern (Figures 2.5.1-256 and 2.5.1-257). This zone is known as the ECMA and includes the BSMA (Figure 2.5.1-266) (References 466 and 974). The presence of thick volcanics on the oceanic basement of the Blake Plateau infers that the Bahamas Platform and Little Bahamas Bank overlie seamounts that were produced by CAMP magmatism. This also infers that volcanic activities continued as seafloor was accreted in the CAO (References 466 and 974). A basement map of the Florida-northern Bahamas region using seismic data compiled by Sheridan et al. (Reference 307) (Figure 2.5.1-384) shows the continental, transitional, and oceanic basement LDP-CS564 rocks along with their approximate ages. Sheridan et al. (Reference 307) concluded that the "transitional crust underlies the northwestern Bahamas to the projected BSMA, and that oceanic crust underlies the Bahamas farther southeast." LDP-CS536

Regional Gravity Field

The gravity field for the site region is shown in Figure 2.5.1-254, which indicates locations of representative field profiles that run through the site region: one oriented north-south parallel to and along the Florida Peninsula and one oriented east-west across the southern portions of the Florida Platform to the northern portions of the Bahama Platform (cross sections A-A' and B-B' in Figure 2.5.1-255). The first-order pattern of the anomalous gravitational field correlates well with bathymetry. Higher gravitational field values are in the range from approximately -20 up to +20 to +40 mGals. These higher values generally are surrounded by steep gravity gradients that generally outline and coincide with the exposed land and surrounding shallow waters of the Florida Platform and Bahama Platform. Intervening deep-water areas such as the Straits of Florida and deep-water channels and basins in the Bahama Bank are characterized by negative values of the gravity field. In addition to the low-density water column, the deep-water channels of the Straits of Florida, Providence Channel, and Tongue of the Ocean have been shown to be floored by thick sequences of low-density sediment, compared to the surrounding platform carbonates (Reference 307). This density contrast and the steep nature of the escarpments that form the boundaries of the Bahama Platform (Reference 307) provide the well-defined nature of the platforms in the gravity field.

The overall positive anomaly associated with the Bahama Platform exhibits a positive gradient to the east from approximately +20 to +40 mGals to over +100 mGals, roughly 225 miles (360 kilometers) east of the Units 6 & 7 site, except where modified by bathymetric effects as described above (Figure 2.5.1-254). The easterly increasing gradient is interpreted as the result of the decreasing importance of transitional crust with more mafic and denser oceanic crust progressively occurring at shallower levels (Reference 307) towards the Atlantic Ocean Basin. This long wavelength, easterly increasing gradient is locally modified by relatively subdued, low amplitude circular to elongate anomalies with amplitudes up to 10 mGals.

The Florida Platform occupies the northwest quadrant of the site region. This portion of the Florida Platform is transected by the Central Florida Gravity Lineament, a well defined northwest-southeast-oriented linear gravity high with an amplitude of a little over +30 mGals in central Florida, at a location approximately 100 miles (162 kilometers) north of the Units 6 & 7 site on gravity profile A-A' (Figures 2.5.1-254 and 2.5.1-255). However, the amplitude of this anomaly is not constant along strike. It appears to decrease slightly to the northwest of profile A-A' and shows higher anomalous values near the coastline to the southeast of profile A-A'. This subsection contains an interpretation of this linear anomaly.

Northeast of the Central Florida Gravity Lineament the Florida Platform is characterized by relatively low values of the gravity field down to a little less than -20 mGals, with the exception of a short wavelength (approximately 12 miles or 19 kilometers) circular gravity high located at approximately mile 40 on profile A-A', which reaches a maximum of a little less than +40 mGals. In contrast, the gravity field associated with the Florida Platform southwest of the Central Florida Gravity Lineament is characterized by relatively long wavelength, on the order of 62 to 93 miles (100 to 150 kilometers), gravitational anomalies that range from 0 to approximately 30 mGals on gravity profile B-B' (Figure 2.5.1-255). These observations indicate that the Central Florida Gravity Lineament effectively forms a boundary that separates the Florida Platform into a northern portion characterized by relatively low gravity field values and short wavelength anomalies and a southern portion characterized by a relatively high anomalous field with broader longer wavelength anomalies.

To the south-southeast of the Units 6 & 7 site a positive anomalous field of approximately 40 mGals is associated with the Cay Sal Bank, which exhibits similar field characteristics to the Bahama Platform just to the east. In the extreme, southern portions of the site region a positive anomalous field occurs in association with the Cuban mainland resulting from relatively dense igneous, metamorphic, and sedimentary basement rocks and their carbonate cover at shallow levels.

A gravitational low anomaly, whose minimum gravity field value of approximately –15 mGals, occurs just north of the site on gravitational profile A-A'.

Regional Magnetic Field

The regional aeromagnetic field for the site region is shown in Figures 2.5.1-256 2.5.1-257, which also indicate the location of magnetic profile A-A' (Figure 2.5.1-258). In distinct contrast with the gravity field in the site region, the magnetic field shows no strong correlation with bathymetry. This is the result of thick carbonate successions that cap the Florida and Bahama Platforms that are essentially nonmagnetic. The magnetic field sources all lie in the sub-Cretaceous basement. However, the fundamental nature of the Central Florida Gravity Lineament (Figure 2.5.1-255) is reflected in the nature and anomalous patterns of the magnetic field in the site region (Central Florida Magnetic Lineament in Figure 2.5.1-256).

The Central Florida Gravity Lineament is associated with similar trending and coincident low values in the magnetic field that exhibit values of -500 nanoteslas (nT) on magnetic profile A-A' (Figure 2.5.1-258) approximately 100 miles (161 kilometers) north of the Units 6 & 7 site. An anomalous magnetic high area on its northwest extension complicates the pattern of this feature, which generally is coincident with the area where the gravitational field associated with this linear feature is also diminishing (Figure 2.5.1-254).

The Florida Platform to the southwest of the Central Florida Gravity and Magnetic Lineament (Figures 2.5.1-256 and 2.5.1-254) and the Bahama Bank exhibit magnetic anomalous features that are circular to ellipsoidal in shape, have relatively long wavelengths, are relatively subdued, and generally trend northwest. Conversely, in central Florida, in the site region and in areas north of the site region, the magnetic field is characterized by relatively high gradient, short wavelength anomalies that are more elongated and linear in shape. In addition, these elongated and linear anomalies are oriented more or less uniformly northeasterly in concert with the structural grain of the Appalachian tectonic province. These trends are truncated by the Central Florida Gravity Lineament. These relationships in the magnetic field further support the fundamental nature of the Central Florida Gravity Lineament, and indicate that it separates two crustal provinces, each of which exhibits different gravity and magnetic field characteristics.

The circular anomalous gravity high noted at mile 40 on gravity profile A-A' (Figures 2.5.1-254 and 2.5.1-255) described in the previous subsection is associated with an apparent magnetic dipole source with a magnetic field high of +300 to +400 nT to the south of a magnetic low of -400 nT. The close association of a dense and magnetic source at this location would suggest that the potential field source for this feature is probably a mafic intrusion in the basement (Reference 212).

Within the site vicinity, a steep northerly increasing magnetic gradient marks the transition from a magnetic field minimum of approximately -200 nT to the south to a magnetic field high of approximately +200 nT to the north. This relationship is opposite of that expected for a magnetic dipole in the northern hemisphere so the significance of the magnetic field is uncertain in terms of a primarily induced field interpretation. However, the occurrence of several magnetic high and low anomalous field regions in the vicinity most probably indicates a magnetized basement with a significant mafic component. However, as noted, the site vicinity is located in association with a gravity low anomaly indicating that the basement in the vicinity is less dense than would be expected from a purely mafic composition and possibly reflects basement lithologic variation.

Summary of Gravity and Magnetic Findings

Klitgord et al. (Reference 212) and Sheridan et al. (Reference 307) present a synthesis and discussion of the anomalous gravitational and magnetic fields for the Florida Bahama Platform including the site region. The following description summarizes the pertinent points that relate to the site region presented in these sources.

In addition to the contrasting character exhibited by the gravity and magnetic fields on either side of the Central Florida Gravity Lineament, the location of the lineament is also correlated with other basic changes in the nature of the crust. The lineament marks a transition in the composition of the crust in the subsurface. In addition, the top of the basement surface becomes much deeper to the southwest. North of the lineament, in the site region, the basement of the Florida Platform is relatively shallow and characterized by Paleozoic igneous and metamorphic rocks that compose the Central Florida basement complex, which roughly corresponds with the Suwannee terrane (Figure 2.5.1-257). On the southwestern side of the central Florida lineament the carbonate platform cap becomes much thicker, and the composition of the crust becomes more "transitional" in nature and is composed of Jurassic volcaniclastic sequences.

Klitgord et al. (Reference 212) notes the fact that the Central Florida Gravity and Magnetic Lineament aligns with the Bahamas Fracture Zone (Figures 2.5.1-257 and 2.5.1-205) and suggests that it likely represents a Jurassic transform that separates a Late Jurassic spreading center in the Gulf of Mexico from the Central Atlantic spreading center. North of this transform plate boundary the crust is continental in nature and exhibits structural features associated with Appalachian tectonics as shown in the distinct northeast trend in the potential field anomalies. The relatively shallow basement and consequent relatively thin carbonate cap results in little attenuation of the high frequency components of the potential field anomalies. For that reason, the high gradient characteristics of the gravity and magnetic sources are preserved.

In contrast, the basement of the Florida Platform and other areas southwest of the transform boundary is much deeper, with a correspondingly thicker carbonate cap on the Florida and Bahama Platforms. The basement in these areas contains rotated and tilted blocks of volcaniclastic rocks. These deeply buried volcaniclastic sources result in subdued potential field anomalies whose high-frequency components have been attenuated and the field gradients subdued; consequently, they exhibit broad long wavelength characteristics. Also, detailed interpretation of the magnetic field anomalous sources associated with the volcaniclastic basement to the southwest of the transform boundary is complicated by the fact that some of these volcanic rocks may contain a component of remnant magnetization that may significantly modify the anomaly produced by the induced field.

2.5.1.1.1.3.2 Principal Tectonic and Structural Features

The site region is covered by a thick sequence of sedimentary rocks and deposits that obscure any Precambrian to Paleozoic tectonic features associated with the formation of Pangea (Figures 2.5.1-240, 2.5.1-242, and 2.5.1-201). In fact, this region has generally recorded only sedimentary processes since Mesozoic rifting, with the exception of the possible tectonic activity associated with the Cuban fold and thrust belt, possibly active faults in northern Cuba, adjacent Straits of Florida normal faults, the Santaren anticline, and the Walker's Cay fault. The Florida Platform has been a site of stable carbonate platform deposition continually since the Cretaceous. Variations in sediment thickness are interpreted as a series of arches, uplifts, basins, or embayments from geophysical or borehole data (Reference 413). Generally, these arches and basins are sedimentary responses to minor warping, regional tilting, sedimentary compaction, or sea level changes and are not considered associated with faulting or tectonic events (Reference 413). In some cases, the highs or lows seen in the stratigraphy may be mimicking Mesozoic paleotopography. The Bahama Platform is also largely undeformed, but does include sparse post-rift faulting or deformation, generally adjacent to the Cuban orogen. The EPRI (Reference 456) earthquake catalog and the updated earthquake catalog completed for the Units 6 & 7 site investigation (Subsection 2.5.2.1) indicate that north of Cuba and the northern Caribbean seismic source model (Subsection 2.5.2.4.4.3) earthquakes are sparsely and randomly distributed within the site region and that none of the earthquakes can be associated with a known geologic structure (Subsection 2.5.2.3).

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2.5.1.1.1.3.2.1 Florida Peninsula and Platform Tectonic and Structural Features

Structures of the Florida Peninsula and Platform

The Florida Peninsula exposes only flat, unfaulted strata at the surface (Figure 2.5.1-201), so all tectonic features are identified with subsurface methods, usually from drilling or seismic reflection data. Tectonic and structural features identified within the Florida Platform province (which includes the emergent peninsula and the submerged carbonate platform) are mostly a series of gentle highs and lows in the regional stratigraphy. In some cases, these may be reflecting original basement topography (such as the Peninsular Arch) or may reflect changes in sedimentation later in time (Figures 2.5.1-259, 2.5.1-260, and 2.5.1-261). Both surface exposures and well data indicate that Cretaceous and younger strata on the Florida Platform are generally gently dipping to horizontal (Figures 2.5.1-261, 2.5.1-240, 2.5.1-242, and 2.5.1-232). Local and regional seismic data and high-resolution bathymetric data indicate that the shallow stratigraphy in southern Florida is undeformed by tectonic faulting (e.g., References 798, 799, and 398). While occasional variations in pre-Miocene stratigraphy recorded in boreholes due to erosional paleotopography or karst have sometimes been interpreted as possible faulting (for example, the queried fault on Figure 2.5.1-234) (Reference 373), local and regional seismic data and high-resolution bathymetric data indicate that the shallow stratigraphy in southern Florida is undeformed by tectonic faulting (e.g., References 798, 799, and 398). Similarly, continuous, unfaulted prograding strata drape the edges of the Florida and Bahama Platforms along the Straits of Florida (Figure 2.5.1-262) (Subsection 2.5.1.1.1.2.2 provides a discussion of the prograding strata). LDP-CS536

Basement Faults of the Florida Peninsula and Platform

Faults cutting pre-Mesozoic basement of the Florida and Bahama Platforms are of two types: (a) normal faults responsible for the extension and thinning of the continental crust during rifting, and (b) hypothetical strike-slip faults inferred from plate reconstructions. Seismic reflection data indicate that the basement beneath the Bahama and Florida Platforms is faulted (e.g., Figure 2.5.1-263), although many regional-scale cross sections beneath the Florida Platform indicate it has a smoothly varying basement surface (Reference 457) (Figure 2.5.1-264). Normal faults have not been mapped confidently on the platform, but some have been preliminarily identified using well data to determine depths to basement in northern and central Florida, outside of the site region (Reference 457) (Figures 2.5.1-261 and 2.5.1-263). Because drilling data and mapping of exposed Eocene and younger strata as well as available seismic reflection profiles (largely PTN RAI 02.05.03-3 offshore) indicate that the Cretaceous and younger strata are unfaulted (Figures 2.5.1-230, 2.5.1-263, and 2.5.1-265), the age of this faulting is pre-Cretaceous (References 457 and 458).

A series of hypothetical faults have been drawn on various tectonic maps depicting the subsurface, pre-Mesozoic lithology of the Florida Platform, including strike-slip structures across central and southern Florida (e.g., References 458 and 212) (Figure 2.5.1-253). These primarily serve to separate the different lithologies encountered through subsurface drilling or potential correlations in magnetic data, or have been proposed to accommodate potential misfits in plate reconstructions (e.g. References 459 and 460). The structures, if they do exist, are expected to have been inactive since the end of the Jurassic because no offset is seen in any younger strata (Reference 458). This includes structures variably referred to as the West Florida-Ouachita megashear (Reference 461), the Jay fault (Reference 351), and the Bahamas Fracture Zone (Reference 212). Most notably, the Bahamas Fracture Zone is drawn through the site region, often along the boundary between the Suwannee terrane and Jurassic basement of southern Florida (Reference 212) (Figures 2.5.1-257, 2.5.1-205, and 2.5.1-229). The Bahamas Fracture Zone is a northwest-trending boundary seen in gravity and magnetic data (Reference 212) and the distribution of basement lithologies (e.g., Reference 463). It is interpreted as a Jurassic transform plate boundary (Reference 212). Offset has been interpreted in the Late Jurassic to Early Cretaceous strata in northwestern Florida, and attributed to a Bahamas Fracture Zone-style structure (Reference 464). No Cretaceous or younger faulting or offset is depicted in regional cross sections that transect this structure (References 344, 212, and 465), nor is any faulting seen at the surface (Figures 2.5.1-260, 2.5.1-261, and 2.5.1-230). In particular, interpreted seismic reflection lines that cross the Bahamas fracture zone show unfaulted Cretaceous and younger strata (e.g., Figures 2.5.1-263 and 2.5.1-262). The most recent mapping of magnetic anomalies on the Atlantic Ocean seafloor indicates that the Bahamas Fracture Zone ends east of the Bahama Bank and outside of the site region (Figure 2.5.1-266). Similarly, any offset of magnetic anomalies across the Blake Spur Fracture Zone (which offsets Chrons 25 by 30 to 50 kilometers [19 to 31 miles]) ends east of the Blake Spur magnetic anomaly, approximately 300 miles (480 kilometers) from the site (Reference 466).

Peninsular Arch

The Peninsular Arch is a northwest-trending feature that formed a relative topographic high until the Cretaceous Period (Reference 467) (Figures 2.5.1-229 and 2.5.1-259). East-west geologic cross sections across northernmost Florida show that Triassic/Jurassic and lower Cretaceous strata are truncated against this basement high (Reference 465) (Figure 2.5.1-259). Upper Cretaceous beds were deposited over the crest of this arch, indicating it had ceased to be a high by that time as the sea-level rose to an elevation that permitted continuous deposition across the arch (References 465 and 467) (Figure 2.5.1-260). However, Oligocene deposition may have been affected by the Peninsular Arch, but Neogene to Holocene sediments are unaffected (Reference 304).

Sarasota Arch

The Sarasota Arch is a northeast-trending basement high extending southwest from the Peninsular Arch in the west-central portion of the Florida Platform (Figure 2.5.1-229). It borders the South Florida Basin to the south and the Tampa Basin to the north. This basement high controlled deposition during the Jurassic and early Cretaceous (Reference 413). Seismic data interpreted by Ball (Reference 468) indicate a rough and faulted basement surface overlain by horizontal strata.

Tampa Basin

The Tampa Basin lies just north of the Sarasota Arch and primarily affects basement rocks of the Florida Platform (Figure 2.5.1-229). Ball (Reference 468) interprets a gentle syncline in Paleozoic reflections, but horizontal strata of Mesozoic and younger age persist upsection across the feature.

Broward Syncline

The Broward Syncline (Figure 2.5.1-229) is a northwest-southeast-trending syncline mapped in the subsurface Cretaceous strata (References 457 and 467) but its presence cannot be "unequivocally demonstrated because of lack of drilling" (Reference 469). This feature is located in Broward and Palm Beach counties, outside of the site vicinity (Figure 2.5.1-229).

South Florida Basin

The South Florida Basin (Figure 2.5.1-229) is a sedimentary basin filled with 3 to 8 miles (5 to 13 kilometers) of Jurassic to Holocene strata (Reference 409) that slowly subsided at the southern end of the Florida Platform (Figure 2.5.1-261). These deposits are the thickest in the Atlantic coastal plain. The Upper Jurassic and younger strata are shallow-water limestones and dolomites, evaporites, and deep-water limestones. The thickening to the southwest displayed in Cretaceous strata is sometimes referred to as the South Florida Shelf (Reference 457). The

South Florida Basin is separated from the Tampa Basin by the Sarasota Arch (Reference 368) (Figure 2.5.1-229). To the south, the edge of the South Florida Basin is sometimes delimited by the Pine Key Arch or the Largo High. However, these features, defined by variations in sedimentary facies, are not consistently identified or described (References 355, 413, and 469).

Ocala Uplift

The Ocala Uplift, or Ocala Platform, is a feature characterized by thickness variations in the Eocene strata in northwest Florida approximately 300 miles (480 kilometers) from the Units 6 & 7 site (Figure 2.5.1-229). The stratigraphic variations are interpreted to result from either compaction shortly after deposition or sedimentary build-ups and do not have a fault-controlled origin (References 389 and 470). The Ocala Uplift was subaerially exposed during the Eocene to Miocene, but the cause of this is uncertain. Mid-Miocene and younger deposition is undisturbed across the Ocala Uplift (Reference 304).

South Georgia Rift Basin

The South Georgia Basin (or Rift) is the southernmost continental rift basin associated with the opening of the Atlantic Ocean (Reference 471), and is located more than 350 miles (560 kilometers) north of the Units 6 & 7 site (Figures 2.5.1-229 and 2.5.1-261). Approximately 50 borings in northern Florida, southern Georgia, and southeastern Alabama have penetrated nonmarine clastics and diabase dikes and sills of Late Triassic and Early Jurassic age, known as the Eagle Mills Formation (References 458 and 344). These strata have been correlated with the Newark Supergroup, which fill rift basins from Newfoundland to Alabama along the East Coast and result from the widespread Mesozoic rifting that accompanied the opening of the Atlantic Ocean. In northern Florida, these strata may be 1830 meters (6000 feet) thick (Reference 211). The clastics have been interpreted to fill a graben up to 60 miles (100 miles) wide (Reference 458).

Suwannee Channel

The Suwannee Channel is a general term for the Suwannee Straits and the Gulf Trough (Figures 2.5.1-229 and 2.5.1-218), two marine channels that are located in roughly the same position, which separated southeastern North America from the Florida carbonate platform during two different time periods. The Suwannee Straits were located in southern Georgia, panhandle Florida, and southernmost South Carolina in the Middle Cretaceous to Late Paleocene (References 258 and 257). The Gulf Trough is middle Eocene to early Oligocene in age

(Reference 473). After the Oligocene, this trough had been filled, which allowed for clastic deposition on the central peninsula in the late Early Miocene (Reference 389). The currents from the Gulf of Mexico that flowed through these features to the Atlantic Ocean might have prevented clastics from the Appalachians and southeastern North America from reaching the platform (Reference 389). There is no faulting or tectonic activity associated with this feature, which is located approximately 400 miles (640 kilometers) to the north of the Units 6 & 7 site (Figure 2.5.1-229).

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Queried Fault from Cunningham et al.

Cunningham et al. (Reference 373) postulate that a fault or paleotopography could be responsible for elevation variations in the Arcadia formation in southwestern Florida (Figure 2.5.1-229). The queried structure is between 50 and 60 kilometers long (30–37 miles) (Figure 2.5.1-229), and at its nearest approach, the eastern end of the queried fault is approximately 41 kilometers (25 miles) west of the Turkey Point Units 6 & 7 site.

Figure 2.5.1-234 shows a cross section across southern Florida that was developed with data from eight wells in southern Florida, with variable horizontal scale between pairs of wells and, thus, with variable vertical exaggeration. Between the southernmost two wells, Cunningham et al. (Reference 373) postulate the existence of a fault that cuts up through Avon Park Formation, Suwannee Limestone, and Oligocene-Miocene-age Arcadia Formation, and potentially places the Arcadia Formation in fault contact with the lower portion of the overlying Miocene-Pliocene Long Key Formation. Alternatively, the Long Key Formation may be interpreted as deposited across a paleoscarp. Reference 373 labels the postulated fault on this cross section with two question marks, indicating the speculative nature of this fault.

In cross section, the postulated fault cuts units as young as the Miocene Arcadia formation, and although the Miocene to Pliocene Long Key Formation and the Pleistocene Key Largo are depicted as unfaulted, they have thickness and elevation differences across the structure (Figure 2.5.1-234). Higher up, section above the queried fault tip, Cunningham et al. (Reference 373) cross section shows marine carbonate stringers that could be interpreted as deformed by slip on the underlying fault. Alternatively, these marine carbonate stringers could represent deposition draped across a paleoscarp and thus could post-date slip on the underlying postulated fault.

Although the postulated fault in Figure 2.5.1-234 would not represent a Quaternary faulting hazard for the site if it existed, in detail the thickness and stratigraphic variations may instead be related to paleotopography. Indeed, the top of the Arcadia Formation is known to be an erosional unconformity with significant paleotopographic variation. For example, "A distinct regional unconformity and subaerial exposure surface at the top of the Arcadia Formation separates the Long Key and Arcadia Formations" (Reference 393). A cross section presented by Reference 393 depicts 90 meters (295 feet) of relief on the top of the Arcadia Formation surface in southern Florida, while the thickness of the Arcadia Formation varies from 200 meters (656 feet) in the central portion of the Florida peninsula to between 0 and 20 meters (0 and 66 feet) farther east (Reference 394). A study in southern Florida determined that intensification of marine currents increased the erosion of marine carbonates and led to a significant time hiatus (more than 4 m.y.) following deposition of the Arcadia Formation (Reference 934) and the influence of Arcadia Formation paleotopography on highs in subsequent carbonate and clastic deposition in southernmost Florida has been recognized (Reference 395). PTN RAI 02.05.01-12

On Key Largo, relief on the top of the Arcadia Formation as large as 40 meters (131 feet) was found between borings only a few kilometers apart (Reference 393). Furthermore, in other cross sections presented by Reference 273, the elevation of the top of the Arcadia Formation varies by approximately 100 meters (328 feet) between wells W-3174 and W-17086 (88 kilometers or 55 miles apart), by 50 meters (164 feet) between wells W-17156 and W-12554 (56 kilometers or 35 miles apart), and by 25 meters (82 feet) or 1.2 miles between wells W-3011 and W-17157 (2 kilometers apart), all interpreted without faulting. The slope required to achieve this latter elevation variation, 0.7 degree, is actually greater than the slope required to achieve the elevation variation observed in the Arcadia Formation between the Everglades Park and Gulf Oil wells, where the queried fault is depicted in Figure 2.5.1-234 (approximately 100 meters [328 feet] over 18 kilometers [11 miles] of distance, or a 0.3-degree slope). Numerous other examples exist throughout southern Florida of steeper paleotopographic slopes on the top of the Arcadia Formation that are not associated with faulting. In addition, the down-to-the-south separation depicted on the postulated fault in Figure 2.5.1-234 is consistent with, and may, in part, be attributed to the regional southward dip of the strata towards the South Florida Basin in the area (References 377 and 389). LDP-CS564

The karst-influenced paleotopography of the Arcadia Formation is detailed in Reference 936. While using borings at a much finer spacing than Cunningham study, the Hine study documents karst sub-basins with as much as 100 meters (328 feet) of relief over distances of kilometers to tens of kilometers on the top of the Arcadia Formation in west-central Florida. They attribute this relief to a mid- to late-Miocene sea level lowstand that caused dissolution in the deeper carbonates, such as the Arcadia Formation, and formed paleotopographic depressions and non-tectonic deformation in the Arcadia Formation (Reference 936). PTN RAI 02.05.01-12

Alternative interpretations of well data in southern Florida, often including the three wells closest to the postulated fault, provide evidence for unfaulted Eocene to Pliocene stratigraphy in the same location (References 389, 393, 934, 935). LDP-CS564 For example, Reference 934 provides a stratigraphic correlation diagram across the projection of the queried fault from Cunningham et al. (Reference 373) and interprets no faulting. This diagram also displays similar relief between boreholes on the top of the Arcadia to the north. Likewise, the regional north-south-oriented cross section shown in Figure 2.5.1-233 intersects the projection of the queried fault and does not indicate faulting in the area.

As shown in Figure 2.5.1-381, there are three wells adjacent to the queried structure: Gulf Oil W-3510 south of the postulated fault and W-1115 and W-2404 north of it. The Gulf Oil well W-3510 appears to control the set of structure contours used to delineate the area of faulting (Figures 2.5.1-234 and 2.5.1-381). Yet, other published contour maps of the same well data use dashed contours and question marks to indicate uncertainty in contouring such sparse data in the Florida Bay area (Reference 393). A later publication (Reference 935) also provides interpretations of unfaulted Miocene to Pliocene stratigraphy in the same location as the postulated fault from Reference 273.

In summary, numerous other sources using similar well data indicate unfaulted strata that gently dips to the south in this location, reflecting the influence of the South Florida Basin (References 389, 393, 396, and 827). The fault postulated by LDP-CS564 Reference 273 has not been documented in any subsequent investigations and numerous examples of paleotopographic variation in the top of the Arcadia support a non-fault-related origin for the stratigraphic variations seen in Figure 2.5.1-234.

Seismicity of the Florida Peninsula and Platform

{The Phase 1 earthquake catalog (Subsection 2.5.2.1) indicates sparse seismicity SOF 2.5.1-1 in the Florida Peninsula tectonic province (Figures 2.5.3-203 and 2.5.1-267). There are only a few widely distributed events within this province, the largest being an Emb 4.3 earthquake that occurred in 1879, located 479 kilometers (298 miles) from the site. The Emb (best estimate body-wave magnitude) is described in Subsection 2.5.2.1. The nearest event, located 53 kilometers (33 miles) from the site, occurred on December 22, 1945, and had an Emb magnitude of 2.7. The overall seismicity pattern and the above-mentioned events show no correlation with geologic or tectonic features (Subsection 2.5.2.3).}

2.5.1.1.1.3.2.2 Bahama Platform Tectonic and Structural Features

Structures of the Bahama Platform

The Bahama Platform, like the Florida Platform, is best characterized by continuous, horizontal carbonate deposition, rarely interrupted by faulting or other deformation (Figure 2.5.1-245). Because the platform is largely submerged, all information about potential structures is gained from interpretations of seismic lines, and therefore is subject to limitations. The vast majority of seismic lines inspected and available to this study confirm the unfaulted nature of Cretaceous and younger strata across the Bahama Platform and southern Florida Platform (Figures 2.5.1-263, 2.5.1-268, 2.5.1-269, 2.5.1-270, 2.5.1-271, and 2.5.1-272). However, a few exceptions to this exist, such as the deformation associated with the Santaren anticline (Figure 2.5.1-278) normal faults in the Straits of Florida (Figure 2.5.1-273), the Walkers Cay fault (Figure 2.5.1-275), and the eastern Bahama Platform (right panel of Figure 2.5.1-264). PTN RAI 02.05.01-13

Mesozoic Normal Faults of the Bahama Platform

As described above, the openings of the Gulf of Mexico and Atlantic Ocean led to the development of Mesozoic normal faults that extended the basement beneath the Florida and Bahama Platforms. No detailed maps of the entire subsurface Bahama Platform exist, but limited mapping of such faults has been done in conjunction with large-scale seismic surveys. For example, a seismic line in the Straits of Florida identified several minor normal faults cutting strata above a mid-Cretaceous shallow-water carbonate platform at a depth of 940 meters (3084 feet) below the seafloor (Figure 2.5.1-274). More commonly, the basement of the Bahama Platform is depicted as a series of fault blocks with syntectonic Triassic to Jurassic strata, draped by undeformed Lower and/or Upper Cretaceous strata. In the eastern Bahama Platform, Sheridan et al. (Reference 307) interpret normal faults cutting Lower Cretaceous strata that are draped by unfaulted Upper Cretaceous (Santonian or Cenomanian) strata (right panel of Figure 2.5.1-264). On Figure 2.5.1-263, a north-south seismic line located east of the site indicates normal faulted basement of Paleozoic to Jurassic strata draped by unfaulted Upper Jurassic to Lower Cretaceous strata. Similarly, the seismic line

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interpretation on Figure 2.5.1-243 indicates faulted basement covered by undeformed Upper Jurassic and younger strata. On Figures 2.5.1-268 and 2.5.1-269, flat unfaulted Lower Cretaceous and younger strata cover the Bahama Platform.

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Walkers Cay Fault

The Walkers Cay fault was initially identified by Mullins and Van Buren (Reference 474) north of Little Bahama Bank based on seismic reflection data. As later mapped by Van Buren and Mullins (Reference 791), the fault is a 33-kilometer-long (21-mile-long) structure that strikes north-northeast (Figures 2.5.1-275 and 2.5.1-366). In contrast, Austin et al. (Reference 785) depict a broad zone of faulting by mapping the northwest and southeast boundaries of the zone, but do not map the extent of any individual strands in the zone. These boundaries of the Walkers Cay fault zone are defined as having a more easterly strike than the fault of Van Buren and Mullins (Reference 791) and a similar length (Figure 2.5.1-366). The spatial coincidence of the faulting expressed in Oligocene- to Cretaceous-age strata with a magnetic anomaly has been used to interpret the Walkers Cay fault as a basement-involved structure (References 307 and 474).

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In the vicinity of the Walkers Cay fault, five seismic reflection lines with variable levels of interpretation have been reproduced in the published literature. Mullins and Van Buren (Reference 474) and Van Buren and Mullins (Reference 791) present two air gun seismic reflection profiles (Profile 4 and Profile E) in their reports about this structure (Figure 2.5.1-366). Shortly thereafter, the Ocean Drilling Program (ODP) Leg 101 conducted another seismic survey of the north slope of Little Bahama Bank and these data are discussed in several publications (References 476, 785, 937, 938, and 940). Three published seismic lines from that work (Lines LBB-13, LBB-17 and LBB-18) depict the Walkers Cay fault or a splay of the fault (Figure 2.5.1-366). In at least one of those lines (Line LBB-18), the authors interpret a normal fault "believed to be the Walkers Cay normal fault" as extending up to the seafloor, suggesting possible Quaternary activity (Reference 785) (Figure 2.5.1-367). Normal faulting is reportedly visible on lines LBB-5, LBB-6, and LBB-15 (Reference 476), but these seismic lines have not been reproduced in any of the publications from ODP Leg 101.

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Borehole data in the vicinity of these seismic profiles indicate that the Quaternary section is limited to a thin veneer. At ODP sites 627, 628, and 630, analysis of cores found that planktonic foraminifers associated with Pleistocene sediments are limited to approximately the uppermost 15.5 meters (50.9 feet), 3.6 meters

(11.8 feet), and 18.2 meters (59.7 feet), respectively (Figure 2.5.1-366) (References 937, 938, 939). There is no indication of abrupt thinning or thickening of layers in the seismic profiles that would suggest these observations are spatial anomalies. Furthermore, these thicknesses are in agreement with regional mapping (Reference 941) that indicates Neogene (Pliocene or Miocene) strata are within 20 meters (66 feet) of the seafloor in this area. Thus, to determine if the Walkers Cay fault is a Quaternary structure, seismic data would need to resolve displacement within approximately the uppermost 20 meters (66 feet) of seafloor sediments. PTN RAI 02.05.01-14

In summary, on only one of the five interpreted seismic lines that cross the Walkers Cay fault (LBB-18) do the authors interpret a fault reaching the seafloor (Figure 2.5.1-367) (Reference 785). This is consistent with the summary of seismic lines collected in ODP Leg 101 that states that "throughout the area it [the Walkers Cay fault] has only a minimal effect on sediments younger than middle Miocene" (Reference 476). The possibility of Quaternary slip on the Walkers Cay fault cannot be precluded by the available data. For this reason, a hazard sensitivity calculation for a Walkers Cay fault source is presented in Subsection 2.5.2.4.4.3.4.

Jacksonville Fracture Zone

Several steep, buried normal faults located outside of the site region northeast of the Bahama Platform are known as the Jacksonville Fracture Zone (also known as the Great Abaco Fracture Zone) (References 424 and 307) (Figures 2.5.1-208 and 2.5.1-253). The faults cut Cretaceous strata and are covered by flat and unfaulted lower Miocene units (Reference 307). Because strata from Upper Cretaceous to Oligocene are missing, it is impossible to know where within this interval the faulting occurred (Figure 2.5.1-208). Sheridan et al. (Reference 307) speculates that the shape of the northern margin of the Little Bahama Bank is controlled by post-Cretaceous faulting on the Jacksonville Fracture Zone. Because lower Miocene and younger strata are unfaulted by these faults (Figure 2.5.1-208), these faults do not represent a capable tectonic source.

Santaren Anticline

The northwest-trending detachment fold primarily affects Cretaceous to Miocene strata and represents the northern limit of the Cuban fold-thrust belt (Reference 501, Figures 2.5.1-229 and 2.5.1-350). Initial work indicated that folding initiated in the Late Cretaceous, reached maximum expression in the early Cenozoic, and experienced differential compaction in the late Cenozoic PTN RAI 02.05.01-15 PTN RAI 02.05.01-15

(Reference 501), a timeline consistent with the end of Cuban orogeny in the latest Eocene.

Detailed analysis of the stratigraphy indicates that the syntectonic growth strata are Eocene and younger and was used to infer Pliocene or potential early Quaternary activity on the structure (References 426 and 479, Figure 2.5.1-278). References 426 and 479 use the geometries and inferred ages of growth strata associated with the Santaren anticline to respectively model the shortening rate and the temporal variability in sedimentation and fold-growth rates since Late Oligocene time. The authors conclude that the geometry of Santaren anticline growth strata results from the interplay between sedimentation and tectonic fold uplift and that sedimentation and fold-growth rates have been highly variable over time, though sedimentary processes, such as localized bottom-current erosion and sediment compaction (Reference 501), could be responsible for the stratigraphic variations. PTN RAI 02.05.01-15 LDP-CS564

Reference 479 interprets the variation as indicating that the "evolution of the Santaren anticline consists of cycles that involved tectonically active periods separated by interruptions in which the tectonic activity fell to zero" (Reference 479). Furthermore, their analysis suggests that the preponderance of tectonic growth of the Santaren anticline occurred before 20 Ma (i.e., before bed E in Figure 2.5.1-278). Since that time, the average fold uplift rate is approximately 0.03 millimeter per year, corresponding to a shortening rate of 0.001 millimeter per year (Reference 426). Reference 479 concludes that, for the time period 6.2 Ma to present, "there were many lapses in this [time period] during which no tectonic uplift occurred" (Reference 479) and that the greatest fold uplift rate since approximately 6.2 Ma occurred during or just before deposition of beds K2 and K3, which are assigned Late Miocene age. Since deposition of beds K2 and K3, Santaren anticline fold uplift rates have been at or near zero (Figure 2.5.1-278). The youngest interval for which a non-zero uplift rate was calculated was the early Quaternary M2–M3 interval, which has a 0.05 millimeter-per-year (0.002-inch-per-year) fold uplift rate (Reference 479, Figure 2.5.1-278). However, it should be noted that the calculation of fold uplift, based on differences in crestal relief, incorporates measurements, calculations, and assumptions that are assigned an error of 10 percent (Reference 426). The calculated crestal relief between beds M2 and M3 is less than 24 meters (79 feet), and this reflects the difference between two values that each may vary by ±130 meters (427 feet) (References 426 and 479). The preponderance of data indicate that this structure was predominantly active in the Eocene, with waning activity throughout the Miocene, and possible, yet questionable, deformation into the early Quaternary. LDP-CS564