2.5 Geology, Seismology, and Geotechnical Engineering

This section presents information on the geological, seismological, and geotechnical characteristics of the VCSNS Units 2 and 3 site and the region surrounding the site. The data and analyses in this section documents SCE&G's evaluation of the suitability of the site. Section 2.5 provides sufficient information to support evaluations of the site-specific ground motion response spectra and provides information to permit adequate engineering solutions to geologic conditions and seismic effects at the site.

Section 2.5 is divided into five subsections that generally follow the organization of Regulatory Guide 1.206 and one subsection (Subsection 2.5.6) retained to follow the DCD organization:

Subsection 2.5.1	Basic Geologic and Seismic Information
Subsection 2.5.2	Vibratory Ground Motion
Subsection 2.5.3	Surface Faulting
Subsection 2.5.4	Stability of Subsurface Materials and Foundations
Subsection 2.5.5	Stability of Slopes
Subsection 2.5.6	Combined License Information for Embankments and Dams

The VCSNS site is located within the Central Piedmont Province, about 20 miles northwest of the Fall Line that separates the Piedmont and Coastal Plain physiographic provinces. The site topography consists of gently to moderately rolling hills and generally well-drained mature valleys. Most of the local terrain is mantled by residual soils and saprolite overlying the Winnsboro granitic plutonic complex that intruded the metamorphic country rock consisting of deformed gneiss and amphibolite.

The geological and seismological information presented in this section was developed from a review of previous reports prepared for Unit 1, published geologic literature, interviews with experts in the geology and seismotectonics of the site region, aerial photo analysis, and geologic field work performed for Units 2 and 3 (including new boreholes drilled at the site of Units 2 and 3, and geologic field reconnaissance). A review of published geologic literature supplements and updates the existing geological and seismological information. A list of the references used to compile the geological and seismological information presented in the following subsections is provided.

The review of regional and site geologic, seismic, and geophysical information and an evaluation of the updated earthquake catalog confirmed the use of appropriate EPRI seismic sources in the Probabilistic Seismic Hazard Analysis (PSHA) as well as the need to include updated Charleston and New Madrid seismic source zones to reflect current information on the source geometries, maximum earthquake magnitudes, and recurrence parameters. Borings at the site provided the geologic and geotechnical data to characterize the soil, underlying rock, and shear wave velocities. The field investigation program was supplemented by a laboratory testing program to characterize material properties of both the soil and rock. Boring and shear wave velocity survey data indicate that the seismic Category I structures in the nuclear island will be founded on hard rock.

Bechtel Power Corporation, supported by William Lettis & Associates, Inc. and Risk Engineering, Inc., conducted an assessment of ground motion at the Units 2 and 3 site using the guidance provided in Regulatory Guide 1.208. The starting point for this site assessment is the Electric Power Research Institute - Seismicity Owners Group PSHA evaluation (EPRI NP-6395-D 1989). Regulatory Guide 1.208 incorporates developments in ground motion estimation models; updated models for

earthquake sources; methods for determining site response; and new methods for defining a site-specific, performance-based earthquake ground motion that satisfy the requirements of 10 CFR 100.23 and led to the establishment of the safe shutdown earthquake ground motion. The purpose of Subsection 2.5.2 is to develop the site-specific ground motion response spectrum characterized by horizontal and vertical response spectra determined as free-field motions on hard rock using performance-based procedures. The ground motion response spectrum represents the first step in development of a safe shutdown earthquake for a site as a characterization of the regional and local seismic hazard under Regulatory Position 5.4 of Regulatory Guide 1.208. In the case of the Units 2 and 3 site, the ground motion response spectrum will be used to supplement the certified seismic design response spectra for the Westinghouse AP1000 DCD. The certified seismic design response spectra will be the safe shutdown earthquake for the site for lower frequency ground motions and the site-specific ground motion response spectrum will be the safe shutdown earthquake for higher frequency ground motions. The safe shutdown earthquake defined in this way will comprise the vibratory ground motion for which certain structures, systems, and components are qualified.

Subsection 2.5.1.1 describes the geologic and tectonic setting of the site region (200 miles), and Subsection 2.5.1.2 describes the geology and structural geology of the site vicinity (25 miles), site area (5 miles), and site (0.6 mile). The geological and seismological information was developed in accordance with the guidance presented in NRC Regulatory Guide 1.206, Section 2.5.1, *Basic Geologic and Seismic Information*, and Regulatory Guide 1.208, and is intended to satisfy the requirements of 10 CFR 100.23(c). The geological and seismological information presented in this subsection is used as a basis for evaluating the detailed geologic, seismic, and man-made hazards at the site.

Subsection 2.5.2 describes the methodology used to develop the ground motion response spectrum for the VCSNS site. Regulatory Guide 1.208 further requires that the geological, seismological, and geophysical database is updated and any new data is evaluated to determine whether revisions to the 1986 EPRI seismic source model are required (presented in Subsection 2.5.2). This subsection, therefore, provides an update of the geological, seismological, and geophysical database for the Units 2 and 3 site, focusing on whether any data published since 1986 indicates a significant change to the 1986 EPRI seismic source model.

Subsection 2.5.3 documents an evaluation of the potential for tectonic and non-tectonic surface deformation at the Units 2 and 3 site. The data, developed as a result of literature and data reviews, interpretations of aerial and satellite imagery, field and aerial reconnaissance, and discussions with current researchers and an analysis of seismicity with respect to geologic structures, indicates that there are no Quaternary faults or capable tectonic sources within 25 miles of the site.

Subsection 2.5.4 describes the site subsurface investigation consisted of 111 soil and rock borings, 36 cone penetrometer tests, 4 test pits, and geophysical logging including P-S suspension logging. Laboratory testing of soil and rock samples provided data on geotechnical/geoengineering parameters. The seismic Category I nuclear island will be founded on rock or on concrete placed on rock. The seismic Category II portions of the annex building and turbine building will be founded on structural fill placed on rock. Any liquefaction of the saprolitic sand, were it to occur, will not impact the stability of any Units 2 and 3 seismic Category I and II structures since the zone of loading influence of these structures does not reach the saprolitic sands. RN-12-029

As discussed in Subsection 2.5.5, the permanent perimeter slopes are at least 600 feet away from the nearest point on the nuclear islands, and at least 500 feet away from the nearest point on the seismic Category II portions of the annex building and turbine building. Thus, failure of these slopes, under any of the conditions to which they could be exposed during the life of the plant, will not adversely affect the safety of the nuclear power plant facilities. There will be no significant impact of seepage through the slopes or erosion of the slopes. The temporary slopes and retaining walls that RN-12-029 RN-12-029

will be installed for plant construction will not adversely affect the safety of the nuclear power plant facilities.

Subsection 2.5.6 is retained from the DCD for completeness. This subsection explains that there are no dams or embankments required to protect the site.

2.5.1 Basic Geologic and Seismic Information

This subsection presents information on the geological and seismological characteristics of the VCSNS site region and site area. The information is divided into two parts. Subsection 2.5.1.1 describes the geologic and tectonic setting of the site region (200 miles), and Subsection 2.5.1.2 describes the geology and structural geology of the site vicinity (25 miles), site area (5 miles), and site (0.6 miles). The geological and seismological information was developed using the guidance presented in NRC Regulatory Guide 1.206, Combined License Applications for Nuclear Power Plants (LWR Edition), Section C.III.1.2.5.1, Basic Geologic and Seismic Information, and Regulatory Guide 1.208, A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion, and is intended to satisfy the requirements of 10 CFR 100.23(c). The geological and seismological information presented in this subsection is used as a basis for evaluating the detailed geologic, seismic, and man-made hazards at the site.

The geological and seismological information presented in this subsection was developed from a review of previous reports prepared for Unit 1, published geologic literature, interviews with experts in the geology and seismotectonics of the site region, and geologic field work performed for Units 2 and 3 (including new boreholes drilled at the site of Units 2 and 3, and geologic field reconnaissance). A review of published geologic literature supplements and updates the existing geological and seismological information. A list of the references used to compile the geological and seismological information presented in the following sections is provided at the end of each major subsection within Section 2.5.

2.5.1.1 Regional Geology

This section describes the regional geology within 200 miles of the VCSNS site. The regional physiography, tectonic setting, geomorphology, and stratigraphy are discussed below. The information provided is a brief summary of the region, with an extensive and current bibliography. This regional information provides the basis for evaluating the geologic and seismologic hazards discussed in the succeeding sections.

2.5.1.1.1 Regional Physiography, Geomorphology, and Stratigraphy

The VCSNS site is located in the Central Piedmont province, about 20 miles (32 kilometers) northwest of the Fall Line that separates the Piedmont and Coastal Plain provinces (Figure 2.5.1-201). From northwest to southeast, the VCSNS site region includes portions of five physiographic provinces: the Appalachian Plateau (the “Cumberland Plateau” at the latitude of the site region), Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain.

Each of these five physiographic provinces is described below, from northwest to southeast, in terms of their physiography, geomorphology, and stratigraphy. A more detailed discussion is provided for the Piedmont physiographic province in which the VCSNS site is located. Although they do not technically constitute a physiographic province, Mesozoic rift basins are also discussed in this subsection since they contain a distinct assemblage of non-metamorphosed sedimentary rocks and are distributed across both the Piedmont and Coastal Plain provinces.

Depending on the focus of a given study, the Appalachian orogenic belt is subdivided in a variety of ways by various researchers. These subdivisions, in the past, included provinces, belts, and

terranes. More recent syntheses are organized around lithotectonic associations based on common tectonic or depositional origins, mainly relative to the Iapetus Ocean and its marginal continental masses, Laurentia and Gondwana (Hibbard et al. 2002) (Reference 283); (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). Physiographic provinces are defined based on both physiography (landforms) and geology (Figure 2.5.1-201). However, with the modern emphasis on lithotectonic association, the influence of physiography has become subordinate and the "belt" concept has been abandoned.

Figure 2.5.1-232 diagrams how the modern lithotectonic classification schemes of Hibbard et al. 2006 (Reference 284; Figure 2.5.1-202) and Hibbard et al. 2007 (Reference 427) relate and compare to Hatcher et al. 2007 (Reference 423) and to the nomenclature for the physiographic provinces. Note for instance that the Tugaloo Terrane (Hatcher et al. 2007) (Reference 423) falls on both sides of the Brevard fault zone, which roughly coincides with the boundary of the Blue Ridge and Piedmont physiographic provinces. Similarly, this same fundamental physiographic boundary also transects the Hibbard et al. 2006 (Reference 284) Piedmont Domain. Also, note that the Piedmont physiographic province, in the scheme of Hibbard et al. 2006 (Reference 284), is divided by the Central Piedmont shear zone into the Piedmont Domain to the west and Carolinia (previously termed the “Carolina Zone” in Hibbard et al. 2002 (Reference 283)) to the east. These examples serve to illustrate the decreased role of physiography in modern lithotectonic classifications.

2.5.1.1.1.1 The Appalachian Plateau Physiographic Province

The Appalachian Plateau physiographic province includes the western part of the Appalachian Mountains, stretching from New York to Alabama. The Appalachian Plateau is bounded on the west by the Interior Low Plateaus and on the east by the Valley and Ridge Province. The Appalachian Plateau surface slopes gently to the northwest and merges imperceptibly into the Interior Low Plateaus. Only a small sliver of this province lies within 200 miles of the VCSNS site (Figure 2.5.1-201).

The Appalachian Plateau physiographic province is underlain by unmetamorphosed sedimentary rocks of Permian to Cambrian age. These strata are generally subhorizontal to gently folded and exhibit relatively little deformation.

2.5.1.1.1.2 The Valley and Ridge Physiographic Province

The Valley and Ridge physiographic province extends from the 25-mile-wide Hudson Valley in New York State to a 75-mile-wide zone in Pennsylvania, Maryland, and Virginia and is about 50 miles wide from southern Virginia southward to Alabama. The Valley and Ridge province is bounded on the west by the Appalachian Plateau and on the east by the Blue Ridge. The northwestern boundary of the Valley and Ridge Province is marked by a topographic escarpment known as the Allegheny front in Pennsylvania and the Cumberland escarpment in Tennessee and Virginia. This physiographic province is underlain by a folded and faulted sequence of Paleozoic sedimentary rocks. The characteristic linear valleys and ridges of this province are the result of differential weathering and erosion of different rock types.

The eastern boundary of the Valley and Ridge province marks a change from folded, lesser-deformed Paleozoic sedimentary rocks to more penetratively deformed Precambrian rocks in the Blue Ridge.

2.5.1.1.1.3 The Blue Ridge Physiographic Province

The Blue Ridge physiographic province is located west of and adjacent to the Piedmont province. The Blue Ridge province extends from Pennsylvania to northern Georgia and varies from about 30 to 75 miles wide. Elevations are highest in North Carolina and Georgia, with several peaks in North

Carolina exceeding 5,900 feet above MSL, including Mount Mitchell, North Carolina, the highest point (6,684 feet MSL) in the Appalachian Mountains. The east-facing Blue Ridge escarpment is about 300 miles in length and averages 1,000 to 1,650 feet in elevation. The Blue Ridge escarpment separates the highlands of the Blue Ridge from the lower relief Piedmont province in the southern Appalachians (Reference 377).

The Blue Ridge province is bounded on the northwest by the Valley and Ridge physiographic province and to the southeast by the Piedmont physiographic province delineated by the Brevard fault zone (References 273 and 304) (Figure 2.5.1-202, Sheet 2 of 2). The province is a metamorphosed basement/cover sequence that has been complexly folded, faulted, penetratively deformed, and intruded. These rocks record multiple late Proterozoic to late Paleozoic deformation events (extension and compression) associated with the formation of the Iapetus Ocean and the Appalachian orogen (References 273, 286, 333, and 272). The Blue Ridge province consists of a series of westward-vergent thrust sheets, each with different tectonic histories and lithologies, including gneisses, plutons, and metavolcanic and metasedimentary rift sequences, as well as continental and platform deposits (see References 273 and 279 for expanded bibliographies). The Blue Ridge–Piedmont fault system thrust the entire Blue Ridge province northwest over Paleozoic sedimentary rock of the Valley and Ridge province during the Alleghanian orogeny (Reference 270, 271, 228, and 230). The Blue Ridge province reaches its greatest width in the southern Appalachians.

The Blue Ridge is divided into western and eastern portions. The western Blue Ridge consists of an assemblage of Middle Proterozoic crystalline continental (Grenville) basement rock nonconformably overlain by Late Proterozoic to Early Paleozoic rift-facies sedimentary rock (Reference 279). The basement consists of various types of gneisses, amphibolite, gabbroic and volcanic rock, and metasedimentary rock. All Grenville basement rock is metamorphosed to granulite or uppermost amphibolite facies (Reference 279). The calculated radiometric ages of these rocks generally range from 1,000 to 1,200 Ma (*e.g.,* References 259, 257, and 258). The rifting event during the Late Proterozoic through Early Paleozoic that formed the Iapetus Ocean is recorded in the terrigenous, clastic, rift-drift sedimentary sequence of the Ocoee Supergroup and Chillhowie Group (*e.g.,* References 401, 351, 309, 334, and 305). These rocks, along with the basement and sedimentary cover, were later affected by Taconic and possibly Acadian deformation and metamorphism. The entire composite thrust sheet was transported west as an intact package during the Alleghanian collision event on the Blue Ridge-Piedmont thrust.

The eastern Blue Ridge is separated from the Inner Piedmont by the Brevard fault zone (Figure 2.5.1-202, Sheet 2 of 2). The eastern Blue Ridge is composed of metasedimentary rocks originally deposited on a continental slope and rise and ocean floor metasedimentary rocks in association with oceanic or transitional to oceanic crust (References 279 and 287 present expanded bibliographies). This is in contrast to the western Blue Ridge that contains metasedimentary rocks suggesting continental rift-drift facies of a paleomargin setting. The eastern Blue Ridge is structurally complex, with several major thrust faults, multiple fold generations, and two high-grade metamorphic episodes (Reference 279). Metamorphism occurred during the Taconic and possibly Acadian orogenies. The stratigraphy within the eastern Blue Ridge includes rare Grenville (Precambrian) gneisses, metasedimentary rocks, metamorphosed Paleozoic granitoids, and mafic and ultramafic complexes and rocks (Figures 2.5.1-203 and 2.5.1-204). The Paleozoic granitoids are a part of a suite of similar granites found in the western Inner Piedmont, suggesting a common intrusive history. Metasedimentary rock sequences in the eastern Blue Ridge are correlative along strike and across some thrust fault boundaries, suggesting a commonality in the original depositional history. Based on geochemical data, the mafic and ultramafic complexes found in particular thrust sheets in the eastern Blue Ridge have oceanic as well as continental affinities. However, their exact tectonic origin is not clear because the contacts with the host metasedimentary rock are obscured.

2.5.1.1.1.4 The Piedmont Physiographic Province

The VCSNS site is located in the Piedmont physiographic province. The Piedmont physiographic province extends southwest from New York to Alabama and lies west of and adjacent to the Atlantic Coastal Plain. It is the easternmost physiographic province of the Appalachian Mountains. The Piedmont is a seaward-sloping plateau varying in width from about 10 miles (16 kilometers) in southeastern New York to almost 125 miles (200 kilometers) in South Carolina and is the least rugged of the Appalachian provinces. Elevation of the inland boundary ranges from about 200 feet (60 meters) MSL in New Jersey to over 1,800 feet (550 meters) MSL in South Carolina.

Within the VCSNS site region, the area of the Piedmont physiographic province is also divided on the basis of its geologic history and lithology into different lithotectonic associations that include:

The Piedmont Zone, also referred to as the Piedmont Domain in more recent publications (Hibbard et al. 2006) (Reference 284), comprises the Inner Piedmont and the terranes that make up the Eastern Blue Ridge. The terranes that compose the Piedmont Zone generally are considered to represent depositional and tectonic environments closely associated with Iapetus and its margins (Figure 2.5.1-202). The terranes of the Eastern Blue Ridge possibly represent a distal Laurentian accretionary wedge subducted beneath Taconic volcanic arcs during the Middle Ordovician. However, the terranes of the Inner Piedmont show both Laurentian and peri-Gondwanan associations (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). The term "peri-Gondwanan" is used to refer to terranes that formed the periphery of Gondwana itself or that broke away from the main Gondwanan supercontinent.

The Carolina Zone is referred to in more recent literature as “Carolinia” (Hibbard et al. 2007) (Reference 427) or "Carolina Superterrane" (Hatcher et al. 2007) (Reference 423). The terranes that compose the Carolina Zone are considered to be of peri-Gondwanan association and represent volcanic arcs resulting from subduction in the Gondwanan Realm of Iapetus (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423).

These two lithotectonic elements, the Piedmont Zone and the Carolina Zone, are separated by a series of faults collectively called the Central Piedmont shear zone. West of the Central Piedmont shear zone, the Piedmont Zone contains the Inner Piedmont block, the Smith River Allochthon in Virginia and North Carolina, and the Sauratown Mountains anticlinorium of north central North Carolina (Reference 290) (Figure 2.5.1-202). The province is a composite stack of thrust sheets containing a variety of gneisses, schists, amphibolites, sparse ultramafic bodies, and intrusive granitoids (References 333 and 262). The protoliths are immature quartzo-feldspathic sandstone, pelitic sediments, and mafic lavas.

The Inner Piedmont block is a fault-bounded, composite thrust sheet with metamorphic complexes of different tectonic affinities (Reference 290). Rocks within the Inner Piedmont block include gneisses, schists, amphibolites, sparse ultramafic bodies, and intrusive granitoids (References 333 and 262). There is some continental basement within the block (Reference 262) and scattered mafic and ultramafic bodies and complexes (Reference 330), suggesting the presence of oceanic crustal material (Reference 290). The rest of the block contains a coherent sequence of metasedimentary rock, metavolcanic gneisses, and schists (Reference 290).

The Smith River Allochthon is a completely fault-bounded terrane that contains two predominantly metasedimentary units and a suite of plutonic rocks (Figure 2.5.1-202). The Sauratown Mountains anticlinorium is a complex structural window of four stacked thrust sheets that has been exposed in eroded structural domes (Figure 2.5.1-202). Each sheet contains Precambrian basement with an overlying sequence of younger Precambrian to Cambrian metasedimentary and metaigneous rocks (Reference 290).

The stratigraphic and structural geologic data in the Western Piedmont reflect a complex tectonic history from the Precambrian Grenville through Late Paleozoic Alleghanian orogenies. Metamorphism affected the basement rocks of the Sauratown Mountains anticlinorium at least twice: during the Precambrian Grenville orogeny and later during the Paleozoic. The metasedimentary cover sequence, the Smith River allochthon, and the Inner Piedmont block were affected by one metamorphic event in the Paleozoic (Reference 290). The Alleghanian continental collision is reflected in the thrust and dextral strike-slip fault systems, including the Brevard and Bowens Creek fault zones. A few late Paleozoic granites were emplaced in the Inner Piedmont block; however, most lie further east in the Carolina Zone. Early Mesozoic extension resulted in the formation of rift basins.

The Central Piedmont shear zone (Reference 283) (Figure 2.5.1-202) includes: the Ocmulgee, Middleton-Lowdensville, Cross Anchor, Kings Mountain, Eufola, and Hyco fault zones (Reference 290). Since the Central Piedmont shear zone marks the boundary between rocks on both sides of Iapetus, it is associated with a "suture" (Hatcher et al. 2007) (Reference 423) although the polarity and timing of the suturing event are under debate (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). The detailed relationship of the Central Piedmont shear zone to the original structure associated with the suture is obscured by the fact that the original structure has been tectonically modified and overprinted by the final orogenic effects of the interactions of the Gondwanan and Laurentian continents during the Carboniferous (late Alleghanian orogeny). Hibbard et al. 2002 (Reference 283) and Hibbard et al. 2007 (Reference 427) consider the Central Piedmont shear zone to be a Late Alleghanian thrust that cut the original suture off in the subsurface and that the portion of the hanging wall containing the cut-off suture has been eroded away (Hibbard et al. 1998) (Reference 282). Hatcher et al. 1989 (Reference 428) also consider that the Central Piedmont shear zone has been tectonically modified in the late Alleghanian orogeny, in large part by folding. This allows infolding of rocks with Laurentian affinities and rocks of peri-Gondwanan affinities to explain terranes considered to have mixed associations, including the Kings Mountain Terrane (Hatcher et al. 2007) (Reference 423).

The VCSNS site is located east of the Central Piedmont shear zone in the Carolina Zone (Hibbard et al. 2007) (Reference 427) (Carolina Superterrane of Hatcher et al. 2007 (Reference 423)). The Carolina Zone represents an amalgamation of metaigneous dominated terranes along the eastern flank of the southern Appalachians (Figure 2.5.1-202) (Reference 283). The Carolina terrane of the Carolina Zone extends for more than 300 miles from central Virginia to eastern Georgia and is characterized by generally low-grade metaigneous and associated metasedimentary rocks. The original definition of the Carolina Terrane (Reference 365) included higher-grade metamorphic rocks along its western margin, but the more recent classification of Hibbard et al. (Reference 283) includes these rocks in the Charlotte Terrane to the west. Hibbard et al.'s (Reference 283) more recent classification results in a southeastward shift in the boundary between these two terranes.

The VCSNS site lies within the Charlotte Terrane, the westernmost terrane of the Carolina Zone (Figure 2.5.1-202). The Charlotte terrane is dominated by Neoproterozoic to Early Paleozoic plutonic rocks that intrude a suite of mainly metaigneous rocks (Reference 283). The western limit of the Charlotte Terrane and Carolina Zone is the Central Piedmont shear zone, a late Paleozoic ductile thrust, located approximately 15 miles northwest of the VCSNS site.

The rocks of the Carolina Zone are unconformably overlain by the sediments of the Carolina Coastal Plain southeast of the Fall Line (Figure 2.5.1-202).

The Carolina Zone is part of a late Precambrian-Cambrian composite arc terrane, exotic to North America (References 365 and 357), that accreted either during the late Ordovician to Silurian (Hibbard et al. 2002) (Reference 283) or during the middle Devonian to early Mississippian (Hatcher et al. 2007) (Reference 423). It consists of felsic to mafic metaigneous and metasedimentary rock. Middle Cambrian fossil trilobite assemblages preserved in metasedimentary rocks near Batesburg, South Carolina indicate these rocks constitute an exotic terrane that was accreted to North America

(Reference 365).

Hibbard et al. (Reference 283) propose updated nomenclature for the Carolina Zone ("Carolinia" in Hibbard et al. 2007 (Reference 427)) based on the tectonothermal overprint of units. Suprastructural terranes (i.e., the upper structural layer in an orogenic belt subjected to relatively shallow or near-surface processes) comprise rocks of lower grade metamorphism where original rock fabric is preserved. Infrastructural terranes (produced at relatively deep crustal levels at elevated temperature and pressure, located beneath suprastructural terranes) comprise higher-grade metamorphic units where original rock fabric has been completely destroyed.

The western part of the Carolina Zone in Georgia, South Carolina, and North Carolina consists of the infrastructural Charlotte Terrane and to a lesser extent the Savannah River Terrane. The easternmost portion of the Carolina Zone in South Carolina and portions in North Carolina contain the Suprastructural Albemarle and South Carolina Sequence. Metamorphic grade increases to the northwest from lower greenschist facies to upper amphibolite facies. Rock types include amphibolite, biotite gneiss, hornblende gneiss, and schist that probably were derived from volcanic, volcaniclastic, or sedimentary protoliths. Pre-Alleghanian structure is dominated by large northeast-trending folds with steeply dipping axial surfaces. All country rock of the Charlotte Terrane was penetratively deformed during the Late Proterozoic to Early Cambrian (Hibbard et al. 2002) (Reference 283), thereby producing axial plane cleavage and foliation. The Charlotte Terrane also contains numerous granitic and gabbroic intrusions dating to about 300 Ma.

2.5.1.1.1.5 The Atlantic Coastal Plain Physiographic Province

The Atlantic Coastal Plain physiographic province extends southeastward from the Fall Line to the coastline, and southwestward from Cape Cod, Massachusetts, to south-central Georgia where it merges with the Gulf Coastal Plain (Figure 2.5.1-201). The Atlantic Coastal Plain is a low-lying, gently rolling terrain developed on a wedge-shaped, seaward-dipping section of Cretaceous, Tertiary, and Quaternary age non-metamorphosed, unconsolidated and semi-consolidated sedimentary rocks that thickens toward the coast. At the latitude of the VCSNS site, sediment thickness increases from 0 feet at the Fall Line to more than 2,500 feet at the South Carolina coastline (Reference 376). Topographic relief is generally less than a few hundred feet, and the topographic gradient is usually less than about 5 feet/mile.

2.5.1.1.1.6 Mesozoic Rift Basins

Mesozoic-age rift basins are found along the entire eastern continental margin of North America from Nova Scotia to the Gulf Coast. The basins formed in response to the continental rifting that broke up the supercontinent, Pangaea, and formed the Atlantic Ocean basin. Rift basins are locally exposed in the Piedmont province, generally buried beneath Cretaceous and younger Atlantic Coastal Plain sediments, and some basins are located offshore (Figure 2.5.1-201). Structurally, the basins are grabens or half-grabens generally elongated in a northeast direction and bounded by normal faults on one or both sides (Reference 322). Some basins are localized along reactivated Paleozoic fault zones (References 344, 295, 352, 316, and 261).

The rift basins are located in extended or rifted continental crust. Rifted crust is crust that has been stretched, faulted, and thinned by extensional tectonics, but is still recognizable as continental crust. The western boundary of this zone of extended crust is defined by the western-most edge of Triassic-Jurassic onshore rift basins or the boundaries of the structural blocks in which they occur (References 311 and 302). The eastern boundary of the zone of extended crust is the continental shelf (Reference 264).

The basins are generally filled with sedimentary and igneous rocks. Sedimentary strata consist mainly of non-marine sandstone, conglomerate, siltstone, and shale. Carbonate rocks and coal are

found locally in several basins. Igneous rocks of basaltic composition occur as flows, sills, and stocks within the basins and as extensive dike swarms within and outside the basins (Reference 306). Basin fill strata have been described and named the Newark Supergroup (*e.g.,* References 256 and 343). In general, the basin stratigraphy can be divided into three sections:

- The lowest section is characteristically fluvial (References 373 and 263) and contains reddish-brown, arkosic, coarse-grained sandstone and conglomerate.
- The middle section mainly includes sediments of lacustrine origin (Reference 373). These sediments include gray-black, fossiliferous solid-state, carbonaceous shale, and thin coal beds (Reference 343).
- The uppermost section is a complex of deltaic, fluvial, and lacustrine sediments (References 342 and 360). These sediments include red-brown siltstone, arkosic sandstone, pebble sandstone, red and gray mudstone, and conglomerate (Reference 343).

A number of Mesozoic rift basins are located within the VCSNS site region. These include the Florence, Dunbarton, Riddleville, Jedburg, Deep River, Dan River, and Crowburg basins, as well as a few additional unnamed basins.

2.5.1.1.2 Regional Tectonic Setting

The regional tectonic setting of the VCSNS site is presented below. This subsection includes discussions of regional tectonic stresses, regional gravity and magnetic data, geophysical anomalies and lineations, principal regional tectonic structures, and regional seismicity.

2.5.1.1.2.1 Regional Geologic History

Numerous researchers have mapped the geology of the VCSNS site region. Figure 2.5.1-203 presents geologic mapping by King and Beikman (Reference 307) (as digitized by Schruben et al. Reference 361). A more recent compilation of Appalachian lithotectonic mapping compiled by Hibbard et al. (Reference 284) covers much of the VCSNS site region (Figure 2.5.1-204).

The VCSNS site lies within the southern part of the northeast-southwest-trending Appalachian orogenic belt, which extends nearly the entire length of the eastern United States from Alabama to southern New York State. The Appalachian orogenic belt formed during the Paleozoic Era and records multiple orogenic events related to the opening and closing of the proto-Atlantic along the eastern margin of ancestral North America.

Before the Appalachian orogenies, the continental mass ancestral to North America, Laurentia, was locally deformed and metamorphosed about 1.1 billion years ago in a deformational event called the Grenville orogeny. Portions of Grenvillian crust are exposed as external massifs in crystalline thrust sheets of the Blue Ridge geologic province and also as an internal massif in the Sauratown Mountains window (Reference 291). Beginning about 750 to 700 Ma, continental rifting of Laurentia led to the opening of the Iapetus Ocean, which formed a new eastern margin of ancestral North America.

Subsequent closing of the Iapetus and other proto-Atlantic ocean basins resulted in the accretion of foreign terranes to the eastern margin of Laurentia. These accreted terranes are of different sizes and are fragments of oceanic crust, volcanic island arcs, and other continental masses, each with its own geologic history. This long period of ocean closing and continental accretion during the Paleozoic was punctuated by four episodes of compression (collision) and associated metamorphism and magmatism (Reference 291). These four episodes occurred in the Late Cambrian to Early

Ordovician (Penobscottian orogeny), Ordovician (Taconic orogeny), Devonian (Acadian orogeny), and Pennsylvanian to Permian (Alleghanian orogeny).

The Grenville Front is the leading edge of a northeast-southwest-trending Precambrian collisional orogen that involved rocks of the pre-Appalachian basement of Laurentia (*i.e.,* ancestral North America). The following discussion is summarized from Reference 409. Like the younger Appalachian orogen, the Grenville orogen may have formed in part from exotic terranes that were assembled before 1,160 million years ago (Ma), then deformed and thrust westward over the pre-Grenville Laurentian margin between 1,120 and 980 Ma. The Grenville orogen and Grenville front primarily are exposed in southeastern Canada, and can be traced in outcrops southwest to the latitude of Lake Ontario. Grenville-age rocks and structures continue on trend to the southeast into the United States, but are depositionally and structurally overlain by younger rocks, including terranes of the Appalachian orogen (References 212 and 280). Seismic reflection profiles indicate that the Grenville front and other prominent reflectors generally dip toward the east and extend to lower crustal depths (Reference 409).

The Penobscottian event is the earliest major orogeny recognized in the Appalachian belt and primarily is expressed in the northern Appalachians. Horton et al. (Reference 292) states that evidence for the Penobscottian orogeny has not been observed south of Virginia, where the orogeny is bracketed in age between Late Cambrian metavolcanic rocks and an Early Ordovician pluton.

The earliest Paleozoic deformation along or adjacent to the ancestral North American margin at the latitude of the VCSNS site region occurred in the Middle Ordovician and is known as the Taconian event or orogeny. The onset of the Taconian event is marked regionally throughout much of the Appalachian belt by an unconformity in the passive-margin sequence and deposition of clastic sediments derived from an uplifted source area or areas to the east. Horton et al. (Reference 292) and Hatcher et al. (Reference 279) interpret the Taconic event at the latitude of the VCSNS site region as the result of the collision of one or more terranes with North America. Rocks of the eastern Blue Ridge and Inner Piedmont are interpreted to have originated east of the Laurentian passive margin in Middle Ordovician time, and are thus candidates for Taconic collision(s).

Horton et al. (Reference 292) include the eastern Blue Ridge at the latitude of the site as part of a large body of sandstones, shales, basalt, and ultramafic rocks interpreted as a metamorphosed accretionary wedge that accumulated above a subduction zone. Hatcher et al. (Reference 279) suggest that the Hayesville thrust, which forms the western structural boundary of the eastern Blue Ridge and dips eastward beneath it, may be the “up-dip leading edge of an early Paleozoic subduction zone.” If this interpretation is correct, the Hayesville thrust fault and the Towaliga fault may also be Taconic sutures.

According to Horton et al. (Reference 292), evidence for the middle Paleozoic Acadian orogeny is “neither pervasive nor widespread” south of New England. The Acadian event primarily is expressed at the latitude of the study region by unconformities in foreland stratigraphic succession, plutonism, and activity of several major faults (Reference 279), and possibly ductile folding elsewhere in the southern Appalachians (Reference 292). To date, geologists have not observed compelling evidence for a major accretion event at the latitude of the VCSNS site region during the Acadian orogeny (References 292 and 279).

The final and most significant collisional event in the formation of the Appalachian belt was the late Paleozoic Alleghanian orogeny, during which Gondwana collided with Laurentia, closing the intervening Paleozoic ocean basin. At the latitude of the VCSNS site region, the Alleghanian collision telescoped the previously accreted Taconic terranes and drove them westward up and across the Laurentian basement, folding the passive margin sequence before them and creating the Valley and Ridge fold-and-thrust belt. The collisional process also thrust a fragment from the underlying Laurentian basement eastward over the passive margin sequence, forming the western Blue Ridge.

Significant strike-slip faulting and lateral transport of terranes also are interpreted to have occurred during the Alleghanian orogeny (Reference 279). According to Horton and Zullo (Reference 291), the effects of the Alleghanian orogeny in the Carolinas include:

- Emplacement of numerous granitoid plutons southeast of the Brevard fault zone
- Amphibolite-facies regional metamorphism and deformation in portions of the eastern Piedmont
- Strike-slip and/or oblique-slip movement, along major faults from the Brevard fault zone southeastward to the Eastern Piedmont fault system
- Westward transport of a composite stack of crystalline thrust sheets which now constitutes the Western Piedmont and Blue Ridge
- Imbricate thrusting and folding in the Valley and Ridge province occurred during this orogeny

Despite uncertainties regarding the precise origin, emplacement, and boundaries of belts and terranes, there is good agreement among tectonic models regarding first-order structural features of the southern Appalachian orogenic belt. At the latitude of the VCSNS site region, the ancestral North American basement of the Paleozoic passive margin underlies the Valley and Ridge, Blue Ridge, and Inner Piedmont provinces at depths of less than 6 to 9 miles (10 to 15 kilometers), and possibly as shallow as 3 miles (5 kilometers) or less beneath the Valley and Ridge. A basal decollement or master detachment fault along the top of the North American basement is the root zone for Paleozoic thrust faults in the Valley and Ridge, Blue Ridge, and Inner Piedmont provinces (Figures 2.5.1-207 and 2.5.1-208). Although potential seismogenic sources may be present within the North American basement below the decollement (References 404 and 217), the locations, dimensions, and geometries of these deeper potential sources are not necessarily expressed in the exposed fold-thrust structures above the detachment.

The modern continental margin includes Mesozoic rift basins that record the beginning of extension and continental rifting during the early to middle Mesozoic leading to the formation of the current Atlantic Ocean. During the later stage of rifting (early Jurassic), the focus of extension shifted eastward to the major marginal basins that would become the site of the Atlantic Ocean basin. Eventually, rifting of continental crust ceased as seafloor spreading began in the Atlantic spreading center sometime around 175 Ma (Reference 311). The oldest oceanic crust in contact with the eastern continental margin is late middle Jurassic (Reference 310). At the present time, the eastern Atlantic margin is characterized as a passive margin setting; rifting is no longer acting on the continental crust of the eastern United States.

After continental extension and rifting ended, a prograding shelf-slope formed over the passive continental margin. The offshore Jurassic-Cretaceous clastic-carbonate bank sequence covered by younger Cretaceous and Tertiary marine sediments and onshore Cenozoic sediments represents a prograding shelf-slope and the final evolution to a passive margin (Reference 279). The fluvial-to-marine sedimentary wedge consists of alternating sand and clay with tidal and shelf carbonates common in the downdip Tertiary section.

Wheeler (Reference 404) suggests that many earthquakes in the eastern part of the Piedmont province and beneath the Coastal Plain province may be associated spatially with buried normal faults related to rifting that occurred during the Mesozoic Era. Normal faults in the site region that bound Triassic basins may be listric into the Paleozoic detachment faults (Reference 246) or may penetrate through the crust as high-angle faults. However, no definitive correlation of seismicity with Mesozoic normal faults has been conclusively demonstrated.

2.5.1.1.2.2 Tectonic Stress in the Mid-Continent Region

Earth Science Teams (ESTs) that participated in the EPRI (Reference 250) evaluation of intra-plate stress found that tectonic stress in the central and eastern United States (CEUS) region is primarily characterized by northeast-southwest directed horizontal compression. In general, the ESTs concluded that the most likely source of tectonic stress in the mid-continent region was ridge-push force associated with the Mid-Atlantic ridge, transmitted to the interior of the North American plate by the elastic strength of the lithosphere. Other potential forces acting on the North American plate were judged to be less significant in contributing to the magnitude and orientation of the maximum compressive principal stress. Some of the ESTs noted that the regional northeast-southwest trend of principal stress may vary in places along the east coast of North America and in the New Madrid region. They assessed the quality of stress indicator data and discussed various hypotheses to account for what were interpreted as variations in the regional stress trajectories.

Since 1986, an international effort to collate and evaluate stress indicator data culminated in publication of a new World Stress Map (References 416 and 417). Data for this map are ranked in terms of quality. Plate-scale trends in the orientations of principal stresses are assessed qualitatively based on analysis of high-quality data (Reference 415). Subsequent statistical analyses of stress indicators confirm that the trajectory of the maximum compressive principal stress is uniform across broad continental regions at a high level of statistical confidence. In particular, the northeast-southwest orientation of principal stress in the CEUS inferred by the EPRI ESTs is statistically robust and is consistent with the theoretical trend of compressive forces acting on the North American plate from the mid-Atlantic ridge (Reference 415).

The more recent assessments of lithospheric stress do not support inferences by some EPRI ESTs that the orientation of the principal stress may be locally perturbed in the New England area, along the east coast of the United States, or in the New Madrid region. Zoback and Zoback (Reference 416) summarize a variety of data, including well-bore breakouts, results of hydraulic fracturing studies, and newly calculated focal mechanisms, that indicate that the New England and eastern seaboard regions of the United States are characterized by uniform horizontal northeast-southwest to east-west compression. Similar trends are present in the expanded set of stress indicators for the New Madrid region. Zoback and Zoback (Reference 416) group all of these regions, along with a large area of eastern Canada, with the CEUS in an expanded "mid-plate" stress province characterized by northeast-southwest directed horizontal compression.

In addition to better documenting the orientation of stress, research conducted since 1986 has addressed quantitatively the relative contributions of various forces that may be acting on the North American plate to the total stress within the plate. Richardson and Reding's (Reference 353) numerical modeling of stress in the continental United States interior suggests that the contribution to total tectonic stress is from three classes of forces:

- Horizontal stresses that arise from gravitational body forces acting on lateral variations in lithospheric density. These forces commonly are called buoyancy forces. Richardson and Reding (Reference 353) emphasize that what is commonly called ridge-push force is an example of this class of force. Rather than a line-force that acts outwardly from the axis of a spreading ridge, ridge-push arises from the pressure exerted by positively buoyant, young oceanic lithosphere near the ridge against older, cooler, denser, less buoyant lithosphere in the deeper ocean basins (Reference 389). The force is an integrated effect over oceanic lithosphere ranging in age from about 0 to 100 Ma (Reference 236). The ridge-push force is transmitted as stress to the interior of continents by the elastic strength of the lithosphere.

- Shear and compressive stresses transmitted across major plate boundaries (strike-slip faults and subduction zones).

- Shear tractions acting on the base of the lithosphere from relative flow of the underlying asthenospheric mantle.

Richardson and Reding (Reference 353) conclude that the observed northeast-southwest trend of principal stress in the CEUS dominantly reflects ridge-push forces. They estimate the magnitude of these forces to be about 2 to 3 x 10^{12} N/m (*i.e.,* the total vertically integrated force acting on a column of lithosphere 3.28 feet [1 meter] wide), which corresponds to average equivalent stresses of about 40 to 60 MPa distributed across a 30-mile-thick elastic plate. Richardson and Reding (Reference 353) conclude that the fit of the model stress trajectories to data is improved by adding compressive stress (about 5 to 10 MPa) acting on the San Andreas fault and Caribbean plate boundary structures. The fit of the model stresses to data further indicates that shear stresses acting on these plate boundary structures must also be in the range of 5 to 10 MPa.

Richardson and Reding (Reference 353) note that the general northeast-southwest orientation of principal stress in the CEUS also could be reproduced in numerical models that assume horizontal shear tractions acting on the base of the North American plate. Richardson and Reding (Reference 353) do not favor this as a significant contributor to total stress in the mid-continent region, however, because their model would require an order-of-magnitude increase in the horizontal compressive stress from the eastern seaboard to the Great Plains.

To summarize, analyses of regional tectonic stress in the CEUS since EPRI (Reference 250) do not significantly alter the characterization of the northeast-southwest orientation of the maximum compressive principal stress. The orientation of a planar tectonic structure relative to the principal stress direction determines the magnitude of shear stress resolved onto the structure. Given that the current interpretation of the orientation of principal stress is similar to that adopted in EPRI (Reference 250), a new evaluation of the seismic potential of tectonic features based on a favorable or unfavorable orientation to the stress field would yield similar results. Thus, there is no significant change in the understanding of the static stress in the CEUS since the publication of the EPRI source models in 1986, and there are no significant implications for existing characterizations of potential activity of tectonic structures.

2.5.1.1.2.3 Gravity and Magnetic Data of the Site Region and Site Vicinity

In 1987, the Geological Society of America published regional maps of the gravity and magnetic fields in North America as part of the Society’s Decade of North American Geology (DNAG) project. The maps present the potential field data at 1:5,000,000-scale and are useful for identifying and assessing regional gravity and magnetic anomalies with wavelengths on the order of about 10 kilometers or greater. Maps of the gravity and aeromagnetic fields also have been published for the state of South Carolina (Reference 245); digital data from these maps were used to prepare the gravity and magnetic maps in Figures 2.5.1-205 and 2.5.1-206, respectively. Gravity and magnetic data also were incorporated in the DNAG E-4 and E-5 crustal transects, which traverse the Appalachian orogen to the northeast and southwest of the VCSNS site, respectively. The DNAG E-4 transect extends from central Kentucky to the Carolina trough in the offshore Atlantic basin, directly north of the South Carolina-North Carolina state line (Reference 350). Figure 2.5.1-207 presents geologic and potential field data from the DNAG E-4 transect. The DNAG E-5 transect extends from the Cumberland Plateau to the Blake Plateau, roughly following the Savannah River along much of its length. Figure 2.5.1-208 presents geologic and potential field data from the DNAG E-5 transect.

2.5.1.1.2.3.1 Regional Gravity Data

The 1987 DNAG gravity map, and the gravity profile along the DNAG E-4 crustal transect (Figure 2.5.1-207), document a long-wavelength anomaly east of the Brevard fault zone, which marks the tectonic boundary between the Blue Ridge province to the west and the Piedmont province to the east (Figure 2.5.1-201). Bouguer gravity values increase by about 80 to 120 mGal across an

approximately 200- to 250-kilometer reach of the Piedmont east of the Blue Ridge (Figure 2.5.1-207). As documented by the DNAG gravity map, this gradient is present across the Piedmont physiographic province along much of the length of the Appalachian belt.

Previous researchers refer to this long-wavelength feature in the gravity field as the “Piedmont gradient” or the “Appalachian gravity gradient” (References 269, 237, and 405). For the purposes of the VCSNS FSAR, the term “Appalachian gravity gradient” is adopted for this feature. At the latitude of Virginia, north of the VCSNS site region, Harris et al. (Reference 269) interpret the Appalachian gravity gradient to reflect the eastward thinning of the North American continental crust and associated positive relief on the Moho with proximity to the Atlantic margin. Gravity models by Iverson and Smithson (Reference 296) along the southern Appalachian COCORP seismic reflection profile, and by Dainty and Frazier (Reference 237) in northeastern Georgia, suggest that the gradient probably arises from both eastward thinning of continental crust and the obduction of the Inner Piedmont and Carolina Zone, which have higher average densities than the underlying Precambrian basement of North America.

Superimposed on the long-wavelength Appalachian gravity gradient are numerous high and low-gravity anomalies that have wavelengths of about 10 to 20 kilometers, and which are elliptical to irregular in plan view. These anomalies are especially well expressed in the Carolina Zone (in accordance with Reference 279) between the Central Piedmont shear zone and the Modoc shear zone (Figure 2.5.1-205). Based on comparison of the gravity maps with geologic maps, many of these anomalies are spatially associated with Paleozoic igneous intrusions and plutons. The basement of the Carolina Zone at this latitude is interpreted to be crust of an oceanic island arc terrane or terranes. The composition of this crust generally is intermediate between felsic and mafic (Reference 350). The intrusions and plutons in the Carolina Zone with associated gravity anomalies fall more toward the extremes in felsic and mafic compositional ranges for igneous rocks, which give rise to density contrasts with the country rock they intrude. In general, gravity highs are associated with mafic intrusions and mafic basement rocks, and gravity lows are associated with granitic plutons. Detailed gravity modeling by Cumbest et al. (Reference 233) in the vicinity of the Dunbarton Basin south-southwest of the VCSNS site supports the general association of 10- to 20-kilometer-high and -low anomalies in the Piedmont gravity field with mafic and felsic intrusions, respectively.

A northwest-southeast trending profile of the gravity field that passes through the VCSNS site (Figure 2.5.1-209) highlights the fact that the gravity is about 20 to 25 mGal higher between the Central Piedmont shear zone and the Modoc shear zone than in adjacent regions to the northwest and southeast. This local gravity high probably arises from relatively dense basement of the accreted Carolina Zone bounded by the two faults. Superimposed on this positive anomaly is a 5 to 10 mGal low gravity anomaly located approximately between horizontal distances of 15 and 60 kilometers on the profile. This gravity low is spatially associated with granitic plutons that intrude the intermediate basement of the Carolina Zone, and probably reflects the relatively lower density of the intrusive rocks.

The origin of the high- and low-gravity anomalies beneath the Coastal Plain southeast of the VCSNS site (Figure 2.5.1-209) is uncertain because of the lack of data on basement rock composition. There are several high-gravity anomalies that appear to be associated with Triassic basin structures approximately 100 to 150 kilometers east of the VCSNS site. A possible analogue for interpreting these anomalies is the well-studied Triassic Dunbarton Basin beneath the Savannah River Site south-southwest of the VCSNS site. Figure 2.5.1-205 shows a pronounced gravity high along the southern margin of the Dunbarton Basin. From a synthesis of borehole data and gravity modeling, Cumbest et al. (Reference 233) demonstrate that the extremes in the local gravity field at the Savannah River Site are highs associated with Triassic-Jurassic mafic intrusive complexes southeast of the Dunbarton Basin, and lows associated with granitic plutons mapped to the north-northeast and east-northeast of the basin. Cumbest et al. (Reference 233) show that the predicted anomaly associated with the Mesozoic Dunbarton Basin fill is a subordinate feature of the gravity field

compared to the anomalies associated with the plutons and mafic intrusions. If similar geologic relations apply for the Triassic basins east of the VCSNS site, it is likely that the high-gravity anomalies are associated with Triassic mafic intrusions. Gravity lows associated with the basin fill strata may be obscured by the relatively high amplitude of the anomalies associated with the mafic rocks.

To summarize, gravity data published since the mid-1980s documents that long-wavelength anomalies in the vicinity of the VCSNS site are characteristic of large parts of the Appalachian belt, and reflect first-order features of the various provinces and accreted Paleozoic terranes, as well as west-to-east thinning of the ancestral North American continental crust. The dominant short-wavelength characteristics of the gravity field in the vicinity of the VCSNS site are gravity highs and lows associated with mafic and granitic intrusions, respectively.

In general, there is better spatial correlation in the VCSNS study region among gravity anomalies and igneous intrusions than faults. The exception is the Paleozoic Modoc shear zone, which appears to separate higher density rocks to the northwest from lower density rocks to the southeast. The juxtaposition of basement terranes with varying densities across this fault occurred during the Paleozoic Alleghanian orogeny (Reference 279), and does not reflect Cenozoic activity. The mapped trace of the southern segment of the East Coast Fault System has no expression in the gravity field and cuts across anomalies with wavelengths on the order of tens of kilometers without noticeably perturbing or affecting them. This implies that the southern segment of the East Coast Fault System, if present, has not accumulated sufficient displacement to systematically juxtapose rocks of differing density, and thus produce an observable gravity anomaly at the scale of Figure 2.5.1-205.

2.5.1.1.2.3.2 Regional Magnetic Data

Regional aeromagnetic data from the eastern United States reveal numerous regional northeast-southwest trending magnetic anomalies that are generally parallel to the structural grain of the Paleozoic Appalachian orogenic belt (References 226 and 331) (Figures 2.5.1-206 and 2.5.1-210). In contrast to the gravity data, the magnetic field does not exhibit a long-wavelength anomaly east of the Brevard fault zone. As shown on the magnetic profile for the DNAG E-4 transect (Figure 2.5.1-207), the magnetic field across the Piedmont generally is characterized by high and low anomalies with wavelengths on the order of about 5 to 10 kilometers. Key features of the regional magnetic field (Figure 2.5.1-206) include:

- The Western Piedmont between the Brevard fault zone and Central Piedmont shear zone is characterized by a relatively uniform to smoothly varying magnetic field about a background value of approximately –500 nT (Figures 2.5.1-206 and 2.5.1-207).

- The Carolina Zone east of the Central Piedmont shear zone is characterized by numerous circular, elliptical, and irregular anomalies with plan dimensions on the order of about 5 to 20 kilometers. The change in character between the magnetic field of the Western Piedmont and Carolina Zone is very distinct across the Central Piedmont shear zone. Comparison of the magnetic data to geologic mapping indicates that nearly all of these anomalies are associated with mafic and felsic intrusions, which are generally characterized by relatively higher and lower magnetic susceptibility than the country rock they intrude.

- The Modoc shear zone is clearly associated with elongate, east-northeast trending high and low magnetic anomalies. These magnetic anomalies are characterized by laterally continuous linear segments whose ends sometimes overlap to form parallel linear features. Based on detailed mapping of the Modoc shear zone in the vicinity of Clarks Hill Reservoir (northwest of Augusta on the Georgia-South Carolina border), Maher et al. (1991) (Reference 426) attribute these linear magnetic anomalies to northwest-dipping orthogneiss sheets within the fault zone. Based on seismic reflection profiling, they also indicate these

orthogneiss sheets can be traced in the subsurface 10 kilometers down-dip to the northwest. As such, the orthogneiss sheets that give rise to the anomalous magnetic field associated with the Modoc shear zone represent both dipping structural contacts and interleaved tabular bodies. In this configuration, the surface and near-surface up-dip edges of the orthogneiss sheets would be the main contributor to the short spatial wavelength components of the magnetic response that characterizes the Modoc shear zone.

- The most regionally extensive magnetic anomalies occur beneath the Coastal Plain east of the Modoc shear zone. In general, the magnetic anomalies are relatively high, indicating the presence of rocks with higher magnetic susceptibility at depth, and they are paired with high-gravity anomalies (Figures 2.5.1-205, 2.5.1-206, 2.5.1-207, and 2.5.1-208), indicating that the rocks are also relatively dense. Detailed modeling of magnetic data from the Savannah River Site south-southwest of the VCSNS site indicates that these anomalies may be associated with mafic intrusions (Reference 233). Felsic plutons in this region, which are inferred to exist from borehole data and gravity modeling, have modest susceptibility contrasts with the country rock they intrude and thus do not generate high-amplitude magnetic anomalies (Reference 233). Similarly, Mesozoic basin sediments are inferred to have relatively low susceptibility contrasts with the pre-intrusive basement rock, and modeling by Cumbest et al. (Reference 233) suggests that the anomaly associated with the sediments and margins of the Dunbarton Basin is a second-order feature of the magnetic field relative to the amplitudes of the anomalies produced by the intrusive mafic rocks.

Several of the characteristics of the regional magnetic field are illustrated in a northwest-southeast trending profile that passes through the VCSNS site (Figure 2.5.1-209). The magnetic intensities between horizontal distances 20 and 33 kilometers are relatively low and likely result from the presence of felsic plutons that have lower magnetic susceptibilities than the intermediate country rocks. The high magnetic anomaly approximately between horizontal distances 33 and 46 kilometers is associated with exposures of mafic basement rocks. The high-amplitude, short-wavelength anomalies around horizontal distance 70 kilometers are associated with the Modoc shear zone, and are characteristic of northwest-dipping, interleaved tabular bodies of varying magnetic susceptibility (Reference 426). To summarize, magnetic data published since the mid-1980s provide additional characterization of the magnetic field in the VCSNS site region. The first-order magnetic anomalies are associated primarily with northeast-southwest trending Paleozoic terranes of the Paleozoic Appalachian orogen. Superimposed on this regional magnetic field are anomalies with wavelengths on the order of 5 to 20 kilometers that are associated with intrusive bodies and plutons.

Not all mapped faults in the site region display a recognizable magnetic signature. For example, the southern segment of the East Coast Fault System has no expression in the magnetic field and cuts across anomalies with wavelengths on the order of tens of kilometers without noticeably perturbing or affecting them. If the fault exists as mapped, then it has not accumulated sufficient displacement to juxtapose rocks of varying magnetic susceptibility, and thus does not produce an observable magnetic anomaly at the scale of Figures 2.5.1-205 and 2.5.1-206.

2.5.1.1.2.4 Principal Regional Tectonic Structures

Principal tectonic structures and features in the southeastern United States and within the 200-mile VCSNS site region are divided into four categories based on their age of formation or reactivation, and are shown in Figures 2.5.1-211 and 2.5.1-212. These categories include structures that were most active during Paleozoic, Mesozoic, Tertiary, or Quaternary time. Most of the Paleozoic and Mesozoic structures are regional in scale and are recognized on the basis of geologic and/or geophysical data. The Mesozoic rift basins and bounding faults show a high degree of parallelism with the structural grain of the Paleozoic Appalachian orogenic belt, which generally reflects reactivation of preexisting Paleozoic structures. Tertiary and Quaternary structures are generally more localized and may be related to reactivation of portions of older bedrock structures.

2.5.1.1.2.4.1 Regional Paleozoic Tectonic Structures

The VCSNS site region encompasses portions of the Atlantic Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau physiographic provinces (Figure 2.5.1-201). Rocks and structures within these provinces are often associated with thrust sheets that formed during convergent Appalachian orogenic events of the Paleozoic Era. Tectonic structures of this affinity also exist beneath the sedimentary cover of the Coastal Plain province. These types of structures are shown on Figures 2.5.1-211 and 2.5.1-212, and include:

- Sutures juxtaposing allochthonous (tectonically transported) rocks with autochthonous (non-transported North American crust) rocks
- Regionally extensive Appalachian thrust faults and oblique-slip shear zones
- Numerous smaller structures that accommodated Paleozoic deformation within individual belts or terranes

Most of these structures dip eastward, initially at a steep angle that shallows with depth as they approach the basal Appalachian decollement (Figures 2.5.1-207 and 2.5.1-208). The Appalachian orogenic crust is relatively thin across the Valley and Ridge province, Blue Ridge province, and western part of the Piedmont province, and thickens eastward beneath the eastern part of the Piedmont province and the Coastal Plain province. Below the decollement are rocks that form the North American basement complex. These basement rocks contain northeast-striking, Late Precambrian to Cambrian normal faults that formed during the Iapetan rifting that preceded the deposition of Paleozoic sediments.

Researchers have observed that much of the sparse seismicity in eastern North America occurs within the North American basement below the basal decollement. Therefore, seismicity within the Appalachians may be unrelated to the abundant, shallow thrust sheets mapped at the surface (Reference 404). For example, seismicity in the Giles County seismic zone, located in the Valley and Ridge province, is occurring at depths ranging from 3 to 16 miles (5 to 25 kilometers) (Subsection 2.5.1.1.3.2.3 provides additional detail) (Reference 222), which is generally below the Appalachian thrust sheets and basal decollement (Reference 217).

Paleozoic faults within 200 miles of the site are shown in Figure 2.5.1-211 and are described as follows:

<u>Chappells Shear Zone</u>

The Chappells shear zone is a broad, ductile shear zone with probable dextral offset (References 267 and 266). The Chappells shear zone strikes east-northeast roughly parallel to the regional structural grain and extends from near Lake Wateree to Lake Thurmond and into Georgia (Figure 2.5.1-212) (References 267, 266, 284, and 363). At its nearest point, the Chappells shear zone is located approximately 2 miles south of the VCSNS site. The unmetamorphosed Winnsboro plutonic complex intrudes the shear zone (References 267, 266, 284, and 363). Based on crosscutting relationships with the Carboniferous Winnsboro plutonic complex, the Chappells shear zone is Paleozoic in age. There is no evidence to suggest post-Paleozoic motion on the Chappells shear zone.

<u>Central Piedmont Shear Zone</u>

The Central Piedmont shear zone forms the northwest boundary of the Carolina Zone where it is tectonically juxtaposed against metamorphic rocks of the Western Piedmont (Figure 2.5.1-202 Sheets 1 and 2). This zone of faulting was originally interpreted to represent a suture that was subjected to late Paleozoic tectonothermal overprinting and termed the Central Piedmont suture by

Hatcher and Zietz (Reference 274). Recent researchers have shown this contact to be a late Paleozoic shear zone without evidence for prior activity (References 282, 403, and 413). West (Reference 403) interprets the Central Piedmont shear zone as a late Paleozoic suture between the Carolina Zone and rocks to the west. However, this boundary is interpreted by Hibbard et al. (References 282 and 283) to represent a major late Paleozoic thrust that decapitated the original suture at depth.

Unnamed Fault Near Parr, South Carolina

As part of an investigation performed for the Parr Hydroelectric Project, Dames & Moore (Reference 239) describes a postulated fault 3 miles south-southwest of the VCSNS site, as shown in Figures 2.5.1-224 and 2.5.1-225. Evidence for this fault includes slickensides observed in a boring at Parr Dam and four bedrock exposures described as “faulted rock”, “dip reversal across narrow disrupted zone”, “discordance in foliation and beds”, and “shear features.” The postulated unnamed fault near Parr is based on a limited number of exposures and the assumption that these exposures all represent the same structure. With the exception of the outcrop in Parr and the boring on Parr Dam, the exposures are separated by distances greater than 1 mile. In addition, none of these exposures provide kinematic indicators and only one of the exposures yields information on orientation. Alternatively, the exposures observed by Dames & Moore (Reference 239) could represent individual local features of limited extent, similar to the minor faults and shears studied in the VC Summer Unit 1 exposure. More recent mapping of the area at 1:24,000 scale (References 363 and 364) does not include this postulated fault. For completeness, the inferred fault was conservatively included on Figures 2.5.1-224 and 2.5.1-225, even though the existence of a single fault connecting each of the Dames & Moore (Reference 239) exposures is highly speculative. This postulated fault, if it exists, is assigned a Paleozoic age, however, there are no data to constrain timing at any of the exposures. It is permissible that some could be as young as Mesozoic in age if they are similar to the bedrock shears mapped in the VC Summer Unit 1 excavation. The brief descriptions of the exposures by Dames & Moore (Reference 239) do not provide sufficient information to even classify the minor deformational features as having formed under ductile or brittle conditions. Field reconnaissance performed as part of this license application did not recognize evidence for faulting in the vicinity of Dames & Moore’s (Reference 239) postulated fault near Parr, South Carolina (Reference 363).

Beaver Creek Shear Zone

The Beaver Creek shear zone is located approximately 10 miles north of the VCSNS site, as shown in Figures 2.5.1-211 and 2.5.1-212. Evidence suggesting dextral strike-slip motion for this shear zone includes feldspar porphyroclasts with tails and shear bands from orthogneiss sheets, as well as from rotated, s-shaped quartz veins. Crosscutting relationships with the mesoscopically undeformed Newberry granite zone indicates that motion on the Beaver Creek shear zone occurred prior to 415 Ma (Reference 403).

Gold Hill Fault Extension

Horton and Dicken (Reference 289) and Hibbard et al. (Reference 284) map an unnamed fault north of the Beaver Creek shear zone that is considered the southwest extension of the Gold Hill-Silver Hill shear zone (Figures 2.5.1-211 and 2.5.1-212). At its nearest point, this fault is located approximately 20 miles north of the VCSNS site. The southwest extension of the Gold Hill fault is truncated by, and therefore predates, the Cross Anchor fault. Based upon crosscutting relationships with the Cross Anchor fault (Figure 2.5.1-211), and with intrusive igneous bodies, West (Reference 403) constrains motion on the Gold Hill fault to between approximately 400 and 325 Ma. Work along the Gold Hill-Silver Hill shear zone to the northeast has variably indicated deformation events of earliest Cambrian dextral-reverse faulting (Allen et al. 2007) (Reference 422), Late Ordovician sinistral deformation (Hibbard et al. 2007) (Reference 424), and Devonian to Mississippian remobilization (Hibbard et al. 2007; Hibbard et al. 2008) (References 424 and 425). The best evidence for the latest movement on the GHSZ, however, is based on its crosscutting relationship with the Cross Anchor fault that indicate

latest motion was sometime prior to 325 Ma (West 1998) (Reference 403).

Cross Anchor Fault

Hibbard et al. (Reference 284) map the more than 60-mile-long Cross Anchor fault as a thrust fault of variable strike, as shown in Figures 2.5.1-211 and 2.5.1-212. At its nearest point, the Cross Anchor fault is located approximately 10 miles north of the VCSNS site, and is associated with the Whitmire reentrant. West (Reference 403) interprets the Cross Anchor fault as the Carolina-Inner Piedmont terrane boundary. Crosscutting and structural relationships indicate that the Cross Anchor fault is Paleozoic (325 Ma) and may be part of the Central Piedmont shear zone (Reference 403).

Modoc Shear Zone

The Modoc zone, located in South Carolina and Georgia about 20 miles south of the VCSNS site (Figures 2.5.1-211 and 2.5.1-212), is a region of high ductile strain separating the Carolina Terrane (Carolina Slate and Charlotte belts) from amphibolite facies migmatitic and gneissic rocks (References 219 and 362). The northeast trending Modoc zone dips steeply to the northwest and can be traced from central Georgia to central South Carolina based on geological and geophysical data. Mylonitic rocks are common within the zone, although the intensity of mylonitization varies widely (Reference 219). Regional relationships and structures within the zone reflect predominantly dextral motion with a northwest-side-down normal component, related to early Alleghanian extension (Reference 356). Geochronologic data from Dallmeyer et al. (Reference 238) indicate movement occurred between 315 and 290 Ma, during the Alleghanian Lake Murray deformation, D2. Recent exposures created for the construction of Saluda Dam on Lake Murray exposed a portion of the Modoc shear zone where four Paleozoic ductile deformational events are recognized. The D4 deformation is recognized as an east-northeast striking zone at least 20 kilometers wide, and it shows a transition from ductile to brittle behavior, which correlates with retrograde mineral assemblages in D4 faults in the Modoc zone (Reference 294). Brittle features observed in the Saluda Dam foundation are interpreted to be the result of a readjustment from differential loading and unloading, as well as tectonic movement associated with latest Alleghanian deformation and initial Triassic rifting (Reference 328). No seismicity is attributed to the Modoc shear zone.

Eastern Piedmont Fault System

Hatcher et al. (Reference 275) suggest that the Modoc shear zone, the Augusta fault, and the Goat Rock fault are part of the proposed Eastern Piedmont Fault System, an extensive series of faults and splays extending from Alabama to Virginia (Figure 2.5.1-211). Aeromagnetic, gravity, and seismic reflection data indicate that the Augusta fault zone continues northeastward in the crystalline basement beneath the Coastal Plain province sediments.

Augusta Fault

The Augusta fault zone is located near Augusta, Georgia, about 50 miles southwest of the VCSNS site (Figure 2.5.1-212) and separates amphibolite facies gneisses and schists to the northwest from greenschist facies volcanic and volcaniclastic rocks to the southeast (References 366, 367, 320, and 362). The Augusta fault strikes east-northeast and dips moderately to the southeast. The Augusta fault zone is characterized as a zone of quartzofeldspathic mylonites, ultramylonites, and blastomylonites with minor amphibolites, schists, and a variety of light-colored granitic veins (Reference 320). The fault contains two distinct deformation fabrics: a mylonite about 800 feet thick is overprinted by a brittle fabric. Before Maher's (Reference 320) detailed structural analysis of the fault zone rocks, the Augusta fault had been characterized variably as a thrust fault, a dextral strike-slip fault, a strain gradient with little displacement, and a possible listric normal fault within the early Mesozoic (References 375, 229, and 213). The sense of movement of the fault zone is now constrained by regional context, mesoscopic structures, and microscopic textures. Maher (Reference 320) notes five observations that indicate a hanging-wall-down, oblique sense of slip:

1. Geometry and orientation of folded discordant granitic veins

2. A sporadically developed lineation

3. Composite planar fabric (S and C surfaces)

4. "Mica fish"

5. Regional geologic relations

The significant normal component of slip during the Alleghanian collisional orogeny is seemingly contradictory, but extension on the Augusta fault (and others within the region) is consistent with a model involving gravitational collapse of a thickened crust, similar to examples from the Himalaya Mountains (Reference 321). Geologic relations and the 40Ar/39Ar cooling ages of Maher et al. (Reference 321) suggest that extensional movement on the Augusta fault zone initiated about 274 Ma. Maher et al. (Reference 321) constrains Augusta fault extension as occurring late in the Alleghanian phase and well after initiation of Alleghanian crustal shortening in the Valley and Ridge and Blue Ridge. Some discontinuous silicified breccias occur along the Augusta fault zone, and minor brittle faults using the mylonitic fabric have striae subparallel to the mylonitic lineation (Reference 320). The brittle striae and faults record the same sense and direction of shear as the mylonitic fabric, indicating Alleghanian movement on the Augusta fault occurred during transition from ductile to brittle conditions (References 320 and 321). Alleghanian extensional events have been interpreted for not only the Augusta fault, but also other faults within the Eastern Piedmont fault system, suggesting that extension played a significant role in the development of the Appalachians. Maher et al. (Reference 321) suggest that the new geochronology indicates Piedmont normal faulting is not solely Mesozoic, but includes late Alleghanian episodes. No seismicity is attributed to the Augusta fault.

<u>Other Paleozoic Faults</u>

Other Paleozoic faults within the site region include the Brevard fault zone, the Hayesville fault, the Towaliga fault, and the Central Piedmont shear zone, Middleton Lowndesville shear zone, Philson Crossroads fault, Tinsley Bridge fault, and others (Figures 2.5.1-211 and 2.5.1-212). While direct timing evidence does not exist for many of these faults, they can be assigned a Paleozoic age based on the following types of indirect evidence:

- Mapping that indicates that these faults only deform rocks of Paleozoic or older age,
- Geometries and kinematics similar to other faults with established Paleozoic ages in the region (e.g., west-directed thrusts); and/or
- Textural fabrics or mineral assemblages consistent with deformation at ductile high-temperature metamorphic conditions, the latest of which generally occurred during the late Paleozoic collision with Gondwana (e.g. Hatcher et al. 2007) (Reference 423).

Furthermore, no seismicity is attributed to these Paleozoic faults in the site region, and published literature does not indicate that any of these faults offset late Cenozoic deposits or exhibit a geomorphic expression indicative of Quaternary deformation. In addition, Crone and Wheeler (Reference 232) and Wheeler (Reference 406) do not show any of these faults to be potentially active Quaternary faults. Therefore, these Paleozoic structures in the site region are not considered to be capable tectonic sources, as defined in Regulatory Guide 1.208.

No new information has been published since 1986 on any Paleozoic fault in the site region that would cause a significant change in the EPRI seismic source model.

2.5.1.1.2.4.2 Regional Mesozoic Tectonic Structures

Tectonic features in the site region of known or postulated Mesozoic age include faults and extensional rift basins, as shown in Figures 2.5.1-211 and 2.5.1-212. These features are described below.

Wateree Creek Fault

Secor et al. (Reference 364) map the more than 8-mile-long Wateree Creek fault as an approximately north striking, unsilicified fault zone. Based upon crosscutting relationships with Triassic or Jurassic diabase dikes, Secor et al. (Reference 364) estimate a minimum age of Triassic for the Wateree Creek fault. At its nearest point, the Wateree Creek fault is located approximately 2 miles south of the VCSNS site, and is therefore discussed under “Site Area Structural Geology” (Subsection 2.5.1.2.4).

Summers Branch Fault

Secor et al. (Reference 364) map the approximately 8-mile-long Summers Branch fault as an approximately north striking, unsilicified fault zone. By association with the Wateree Creek fault, Secor et al. (Reference 364) estimate a minimum age of Triassic for the Summers Branch fault. At its nearest point, the Summers Branch fault is located approximately 5 miles southwest of the VCSNS site, and is therefore discussed under “Site Area Structural Geology” (Subsection 2.5.1.2.4).

Ridgeway Fault

The more than 9-mile-long Ridgeway fault is mapped by Secor et al. (Reference 368) and Barker and Secor (Reference 208) as an approximately north striking, unsilicified fault zone located approximately 20 miles east of the VCSNS site (Figure 2.5.1-212). By association with the Wateree Creek fault, Secor et al. (Reference 368) estimate a minimum age of Triassic for the Ridgeway fault.

Longtown Fault

The Longtown fault strikes west-northwest in the Ridgeway-Camden area (Figure 2.5.1-213), about 25 miles from the VCSNS site. As mapped by Secor et al. (Reference 368), the Longtown fault terminates eastward against the Camden fault. The Longtown fault is associated with fracturing and brecciation of the crystalline rocks, and fragments of silicified breccia are found along its trace (Reference 368). Total slip on the Longtown fault is unresolved, although Secor et al. (Reference 368) suggest total displacement on the order of hundreds to thousands of meters is likely in order to explain the apparent disruption of crystalline rocks across the fault. Map relationships suggest that the Longtown fault vertically separates the Late Cretaceous basal unconformity (Reference 368). However, it is possible that the irregularity in the basal unconformity represents buried topography and not tectonic deformation (Reference 208). Mapping by Barker and Secor (Reference 208) shows diabase dikes of Triassic or Jurassic age that cross, but are not offset by, the Longtown fault (Figure 2.5.1-213). As such, these data indicate a Mesozoic or older age for the Longtown fault.

Mulberry Creek Fault

The Mulberry Creek fault is located approximately 45 miles northwest of the VCSNS site (Figure 2.5.1-212). This sub-vertical fault contains silicified breccia, microbreccia, and cataclasite (Reference 403). The age of the Mulberry Creek fault is poorly constrained but, based on 180 ± 3 Ma whole rock dates (Reference 429) from similar silicified breccias and cataclasites elsewhere in the Carolinas, West (Reference 403) suggests a Late Triassic to Early Jurassic age for the Mulberry Creek fault. As additional support for a Mesozoic age for the Mulberry Creek fault, Secor et al. (Reference 368) suggest that silicified breccias are characteristic of Mesozoic faults in the Piedmont and likely reflect hydrothermal activity indicative of a Mesozoic age. Moreover, Hatcher (Reference 430) indicates silicified cataclasite fault zones in the Piedmont formed coevally with

Mesozoic (170-190 Ma) diabase dikes.

Unnamed Fault Near Ridgeway, South Carolina

Secor et al. (Reference 368) and Barker and Secor (Reference 208) map an unnamed fault south of the Longtown fault that terminates westward against the Ridgeway fault near Ridgeway, South Carolina. Secor et al. (Reference 368) and Barker and Secor (Reference 208) map six diabase dikes of Triassic or Jurassic age that cross, but are not offset by, this unnamed fault. Based on these crosscutting relationships, a minimum age of Triassic is established for the unnamed fault of Secor et al. (Reference 368) and Barker and Secor (Reference 208).

Mesozoic Rift Basins

A broad zone of fault-bounded, elongate depositional basins associated with crustal extension and rifting formed during the opening of the Atlantic Ocean in early Mesozoic time. These rift basins are common features along the eastern coast of North America from Florida to Newfoundland. Wheeler (Reference 404) suggests that many earthquakes in the eastern part of the Piedmont province and beneath the Coastal Plain province may be associated spatially with buried normal faults related to rifting that occurred during the Mesozoic Era. However, no definitive correlation of seismicity with Mesozoic normal faults has been conclusively demonstrated. Figure 2.5.1-212 shows the lack of spatial correlation between Mesozoic basins and seismicity within 50 miles of the site. To date, there is no positive correlation between earthquakes in the site region and Mesozoic basins. Normal faults in this region that bound Triassic basins may be listric into the Paleozoic detachment faults, or may penetrate through the crust as high-angle faults (*e.g.,* Reference 359). Within regions of stable continental cratons, areas of extended crust potentially contain the largest earthquakes (Reference 301) (Figure 2.5.1-214). Mesozoic basins have long been considered potential sources for earthquakes along the eastern seaboard (Reference 402) and were considered by most EPRI ESTs in their definition of seismic sources (Reference 250).

The Dunbarton Basin is a roughly east-northeast-trending Mesozoic rift basin and is approximately 31 miles long and 6 to 9 miles wide. Marine and Siple (Reference 323) identify the general extent and shape of the Dunbarton Basin on the basis of Coastal Plain sediment cores and a limited amount of seismic data from the Savannah River Site. The Dunbarton Basin coincides with both gravity and magnetic lows and is bounded on the north by the Pen Branch fault (References 323, 221, 380, 233, 234, 235, and 247). The Pen Branch fault has had a long and varied history. The Pen Branch fault likely formed in the Paleozoic Era, and was reactivated as a normal fault during the Triassic Period. The Pen Branch fault was most recently reactivated as an oblique-reverse fault in the Cenozoic Era (References 233, 234, and 235). It has been suggested that the Martin fault is the southeastern bounding fault of the Dunbarton Basin (Reference 374), although Domoracki et al. (Reference 248) suggest that the Dunbarton Basin is instead a half-graben bounded only by the Pen Branch fault to the north.

2.5.1.1.2.4.3 Regional Cenozoic Tectonic Structures

Within 200 miles of the VCSNS site, only a few tectonic features, including faults, arches, domes, and embayments, were active during the Cenozoic Era (Figure 2.5.1-211).

Camden Fault

The northeast striking Camden fault is located in the eastern part of the Ridgeway-Camden area (Figure 2.5.1-213), about 40 miles from the VCSNS site. Along much of its length, the Camden fault juxtaposes crystalline rocks of the Carolina terrane on the northwest against crystalline rocks interpreted to be part of the Alleghanian Modoc shear zone on the southeast (Reference 368). Total slip on the Camden fault is uncertain, although, based on geologic mapping; Secor et al. (Reference 368) suggest total displacement on the order of kilometers is likely in order to explain the apparent disruption of crystalline rocks across the fault.

Up-to-the-north vertical separation of the basal Late Cretaceous unconformity of about 50 to 120 feet indicates Late Mesozoic and possibly Cenozoic reactivation of the Camden fault (References 207, 312, and 368). Mapping by Barker and Secor (Reference 208) in the southeast corner of the Longtown quadrangle suggests that the base of the unconformity is not offset by the Camden fault, at least in this quadrangle. Balinsky (1994) suggests latest movement on the Camden fault predates deposition of the Oligocene Upland formation gravels (Reference 207). Likewise, Knapp et al. (Reference 312) suggest that undeformed and unfaulted deposits of the Oligocene Upland formation cover the southwest projection of the Camden fault. Taken together, these data suggest that the Camden fault is Oligocene or older in age (References 207, 312, and 208).

Arches and Embayments

The basement surface on which Coastal Plain sediments were deposited is not a simple planar platform. Instead, it is a characterized by broad structural upwarps (arches) that separate depositional basins (embayments) (Horton and Zullo 1991) (Reference 291). The hinge lines of these upwarps are aligned roughly perpendicular to the coastline. Two of these upwarps, the Cape Fear and Yamacraw arches, are located within the site region. The Cape Fear arch is located near the South Carolina-Georgia border (Figure 2.5.1-211).

Evidence constraining the timing of most-recent movement on the Cape Fear and Yamacraw arches is limited. Based on subsurface structure contour maps, Gohn (1988) (Reference 418) indicates that the Cape Fear arch has affected the thickness and distribution of Late Cretaceous to late Tertiary strata. Prowell and Obermeier (1991) (Reference 419) suggest that upwarping on the Cape Fear arch may have continued through the Pleistocene Epoch. Data constraining the timing of most-recent movement on the Yamacraw arch are unavailable. However, due to the roughly parallel orientations and similar structural styles of the Cape Fear and Yamacraw arches, the timing of the most-recent movement on these two arches is assessed to be similar. Crone and Wheeler (2000) (Reference 232) classify the Cape Fear Arch as a Class C feature based on lack of evidence for Quaternary faulting and do not include the Yamacraw Arch in their assessment.

2.5.1.1.2.4.4 Regional Quaternary Tectonic Structures

In an effort to provide a comprehensive database of Quaternary tectonic features, Crone and Wheeler (Reference 232) and Wheeler (Reference 406) compiled geological information on Quaternary faults, liquefaction features, and possible tectonic features in the CEUS. They evaluate and classify these features into one of four categories (Classes A, B, C, and D; see Table 2.5.1-201 for definitions) based on strength of evidence for Quaternary activity.

Within a 200-mile radius of the VCSNS site, Crone and Wheeler (Reference 232) and Wheeler (Reference 406) identify 14 potential Quaternary features (Table 2.5.1-201 and Figure 2.5.1-215). These include:

- Fall Lines of Weems (1998) (class C)
- Belair fault (class C)
- Pen Branch fault (class C)
- Cooke fault (Charleston feature, class C)
- East Coast Fault System (Charleston feature, class C)
- Charleston liquefaction features (Charleston feature, class A)
- Bluffton liquefaction features (Charleston feature, class A)

- Georgetown liquefaction features (Charleston feature, class A)
- Eastern Tennessee Seismic Zone (class C)
- Cape Fear arch (class C)
- Helena Banks fault (class C)
- Hares Crossroads fault (class C)
- Stanleytown-Villa Heights faults (class C)
- Pembroke faults (class B)

Table 2.5.1-202 presents orientation and length information for these fourteen potential Quaternary features. The Charleston features (including the East Coast Fault System; the Cooke fault, the Helena Banks fault zone; and the Charleston, Georgetown, and Bluffton paleoliquefaction features) are discussed in Subsection 2.5.1.1.3.2.1. The Eastern Tennessee Seismic Zone is discussed in Subsection 2.5.1.1.3.2.2. The remaining seven potential Quaternary features (namely, the Fall Lines of Weems (Reference 398), the Belair fault zone, the Pen Branch fault, the Cape Fear arch, the Hares Crossroads fault, the Stanleytown-Villa Heights faults, and the Pembroke faults) are discussed in detail below:

Fall Lines of Weems (1998)

The Fall Lines of Weems (Reference 398) are alignments of rapids or anomalously steep sections of rivers draining the Piedmont and Blue Ridge Provinces of North Carolina and Virginia. Weems' (Reference 398) delineation of these fall zones is crude, but, as presented in his Figure 8, the Western Piedmont Fall Line appears to be located less than 50 miles from the VCSNS site at its nearest point (Figure 2.5.1-215). Wheeler (Reference 406) classifies the Fall Lines of Weems (Reference 398) as a Class C feature (Table 2.5.1-201) because: (1) identification of the fall zones is subjective and the criteria for recognizing them are not stated clearly enough to make the results reproducible; and (2) a tectonic faulting origin has not yet been demonstrated for the fall zones. Based on review of published literature, field reconnaissance, and work performed as part of the North Anna ESP application (Reference 336), it is the assessment that the Fall Lines of Weems (Reference 398) are erosional features related to contrasting erosional resistances of adjacent rock types, and are not tectonic in origin.

Belair Fault Zone

The Belair fault zone is mapped for at least 15 miles (24 kilometers) as a series of northeast striking, southeast dipping, oblique-reverse slip faults near Augusta, Georgia, that generally parallel the structural grain of the Piedmont (Figure 2.5.1-215). The Belair fault juxtaposes Paleozoic phyllite over Late Cretaceous sands of the Coastal Plain province (Reference 348). No geomorphic expression of the fault has been reported (Reference 232). Shallow trenches excavated across the Belair fault near Fort Gordon in Augusta, Georgia, were initially interpreted as revealing evidence for Holocene movement (Reference 349), but the apparent youthfulness of movement was probably the result of contaminated radiocarbon samples (Reference 347). Prowell and O'Connor (Reference 348) demonstrate that the Belair fault cuts beds of Late Cretaceous and Eocene age. Overlying, undeformed strata provide a minimum constraint on the last episode of faulting, which is constrained to sometime between post-late Eocene and pre-26,000 years ago (Reference 347). There is no evidence of historical or recent seismicity associated with the Belair fault. Crone and Wheeler (Reference 232) classified the Belair fault zone as a Class C feature, since the most recent faulting is not demonstrably of Quaternary age. Quaternary slip on the Belair fault zone is allowed, but not demonstrated, by the available data.

Mapping and structural analysis by Bramlett et al. (Reference 219) indicates that the Belair fault likely formed as a lateral ramp or tear associated with the Augusta fault when displacement on these faults initiated during the Paleozoic Alleghanian orogeny. The timing and sense-of-slip for the most recent movements on the Belair and Augusta faults, however, demonstrates that these two structures have not reactivated as a single tectonic element in Cenozoic or younger time. Prowell et al. (Reference 349) and Prowell and O'Connor (Reference 348) document Cenozoic, brittle, reverse slip on the Belair fault. In contrast, the latest movement on the Augusta fault, as demonstrated by brittle overprinting of ductile fabrics, exhibits a normal sense-of-slip and is constrained to have occurred in late Alleghanian time during the transition from ductile to brittle conditions (References 320 and 321). The brittle overprinting on the Augusta fault is consistent with the ductile normal sense of slip. In contrast, the Belair fault exhibits a reverse sense-of-slip during its Cenozoic reactivation. Therefore, different slip histories and opposite senses of dip-slip for the Belair and Augusta faults demonstrate that these two faults have not been reactivated as a single structure during the Cenozoic.

Pen Branch Fault

The more than 20-mile-long Pen Branch fault is the northwest bounding fault of the Mesozoic Dunbarton Basin, strikes northeast, traverses the central portion of the Savannah River Site, and strikes southwestward into Georgia near the Vogtle Electric Generating Plant site near Waynesboro, Georgia (Reference 374) (Figure 2.5.1-215). The Pen Branch fault is not exposed or expressed at the surface (References 374, 378, and 235). Borehole and seismic reflection data collected from the Savannah River Site show no evidence for post-Eocene slip on the Pen Branch fault (Reference 235). Savannah River Site studies and work performed as part of the Vogtle ESP application (Reference 337) specifically designed to assess the youngest deformed strata overlying the fault through shallow, high-resolution reflection profiles, drilling of boreholes, and geomorphic analyses have consistently concluded that the youngest strata deformed are late Eocene in age (Reference 337). Therefore, it is concluded that Pen Branch fault is not a capable tectonic source.

Cape Fear Arch

The Cape Fear Arch is discussed previously in this subsection (under Regional Tertiary Tectonic Structures). Crone and Wheeler (Reference 232) classify the Cape Fear Arch as a Class C feature based on lack of evidence for Quaternary faulting.

Hares Crossroads Fault

The postulated Hares Crossroads fault (identified by Prowell [Reference 346] as fault #46) in east-central North Carolina is a single reverse fault that offsets the base of the Coastal Plain section, approximately 200 miles northeast of the VCSNS site. This fault is recognized in a roadcut exposure. The fault is not recognized beyond this exposure, and geomorphic expression is negligible. This fault is likely the result of landsliding and is therefore likely non-tectonic in origin. Crone and Wheeler (Reference 232) classify the Hares Crossroads fault as a class C feature based on lack of evidence for Quaternary faulting.

Stanleytown-Villa Heights Faults

The postulated Stanleytown-Villa Heights faults are located in the Piedmont of southern Virginia, approximately 200 miles north-northeast of the VCSNS site. These approximately 600-foot-long faults juxtapose Quaternary alluvium against rocks of Cambrian age. The Stanleytown-Villa Heights faults are both short in mapped length, drop their east sides down in the downhill direction, and no other faults are mapped nearby (Crone and Wheeler Reference 232). These faults are likely the result of landsliding and are therefore likely non-tectonic in origin. Crone and Wheeler (Reference 232) classify the Stanleytown-Villa Heights faults as a Class C feature based on lack of evidence for Quaternary faulting.

Pembroke Faults

The postulated Pembroke faults of western Virginia are located within alluvial deposits of probable Quaternary age (Reference 232), approximately 200 miles north of the VCSNS site. The Pembroke faults are identified by geologic mapping, seismic profiles, gravity and magnetics, and ground-penetrating radar. The Pembroke faults are not expressed geomorphically, and it is unclear if the faults are of tectonic origin or the result of dissolution collapse. Law et al. (Reference 313) interpret the Pembroke faults as tectonic in origin, but suggest the possibility that they may be related to either solution collapse or landsliding. Law et al. (Reference 314) describe the preservation of delicate grain-scale textures in clay-rich faults that preclude sudden slip along the Pembroke faults. Crone and Wheeler (Reference 232) classify the Pembroke faults as a Class B feature based on evidence suggesting possible Quaternary faulting.

Prowell (Reference 346) compiled a preliminary list of faults and tectonic features of postulated Cretaceous and Cenozoic age in the eastern United States. Prowell (Reference 346) describes a number of small, N80ºE striking, near vertical (dipping 87º to the north) reverse faults exposed in a construction excavation near Irmo, South Carolina. One fault strand is described as offsetting postulated Eocene to Pliocene fluvial sands and gravels about 5 feet. Prowell's (Reference 346) fault #67 is not mapped beyond the single construction site exposure, which is now covered, and this feature does not appear on more recent geologic maps of the area. This feature, which was exposed in an excavation over 25 years ago, has not been mapped beyond the initial exposure nor correlated to any other fault of known tectonic origin.

Crone and Wheeler (Reference 232), Wheeler (Reference 406), and Prowell (Reference 346) identify potential Quaternary tectonic features in the CEUS. Evaluations, including literature review, interviews with experts, and geologic reconnaissance, did not identify any additional potential Quaternary tectonic features within the VCSNS site region.

2.5.1.1.2.4.5 Regional Geophysical Anomalies and Lineaments

In addition to the tectonic structures described above, a number of regional geophysical anomalies are located within approximately 200 miles of the VCSNS site. From southeast to northwest these include the East Coast Magnetic Anomaly, the southeast boundary of Iapetan normal faulting, Clingman lineament, Ocoee lineament, New York-Alabama lineament, the Appalachian gravity gradient, the northwest boundary of Iapetan normal faulting, Appalachian thrust front, and the Grenville front (Figures 2.5.1-210 and 2.5.1-211). These features are described below, with more detail provided for those features within the 200-mile site region.

East Coast Magnetic Anomaly

The East Coast Magnetic Anomaly (ECMA) is a broad, 200 to 300 nT magnetic high that is located approximately 30 to 120 miles (50 to 200 kilometers) off the coast of North America, and which is continuously expressed for about 1,200 miles (1,900 kilometers) from the latitude of Georgia to Nova Scotia (References 311 and 412) (Figure 2.5.1-210). The ECMA is subparallel to the Atlantic coastline, and is spatially associated with the eastern limit of North American continental crust (Reference 311). The ECMA has been variously interpreted to be a discrete, relatively magnetic body such as a dike or ridge, or an "edge effect" due to the juxtaposition of continental crust on the west with higher susceptibility oceanic crust on the east (see summary and additional references in Reference 205). In the vicinity of the ECMA, deep seismic reflection profiling in the Atlantic basin has imaged packages of east-dipping reflectors that underlie the sequence of Mesozoic-Tertiary passive-margin marine strata (Reference 371). The rocks associated with the east-dipping reflectors are interpreted to be an eastward-thickening wedge of volcanic and volcaniclastic rocks that were deposited during the transition between rifting of the continental crust and opening of the Atlantic basin during the Mesozoic (Reference 412). Models of the magnetic data show that the presence of this volcanic "wedge" can account for the wavelength and amplitude of the ECMA (Reference 311).

To summarize, the ECMA is a relict of the Mesozoic opening of the Atlantic basin, and probably arises from the presence of a west-tapering wedge of relatively magnetic volcanic rocks deposited along the eastern margin of the continental crust as the Atlantic basin was opening, rather than juxtaposition of rocks with differing magnetic susceptibilities across a fault. The ECMA is not directly associated with a fault or tectonic feature, and thus is not a potential seismic source.

Appalachian Gravity Gradient

This regional gravity gradient extends the length of the Appalachian orogen (Figure 2.5.1-211) and exhibits a southeastward rise in Bouguer gravity values as much as 50 to 80 mGal (References 217 and 405). The Appalachian gravity gradient represents the southeastern thinning of relatively intact Precambrian continental crust, and the early opening of the Iapetan Ocean (*e.g.,* Reference 217).

Southeast and Northwest Boundaries of Iapetan Normal Faults

The southeast and northwest boundaries of Iapetan normal faults shown in Figure 2.5.1-211 define the extent of the Iapetan margin of the craton containing normal faults that accommodated extension during the late Proterozoic to early Paleozoic rifting that formed the Iapetan Ocean basin. Wheeler (Reference 405) defines the southeast boundary as the southeastern limit of the intact Iapetan margin, which is nearly coincident with the Appalachian gravity gradient in the southeastern United States. The Iapetan normal faults are concealed beneath Appalachian thrust sheets that overrode the margin of the craton during the Paleozoic. A few of these Iapetan faults are thought to be reactivated and responsible for producing earthquakes in areas such as eastern Tennessee; Giles County, Virginia; and Charlevoix, Quebec (References 217 and 405).

The southeast margin of the Iapetan normal faults shown on Figure 2.5.1-211 does not represent a potential seismic source since it does not represent a discrete crustal discontinuity or tectonic structure. The linear feature shown in the figure represents the southeastern extent of the intact Iapetan margin (with a location uncertainty of 30 to 35 kilometers), and therefore, the southeastern limit of potentially seismogenic Iapetan faults (Reference 405).

The New York-Alabama, Clingman, and Ocoee Lineaments

King and Zietz (Reference 308) identified a 1,000-mile (1,600-kilometer)-long lineament in magnetic maps of the eastern United States that they referred to as the “New York-Alabama lineament” (Figure 2.5.1-211). The New York-Alabama lineament primarily is defined by a series of northeast-southwest-trending linear magnetic gradients in the Valley and Ridge province of the Appalachian fold belt that systematically intersect and truncate other magnetic anomalies. The New York-Alabama lineament also is present as a complementary but less well-defined lineament on regional gravity maps (Reference 308).

The Clingman lineament is an approximately 750-mile (1,200-kilometer)-long, northeast trending aeromagnetic lineament that passes through parts of the Blue Ridge and eastern Valley and Ridge provinces from Alabama to Pennsylvania (Reference 332). The Ocoee lineament is a described as a splay that branches southwest from the Clingman lineament at about latitude 36°N (see summary in Reference 300). The Clingman-Ocoee lineaments are subparallel to and located about 30 to 60 miles (50 to 100 kilometers) east of the New York-Alabama lineament.

King and Zietz (Reference 308) interpret the New York-Alabama lineament to be a major strike-slip fault in the Precambrian basement beneath the thin-skinned, fold-and-thrust structures of the Valley and Ridge, and suggested that it may separate rocks on the northwest that acted as a mechanical buttress from the intensely deformed Appalachian fold belt to the southeast. Shumaker (Reference 372) interprets the New York-Alabama lineament to be a right-lateral wrench fault that formed during an initial phase of late Proterozoic continental rifting that eventually led to the opening of the Iapetan Ocean. The Clingman lineament also is interpreted to arise from a source or sources in the Precambrian basement beneath the accreted and transported Appalachian terranes

(Reference 332).

Johnston et al. (Reference 300) observes that the “preponderance of southern Appalachian seismicity” occurs within the “Ocoee block,” a Precambrian basement block bounded by the New York-Alabama lineament and Clingman-Ocoee lineaments (the Ocoee block was previously defined by Reference 298). The proximity of these lineaments to current seismicity in the Eastern Tennessee Seismic Zone therefore suggests the possibility that they are potential seismic sources. Based on the orientations of nodal planes from focal mechanisms of small earthquakes, Johnston et al. (Reference 300) notes that most events within the Ocoee block occurred by strike-slip displacement on north-south and east-west striking faults, and thus these workers did not favor the interpretation of seismicity occurring on a single, through-going northeast-southwest trending structure parallel to the Ocoee block boundaries.

The Ocoee block lies within a zone defined by Wheeler (References 404 and 405) as the cratonward limit of normal faulting along the ancestral rifted margin of North America that occurred during the opening of the Iapetan ocean in late Precambrian to Cambrian time. Synthesizing geologic and geophysical data, Wheeler (References 404 and 405) mapped the northwest extent of the Iapetan faults in the subsurface below the Appalachian detachment, and proposed that earthquakes within the region defined by Johnston and Reinbold (Reference 298) as the Ocoee block may be the result of reactivation of Iapetan normal faults as reverse or strike-slip faults in the modern tectonic setting.

<u>Appalachian Thrust Front</u>

The northwestern limit of allochthonous crystalline Appalachian crust was termed the Appalachian thrust front by Seeber and Armbruster (Reference 370) (Figure 2.5.1-211). This front, which lies beyond the 200-mile site region, is a sharply defined boundary interpreted as a major splay of the master Appalachian detachment.

<u>Grenville Front</u>

The Grenville front, which is located beyond the 200-mile site region (Figure 2.5.1-211), is defined by geophysical, seismic reflection, and scattered drill hole data in the southeastern United States. This feature lies within the continental basement and is interpreted to separate the relatively undeformed eastern granite-rhyolite province on the northwest from the more highly deformed rocks of the Grenville province on the southeast (Reference 395).

2.5.1.1.3 Regional Seismicity and Paleoseismology

This subsection includes descriptions of instrumental and historic earthquake activity in the VCSNS site region and beyond. Special emphasis is placed on the Charleston seismic source because it produced one of the largest historical earthquakes in the eastern United States.

2.5.1.1.3.1 Central and Eastern United States Seismicity

Seismicity in the CEUS is broadly distributed, but defines areas of concentrated earthquake activity (Figure 2.5.1-216). Significant areas of concentrated seismicity are described in this subsection.

2.5.1.1.3.2 Seismic Sources Defined by Regional Seismicity

Within 200 miles of the VCNS site, there are four principal areas of concentrated seismicity. Three of these (the Middleton-Place Summerville, Bowman, and Adams Run seismic zones) are located in the Charleston, South Carolina, area and are discussed in Subsection 2.5.1.1.3.2.1. The fourth area of concentrated seismicity in the site region is the Eastern Tennessee Seismic Zone (Figure 2.5.1-216). Three additional areas of concentrated seismicity beyond the site region (*i.e.,* the New Madrid, Central Virginia, and Giles County seismic zones) are also discussed in this subsection.

2.5.1.1.3.2.1 Charleston Seismic Zone

The August 31, 1886, Charleston, South Carolina, earthquake is one of the largest historical earthquakes in the eastern United States. The event produced Modified Mercalli Intensity (MMI) X shaking in the epicentral area and was felt strongly as far away as Chicago (MMI V) (Reference 297). As a result of this earthquake and the relatively high risk in the Charleston area, government agencies have funded numerous investigations to identify the source of the earthquake and recurrence history of large magnitude events in the region. In spite of this effort, the source of the 1886 earthquake has not been definitively attributed to any particular fault shown in Figures 2.5.1-218 and 2.5.1-219.

The 1886 Charleston earthquake produced no identifiable primary tectonic surface deformation; therefore, the source of the earthquake has been inferred based on the geology, geomorphology, and instrumental seismicity of the region (Figures 2.5.1-217, 2.5.1-218, and 2.5.1-219). Talwani (Reference 382) infers that the 1886 event was produced by the north-northeast striking Woodstock fault (inferred from seismicity) near its intersection with the northwest striking Ashley River fault (also inferred from seismicity). Marple and Talwani (Reference 325) suggest that a northeast trending zone of river anomalies, referred to as the East Coast Fault System, represents the causative fault for the 1886 Charleston event. The southern segment of the East Coast Fault System coincides with a linear zone of micro-seismicity that defines the northeast trending Woodstock fault of Talwani (Reference 382) and the isoseismal zone from the 1886 earthquake.

Johnston (Reference 297) estimates a moment magnitude (**M**) of **M** 7.3±0.26 for the 1886 Charleston event. More recently, Bakun and Hopper (Reference 206) estimate a smaller magnitude of **M** 6.9 with a 95% confidence level corresponding to a range of **M** 6.4 to 7.1. Both of these more recent estimates of maximum magnitude (M_{max}) are similar to the upper-bound maximum range of M_{max} values used in EPRI (Reference 250) (using body wave magnitudes [m_b] 6.8 to 7.5). However, significant new information regarding the source geometry and earthquake recurrence of the Charleston seismic source warrants an update of the EPRI (Reference 250) source models in the PSHA. The updated Charleston seismic source parameters are presented in Subsection 2.5.2.

Potential Charleston Source Faults

Since the EPRI (Reference 250) source models were developed, a number of faults have been identified or described in the literature as possible sources related to the 1886 Charleston earthquake. These include numerous faults localized in the Charleston meizoseismal area.

There is evidence, in the form of paleoliquefaction features in the South Carolina Coastal Plain, that the source of the 1886 Charleston earthquake has repeatedly generated vibratory ground motion. Paleoliquefaction evidence is lacking for prehistoric earthquakes elsewhere along much of the eastern seaboard (*e.g.,* References 201, 202, and 203). At a minimum, the Charleston seismic source is defined as a seismogenic source according to Regulatory Guide 1.208. Whereas the 1886 Charleston earthquake almost certainly was produced by a capable tectonic source, the causative tectonic structure has yet to be identified. Various studies propose potential candidate faults for the 1886 event; however, a positive linkage between a discrete structure and the Charleston earthquake has yet to be determined.

These potential causative faults are shown in Figures 2.5.1-217, 2.5.1-218, and 2.5.1-219 as described below:

- *East Coast Fault System*. The inferred East Coast Fault System, the southern section of which is also known as the “zone of river anomalies” or ZRA, (based on the alignment of river bends) is a northeast trending, approximately 600-kilometer-long fault system extending from west of Charleston, South Carolina, to southeastern Virginia (Reference 325). The East Coast Fault System comprises three approximately 200-kilometer-long, right-stepping

sections (southern, central, and northern). Evidence for the southern section is strongest, with evidence becoming successively weaker northward (Reference 406). Marple and Talwani (Reference 324) identify a series of geomorphic anomalies (*i.e.,* ZRA) located along and northeast of the Woodstock fault and attributed these to a buried fault much longer than the Woodstock fault. Marple and Talwani (References 324 and 325) suggest that this structure, the East Coast Fault System, may have been the source of the 1886 Charleston earthquake. Marple and Talwani (Reference 325) provide additional evidence for the existence of the southern section of the East Coast Fault System, including seismic reflection data, linear aeromagnetic anomalies, exposed Plio-Pleistocene faults, local breccias, and upwarped strata. Because most of the geomorphic anomalies associated with the southern section of the East Coast Fault System are in late Pleistocene sediments, Marple and Talwani (Reference 325) speculate that the fault has been active in the past 130 to 10 ka (thousands of years before present), and perhaps remains active. Wildermuth and Talwani (Reference 411) use gravity and topographic data to postulate the existence of a pull-apart basin between the southern and central sections of the East Coast Fault System, which would imply a component of right-lateral slip on the fault. Wheeler (Reference 406) classifies the East Coast Fault System as a Class C feature based on the lack of demonstrable evidence that the East Coast Fault System has or can generate strong ground motion and the lack of any demonstrable evidence for any sudden uplift anywhere along the proposed fault.

- *Adams Run Fault*. Weems and Lewis (Reference 399) postulate the existence of the Adams Run fault on the basis of microseismicity and borehole data. Their interpretation of borehole data suggests the presence of areas of uplift and subsidence separated by the inferred fault. However, review of this data shows that the pattern of uplift and subsidence does not appear to persist through time (*i.e.,* successive stratigraphic layers) in the same locations and that the intervening structural lows between the proposed uplifts are highly suggestive of erosion along ancient river channels. In addition, there is no geomorphic evidence for the existence of the Adams Run fault, and analysis of microseismicity in the vicinity of the proposed Adams Run fault does not clearly define a discrete structure (Figure 2.5.1-219).

- *Ashley River Fault*. Talwani (Reference 382) identifies the Ashley River fault on the basis of a northwest-oriented, linear zone of seismicity located about 6 miles west of Woodstock, South Carolina, in the meizoseismal area of the 1886 Charleston earthquake. The postulated Ashley River fault, a southwest-side-up reverse fault, is thought to offset the north-northeast striking Woodstock fault about 3 to 4 miles to the northwest near Summerville (References 382, 384, and 399).

- *Charleston Fault*. Lennon (Reference 315) proposed the Charleston fault on the basis of geologic map relations and subsurface borehole data. Weems and Lewis (Reference 399) suggest that the Charleston fault is a major, high-angle reverse fault that has been active at least intermittently in Holocene to modern times. The Charleston fault has no clear geomorphic expression, nor is it clearly defined by microseismicity (Figure 2.5.1-219).

- *Cooke Fault*. Behrendt et al. (Reference 210) and Hamilton et al. (Reference 268) identify the Cooke fault based on seismic reflection profiles in the meizoseismal area of the 1886 Charleston earthquake. This east-northeast striking, steeply northwest-dipping fault has a total length of about 6 miles (10 kilometers) (References 210 and 268). Marple and Talwani (References 324 and 325) reinterpret this data to suggest that the Cooke fault may be part of a longer, more northerly striking fault (*i.e.,* the ZRA of Marple and Talwani [Reference 324] and the East Coast Fault System of Marple and Talwani [Reference 325]). Crone and Wheeler (Reference 232) classify the Cooke fault as a Class C feature based on lack of evidence for faulting younger than Eocene.

- *Drayton Fault*. The Drayton fault is imaged on onshore seismic reflection lines and was known to the six EPRI ESTs in 1986 (Reference 250). The Drayton fault is mapped as a 5.5-mile-long, apparently northeast-trending, high-angle, reverse fault in the meizoseismal area of the 1886 Charleston earthquake (Reference 268) (Figures 2.5.1-219 and 2.5.1-220). The Drayton fault terminates upward at approximately 2,500 feet below the ground surface within a Jurassic-age basalt layer (Reference 268), precluding significant Cenozoic slip on this fault.

- *Gants Fault*. The Gants fault is imaged on onshore seismic reflection lines and was known to the six EPRI ESTs (Reference 250) as a possible Cenozoic-active fault. The Gants fault is mapped as a 5.5-mile-long, apparently northeast-trending, high-angle, reverse fault in the meizoseismal area of the 1886 Charleston earthquake (References 210 and 268) (Figures 2.5.1-219 and 2.5.1-220). The Gants fault displaces vertically a Jurassic-age basalt layer by about 150 feet at approximately 2,500 feet below the ground surface (Reference 268). Overlying Cretaceous and Cenozoic beds show apparent decreasing displacement with decreasing depth (Reference 268), indicating likely Cenozoic activity, but with decreasing displacement on the Gants fault during the Cenozoic.

- *Helena Banks Fault Zone*. The Helena Banks fault zone (Figure 2.5.1-218) is clearly imaged on seismic reflection lines offshore of South Carolina (References 211 and 209) and was known to the six EPRI ESTs in 1986 (Reference 250) as a possible Cenozoic-active fault zone. Some ESTs recognized the offshore fault zone as a candidate tectonic feature for producing the 1886 event and included it in their Charleston seismic source zones. However, since 1986, three additional sources of information have become available:

  – In 2002, two magnitude $m_b \geq 3.5$ earthquakes (m_b 3.5 and 4.4) occurred offshore of South Carolina in the vicinity of the Helena Banks fault zone in an area previously devoid of seismicity.

  – Bakun and Hopper (Reference 206) reinterpret intensity data from the 1886 Charleston earthquake and show that the calculated intensity center is located about 100 miles offshore from Charleston (although they ultimately concluded that the epicentral location most likely lies onshore near the Middleton Place-Summarily seismic zone).

  – Crone and Wheeler (Reference 232) describe the Helena Banks fault zone as a potential Quaternary tectonic feature (although it was classified as a Class C feature that lacks sufficient evidence to demonstrate Quaternary activity). The occurrence of the 2002 earthquakes and the location of the Bakun and Hopper (Reference 206) intensity center offshore suggest, at a low probability, that the fault zone could be considered a potentially active fault. If the Helena Banks fault zone is an active source, its length and orientation could possibly explain the distribution of paleoliquefaction features along the South Carolina coast.

- *Sawmill Branch Fault*. Talwani and Katuna (Reference 385) postulate the existence of the Sawmill Branch fault on the basis of microseismicity and speculate that this feature experienced surface rupture in the 1886 earthquake. According to Talwani and Katuna (Reference 385), this approximately 3-mile (5-kilometer)-long, northwest trending fault, which is a segment of the larger Ashley River fault, offsets the Woodstock fault in a left-lateral sense. Earthquake damage at three localities is used to infer that surface rupture occurred in 1886. Field review of these localities was performed. Features along the banks of the Ashley River (small, discontinuous cracks in a tomb that dates to 1671 AD and displacements [less than 4 inches] in the walls of colonial Fort Dorchester) are almost certainly the product of shaking effects as opposed to fault rupture. Moreover, assessment of microseismicity in the vicinity of the proposed Sawmill Branch fault does not clearly define a discrete structure

distinct or separate from the larger Ashley River fault, which was defined based on seismicity (Figure 2.5.1-219).

- *Summerville Fault*. Weems et al. (Reference 400) postulate the existence of the Summerville fault near Summerville, South Carolina, on the basis of previously located microseismicity. However, there is no geomorphic or borehole evidence for the existence of the Summerville fault, and analysis of microseismicity in the vicinity of the proposed Summerville fault does not clearly define a discrete structure (Figure 2.5.1-219).

- *Woodstock Fault*. Talwani (Reference 382) identifies the Woodstock fault, a postulated north-northeast trending, dextral strike-slip fault, on the basis of a linear zone of seismicity located approximately 6 miles west of Woodstock, South Carolina, in the meizoseismal area of the 1886 Charleston earthquake (Figures 2.5.1-218 and 2.5.1-219). Madabhushi and Talwani (References 318 and 319) use a revised velocity model to relocate Middleton Place-Summerville seismic zone earthquakes, and the results of this analysis are used to further refine the location of the postulated Woodstock fault. Talwani (References 383 and 384) subdivides the Woodstock fault into two segments that are offset in a left-lateral sense across the northwest-trending Ashley River fault. Marple and Talwani include the Woodstock fault as part of their larger ZRA (Reference 324) and East Coast Fault System (Reference 325).

Charleston Area Seismic Zones

Three zones of concentrated microseismic activity have been identified in the greater Charleston area. These include the Middleton Place-Summerville, Bowman, and Adams Run seismic zones. Each of these features is described in detail below, and the specifics of the seismicity catalog are discussed in Subsection 2.5.2.

- *Middleton Place–Summerville Seismic Zone*. The Middleton Place–Summerville seismic zone is an area of elevated microseismic activity located about 12 miles northwest of Charleston (References 387, 218, 319, and 385) (Figure 2.5.1-218). Between 1980 and 1991, 58 events with m_b 0.8 to 3.3 were recorded in an 11 x 14 kilometer area, with hypocentral depths ranging from about 1 to 7 miles (2 to 11 kilometers) (Reference 319). The elevated seismic activity of the Middleton Place-Summerville seismic zone has been attributed to stress concentrations associated with the intersection of the Ashley River and Woodstock faults (References 382, 319, 385, and 260). Persistent foreshock activity was reported in the Middleton Place-Summerville seismic zone area (Reference 249), and it has been speculated that the 1886 Charleston earthquake occurred within this zone (*e.g.,* References 382, 387, and 206).

- *Bowman Seismic Zone*. The Bowman seismic zone is located approximately 50 miles northwest of Charleston, South Carolina, outside of the meizoseismal area of the 1886 Charleston earthquake (Figure 2.5.1-216). The Bowman seismic zone is defined on the basis of a series of $3<M_L<4$ earthquakes that occurred between 1971 and 1974 (References 388 and 218).

- *Adams Run Seismic Zone*. The Adams Run seismic zone is located within the meizoseismal area of the 1886 Charleston earthquake, approximately 115 miles southeast of VCSNS site (Figure 2.5.1-219). The Adams Run seismic zone was originally identified on the basis of four **M**<2.5 earthquakes, three of which occurred in a two-day period in December 1977 (References 387 and 388). Bollinger et al. (Reference 218) downplay the significance of the Adams Run seismic zone, noting that, in spite of increased instrumentation, no additional events were detected after October 1979. Between October 1979 and December 2002, only one additional earthquake occurred in the zone, a coda magnitude 2 event in May 1994 (SCSN 2002) (Reference 421). Weems and Lewis (2002) (Reference 399) used the microseismicity of the Adams Run seismic zone to help define the southern end of their

postulated Adams Run fault (Figure 2.5.1-219). More recently, however, Marple and Miller (2006) (Reference 420) question the existence of the Adams Run fault based on their assessment of seismic reflection data.

Charleston Area Seismically Induced Liquefaction Features

The presence of liquefaction features in the geologic record may be indicative of past earthquake activity in a region (*e.g.,* Reference 339). Liquefaction features are recognized throughout coastal South Carolina and are attributed to both the 1886 Charleston and earlier moderate to large earthquakes in the region.

- *1886 Charleston Earthquake Liquefaction Features.* Liquefaction features produced by the 1886 Charleston earthquake are most heavily concentrated in the meizoseismal area (References 249, 369, and 201), but are reported as far away as Columbia, Allendale, Georgetown (Reference 369) and Bluffton, South Carolina (Reference 386) (Figures 2.5.1-217 and 2.5.1-218).

- *Paleoliquefaction Features in Coastal South Carolina.* Liquefaction features predating the 1886 Charleston earthquake are found throughout coastal South Carolina (Figures 2.5.1-217 and 2.5.1-218). The spatial distribution and ages of paleoliquefaction features in coastal South Carolina constrain possible locations and recurrence rates for large earthquakes (References 340, 341, 201, 202, and 203). Talwani and Schaeffer (Reference 386) combine previously published data with their own studies of liquefaction features in the South Carolina coastal region to derive possible earthquake recurrence histories for the region. Talwani and Schaeffer's (Reference 386) Scenario 1 allows for the possibility that some events in the paleoliquefaction record are smaller in magnitude (approximately **M** 6+), and that these more moderate events occurred to the northeast (Georgetown) and southwest (Bluffton) of Charleston. In Talwani and Schaeffer's (Reference 386) Scenario 2, all earthquakes in the record are large events (approximately **M** 7+) located near Charleston. Talwani and Schaeffer (Reference 386) estimate recurrence intervals of about 550 years and approximately 900 to 1,000 years from their two scenarios. Subsection 2.5.2 provides discussion of the interpretation of the paleoliquefaction record used to define earthquake recurrence for the Charleston earthquake source.

  Because there is no surface expression of faults within the Charleston seismic zone, earthquake recurrence estimates are based largely on dates of paleoliquefaction events. The most recent summary of paleoliquefaction data (Reference 386) suggests a mean recurrence time of 550 years for Charleston, which was used in the 2002 USGS hazard model (Reference 255). This recurrence interval is less than the 650-year recurrence interval used in the earlier USGS hazard model (Reference 254) and is roughly an order of magnitude less than the seismicity based recurrence estimates used in EPRI (Reference 250). Refinements of the estimate of Charleston area earthquake recurrence are presented in detail in Subsection 2.5.2.

  In an abstract published after Talwani and Schaeffer's (Reference 386) compilation and interpretation of South Carolina liquefaction and paleoliquefaction data, Talwani et al. (Reference 432) describe a previously undiscovered paleoliquefaction feature near Fort Dorchester in the meizoseismal area of the 1886 Charleston, South Carolina, earthquake. Talwani et al. (Reference 432) describe this feature as a 1-m-wide sandblow at a depth of approximately 0.5 m below the ground surface. There are no radiocarbon or other quantitative age constraints on this feature. Talwani et al. (Reference 432), however, indicate a pre-1886 age for this sandblow, presumably on the basis of burial depth and degree of soil formation. Based on unspecified back calculation techniques, Talwani et al. (Reference 432)

estimate a magnitude of ~6.9 (magnitude scale unspecified) for the causative earthquake. Very little is known about the earthquake that produced Talwani et al.'s (Reference 432) paleoliquefaction feature. As such, the discovery of this paleoliquefaction feature does not provide any additional constraints on the timing, magnitude, or location of Charleston paleoearthquakes, beyond those presented in Talwani and Schaeffer (Reference 386).

2.5.1.1.3.2.2 Eastern Tennessee Seismic Zone

The Eastern Tennessee Seismic Zone is one of the most active seismic zones in eastern North America. The Eastern Tennessee Seismic Zone is located in the Valley and Ridge province of eastern Tennessee, approximately 175 miles northwest of the VCSNS site. The Eastern Tennessee Seismic Zone is about 185 miles (300 kilometers) long and 30 miles (50 kilometers) wide and has not produced a damaging earthquake in historical time (Reference 345) (Figure 2.5.1-216). Despite its high rate of activity, the largest known earthquake was magnitude 4.6 (magnitude scale not specified) (Reference 224).

Earthquakes in the Eastern Tennessee Seismic Zone are occurring at depths from 3 to 16 miles (5 to 26 kilometers) within Precambrian crystalline basement rocks buried beneath the exposed thrust sheets of Paleozoic rocks. The mean focal depth within the seismic zone is 9 miles (15 kilometers), which is well below the Appalachian basal decollement's maximum depth of 3 miles (5 kilometers) (Reference 345). The lack of seismicity in the shallow Appalachian thrust sheets implies that the seismogenic structures in the eastern Tennessee Seismic Zone are unrelated to the surface geology of the Appalachian orogen (Reference 300). The majority of earthquake focal mechanisms show right-lateral slip on northerly striking planes or left-lateral slip on easterly striking planes (Reference 223). A smaller number of focal plane solutions show right-lateral motion on northeasterly trending planes that parallel the overall trend of seismicity (Reference 224). Statistical analyses of focal mechanisms and epicenter locations suggest that seismicity is occurring on a series of northeast striking en-echelon basement faults intersected by several east-west striking faults (Reference 223). Potential structures most likely responsible for the seismicity in eastern Tennessee are reactivated Cambrian or Precambrian normal faults formed during the rifting that formed the Iapetan Ocean and presently located beneath the Appalachian thrust sheets (References 217 and 404).

Earthquakes within the Eastern Tennessee Seismic Zone cannot be attributed to known surface faults (Reference 345), and no capable tectonic sources have been identified within the seismic zone. However, the seismicity is spatially associated with major geophysical lineaments. The western margin of the Eastern Tennessee Seismic Zone is sharply defined and is coincident with the prominent gradient in the magnetic field defined by the New York-Alabama magnetic lineament (Reference 224).

The EPRI Seismicity Owners Group source model (Reference 250) includes various source geometries and parameters to represent the seismicity of the Eastern Tennessee Seismic Zone. Each of the EPRI ESTs modeled source zones to capture this area of seismicity and some ESTs included multiple source zones (see detailed discussion in Subsection 2.5.2). A wide range of maximum magnitude (M_{max}) values and associated probabilities were assigned to these sources to reflect the uncertainty of multiple experts from each EST. The EPRI M_{max} distributions for these sources range from m_b 5.2 to 7.2.

Subsequent hazard studies have used M_{max} values within the range of maximum magnitudes used by the six EPRI models. Collectively, upper-bound maximum values of M_{max} used by the EPRI ESTs range from **M** 6.3 to 7.5 (conversion from m_b to **M** by arithmetic mean of three equally weighted relations: Atkinson and Boore (Reference 204), Frankel et al. (Reference 254), and EPRI (Reference 251). Subsection 2.5.2.2.2.5 describes M_{max} values used for the ETSZ in hazard studies subsequent to the EPRI models.

In spite of the observations of small to moderate earthquakes in the Eastern Tennessee Seismic Zone, no geological evidence, such as paleoliquefaction, demonstrates the occurrence of prehistoric earthquakes larger than any historical shocks within the seismic zone (References 224 and 406). As a result, Wheeler (Reference 406) classifies the Eastern Tennessee Seismic Zone as a Class C feature for lack of geological evidence of large earthquakes. While the lack of large earthquakes in the relatively short historical record cannot preclude the future occurrence of large events, there is a much higher degree of uncertainty associated with the assignment of M_{max} for the Eastern Tennessee Seismic Zone than other CEUS seismic source zones, such as New Madrid and Charleston, where large historical earthquakes are known to have occurred. In conclusion, no new information has been developed since 1986 that would require a revision to the magnitude distribution of EPRI representations of the Eastern Tennessee Seismic Zone. EPRI representations of the geometry, recurrence, and M_{max}, for the Eastern Tennessee Seismic Zone encompass the range of values used in more recent characterizations of the Eastern Tennessee Seismic Zone such as the Trial Implementation Project Study (Reference 358) and USGS source model (Reference 255).

2.5.1.1.3.2.3 Selected Seismogenic and Capable Tectonic Sources Beyond the Site Region

In addition to the areas of concentrated seismicity within the site region, three additional areas of concentrated seismicity beyond the site region (*i.e.,* the New Madrid, Central Virginia, and Giles County seismic zones) are discussed below:

New Madrid Seismic Zone

The New Madrid seismic zone extends from southeastern Missouri to southwestern Tennessee and is located more than 450 miles west of the VCSNS site (Figure 2.5.1-216). The New Madrid seismic zone lies within the Reelfoot rift and is defined by post-Eocene to Quaternary faulting and historical seismicity. Given the significant distance between the site and the seismic zone, the New Madrid seismic zone did not contribute to 99% of the hazard at the VCSNS site in EPRI (Reference 250). However, it is described in this subsection because several recent studies provide significant new information regarding magnitude and recurrence interval for the seismic zone. The updated New Madrid seismic source model is presented in Subsection 2.5.2.

The New Madrid seismic zone is approximately 125 miles (220 kilometers) long and 25 miles (40 kilometers) wide. Research conducted since 1986 identifies three distinct fault segments embedded within the seismic zone. These three fault segments include a southern northeast trending dextral slip fault, a middle northwest trending reverse fault, and a northern northeast trending dextral strike-slip fault (Reference 407). In the current east-northeast to west-southwest directed regional stress field, Precambrian and Late Cretaceous age extensional structures of the Reelfoot rift appear to have been reactivated as right-lateral strike-slip and reverse faults.

The New Madrid seismic zone produced a series of historical, large magnitude earthquakes between December 1811 and February 1812 (Reference 293). The December 16, 1811 earthquake is associated with strike-slip fault displacement along the southern portion of the New Madrid seismic zone. Johnston (Reference 297) estimates a magnitude of **M** 8.1±0.31 for the December 16, 1811 event. However, Hough et al. (Reference 293) reevaluate the isoseismal data for the region and conclude that the December 16 event had a magnitude of **M** 7.2 to 7.3. Bakun and Hopper (Reference 206) similarly conclude this event had a magnitude of **M** 7.2.

The February 7, 1812 New Madrid earthquake is associated with reverse fault displacement along the middle part of the New Madrid seismic zone (Reference 299). This earthquake most likely occurred along the northwest trending Reelfoot fault that extends approximately 43 miles from northwestern Tennessee to southeastern Missouri. The Reelfoot fault is a northwest trending, southwest vergent reverse fault. The Reelfoot fault forms a topographic scarp developed as a result

of fault propagation folding (References 394, 303, and 393). Johnston (Reference 297) estimates a magnitude of **M** 8.0±0.33 for the February 7, 1812, event. However, Hough et al. (Reference 293) reevaluate the isoseismal data for the region and conclude that the February 7 event had a magnitude of **M** 7.4 to 7.5. More recently, Bakun and Hopper (Reference 206) estimate a similar magnitude of **M** 7.4.

The January 23, 1812 earthquake is associated with the northern portion of the New Madrid seismic zone (References 293 and 206). Johnston (Reference 297) estimates a magnitude of **M** 7.8±0.33 for the January 23, 1812, event. Hough et al. (Reference 293), however, reevaluate the isoseismal data for the region and conclude that the January 23 event had a magnitude of **M** 7.1. More recently, Bakun and Hopper (Reference 206) estimate a similar magnitude of **M** 7.1.

Because there is very little surface expression of faults within the New Madrid seismic zone, earthquake recurrence estimates are based largely on dates of paleoliquefaction and offset geological features. The most recent summaries of paleoseismologic data (References 390, 391, and 265) suggest a mean recurrence time of 500 years, which was used in the 2002 USGS model (Reference 255). This recurrence interval is half of the 1,000-year recurrence interval used in the 1996 USGS hazard model (Reference 254), and an order of magnitude less than the seismicity based recurrence estimates used in EPRI (Reference 250).

The upper-bound maximum values of M_{max} used in EPRI (Reference 250) range from m_b 7.2 to 7.9. Since the EPRI study, estimates of M_{max} are generally within the range of maximum magnitudes used by the six EPRI models. The most significant update of source parameters in the New Madrid seismic zone since the 1986 EPRI study is the reduction of the recurrence interval to 500 years.

Central Virginia Seismic Zone

The Central Virginia Seismic Zone is an area of persistent, low-level seismicity in the Piedmont province, located more than 250 miles from the VCSNS site (Figure 2.5.1-216). The zone extends about 75 miles in a north-south direction and about 90 miles in an east-west direction from Richmond to Lynchburg, Virginia (Reference 216). The largest historical earthquake to occur in the Central Virginia Seismic Zone was the body-wave magnitude (m_b) 5.0 Goochland County event on December 23, 1875 (Reference 216). The maximum intensity estimated for this event was MMI VII in the epicentral region. In addition to the historical record of earthquakes in this zone, evidence for prehistoric ground shaking is recorded at two paleoliquefaction sites within the zone (References 232 and 238).

Seismicity in the Central Virginia Seismic Zone ranges in depth from about 2 to 8 miles (4 to 13 kilometers) (Reference 408). Coruh et al. (Reference 231) suggest that seismicity in the central and western parts of the zone may be associated with west dipping reflectors that form the roof of a detached antiform, while seismicity in the eastern part of the zone near Richmond may be related to a near-vertical diabase dike swarm of Mesozoic age. However, given the depth distribution of 2 to 8 miles (4 to 13 kilometers) (Reference 408) and broad spatial distribution, it is difficult to uniquely attribute the seismicity to any known geologic structure, and it appears that the seismicity extends both above and below the Appalachian detachment.

The historical and prehistoric seismicity within the Central Virginia Seismic Zone is not positively associated with any clearly defined fault or faults. As such, the seismic hazard in this zone is modeled as areal seismic source zones.

The 1986 EPRI source model includes various source geometries and parameters to capture the seismicity of the Central Virginia Seismic Zone (Reference 250). Subsequent hazard studies use M_{max} values that are within the range of maximum magnitudes used by the six EPRI models. Collectively, upper-bound maximum values of M_{max} used by the EPRI ESTs range from m_b 6.6 to 7.2 (discussed in Subsection 2.5.2). More recently, Bollinger (Reference 215) estimates an M_{max} of m_b

6.4 for the Central Virginia seismic source. Chapman and Krimgold (Reference 222) use an M_{max} of m_b 7.25 for the central Virginia seismic source and most other sources in their seismic hazard analysis of Virginia. This more recent estimate of M_{max} is similar to the M_{max} values used in EPRI (Reference 250). Similarly, the distribution and rate of seismicity in the central Virginia seismic source have not changed since the 1986 EPRI study (discussed in Subsection 2.5.2). Thus, there is no change to the source geometry or rate of seismicity. Therefore, the conclusion is that no new information has been developed since 1986 that would require a significant revision to the EPRI seismic source model.

Giles County Seismic Zone

The Giles County seismic zone is located in Giles County, southwestern Virginia, near the border with West Virginia, approximately 200 miles from the VCSNS site (Figure 2.5.1-216). The largest known earthquake to occur in Virginia and the second largest earthquake in the entire southeastern United States is the 1897 **M** 5.9 (Reference 301) Giles County event, which likely produced an MMI VIII in the epicentral area.

Earthquakes in the Giles County seismic zone occur within Precambrian crystalline basement rocks beneath the Appalachian thrust sheets at depths from 3 to 16 miles (5 to 25 kilometers) (Reference 217). Earthquake foci define a 25-mile (40-kilometer)-long, northeasterly striking, tabular zone that dips steeply to the southeast beneath the Valley and Ridge thrust sheets (References 217 and 222). The lack of seismicity in the shallow Appalachian thrust sheets, estimated to be about 2 to 3.5 miles (4 to 6 kilometers) thick, implies that the seismogenic structures in the Giles County seismic zone, similar to those inferred for the Eastern Tennessee Seismic Zone, are unrelated to the surface geology of the Appalachian orogen (Reference 217). The spatial distribution of earthquake hypocenters, together with considerations of the regional tectonic evolution of eastern North America, suggests that the earthquake activity is related to contractional reactivation of late Precambrian or Cambrian normal faults that initially formed during rifting associated with opening of the Iapetan Ocean (References 217 and 218).

No capable tectonic sources are identified within the Giles County seismic zone, nor does the seismic zone have recognizable geomorphic expression (Reference 406). Thus, in spite of the occurrence of small to moderate earthquakes, no geological evidence has demonstrated the occurrence of prehistoric earthquakes larger than any historical shocks within the zone (Reference 406). As a result, Wheeler (Reference 406) classifies the Giles County seismic zone as a Class C feature for lack of geological evidence of large earthquakes.

A zone of small Late Pliocene to Early Quaternary age faults is identified within the Giles County seismic zone near Pembroke, Virginia (References 313 and 232). The Pembroke faults are a set of extensional faults exposed in terrace deposits overlying limestone bedrock along the New River. Law et al. (Reference 313) interpret the Pembroke faults as tectonic in origin, but suggest the possibility that they may be related to either solution collapse or landsliding. Crone and Wheeler (Reference 232) rate these faults as Class B features because it has not yet been determined whether these faults are tectonic or the result of solution collapse in underlying limestone units. The shallow Pembroke faults do not appear to be related to the seismicity within the Giles County seismic zone, which is occurring beneath the Appalachian basal decollement in the North American basement. Subsection 2.5.1.1.2.4.4 presents additional discussion of the Pembroke faults.

The EPRI source model includes various source geometries and parameters to represent the seismicity of the Giles County seismic zone (Reference 250). Subsequent hazard studies use M_{max} values that are within the range of maximum magnitudes used by the six EPRI models. Collectively, upper-bound maximum values of M_{max} used by the EPRI teams ranged from m_b 6.6 to 7.2 (discussed in Subsection 2.5.2). More recently, Bollinger (Reference 215) estimates an M_{max} of m_b 6.3 for the Giles County seismic source using three different methods. Chapman and Krimgold (Reference 222) use an M_{max} of m_b 7.25 for the Giles County zone and most other sources in their

seismic hazard analysis of Virginia. Both of these more recent estimates of M_{max} are similar to the range of M_{max} values used in EPRI (Reference 250). Therefore, no new information has been developed since 1986 that would require a significant revision to the EPRI seismic source model.

2.5.1.2 Site Geology

This subsection presents descriptions of the geologic conditions present in the VCSNS site area (and, in some cases, the site vicinity). Subsections detailing the physiography and geomorphology, geologic history, stratigraphy, structural geology, engineering geology, seismicity and paleoseismology, and groundwater of the site area are included.

The site geology is typical of the region as verified through field reconnaissance and evaluation of core obtained from the foundation investigation. Data from previous geologic studies are also used as well as a literature review and discussions with regional experts. The following subsections discuss the physiography, general geology, and structural setting of the site area.

The geology of the site and surrounding area has been extensively studied. Previous investigations performed for Unit 1, as well as published geologic mapping, provide valuable information regarding the geologic history, stratigraphy, and structure of site area. Recent geologic investigations including additional borings completed for the foundation investigation and field mapping within the site area, complement the existing data.

2.5.1.2.1 Site Area Physiography and Geomorphology

The site is located within the Piedmont physiographic province of central South Carolina. The Piedmont physiographic province is bounded on the southeast and northwest by the Coastal Plain and Blue Ridge physiographic provinces, respectively. The site lies approximately 1.5 miles northeast of Parr, South Carolina and about 1 miles east of the Broad River. The site topography is characteristic of the region, consisting of gently to moderately rolling hills and generally well-drained mature valleys (Figures 2.5.1-221 and 2.5.1-222). Within the 5-mile site area, topography ranges from about 220 to 520 feet MSL. All local tributaries drain into the Broad River. The local drainage pattern is generally dendritic, with subtle trellis patterns that are likely the result of regional bedrock structure and joint systems. Steep gullies exist within the site area resulting from differential weathering of the basement rock and possible exacerbation by previous agricultural activity. Construction activities associated with Unit 1 have altered the topography of the site, as shown by comparison of pre-Unit 1 construction site topography (Figure 2.5.1-222) with post-Unit 1 shaded relief (Figure 2.5.1-223).

Most of the local terrain is mantled by residual soils and saprolite that overlie igneous and metamorphic bedrock at depth. Relatively few natural bedrock outcrops are present within the site area, indicative of the long weathering history of the Piedmont.

2.5.1.2.2 Site Area Geologic Setting and History

The site is located in the Carolina Zone, an amalgamation of metaigneous-dominated terranes along the eastern flank of the southern Appalachians (Reference 283). The site lies within the Charlotte Terrane, the westernmost subdivision of the Carolina Zone. The Charlotte Terrane is dominated by Neoproterozoic to Early Paleozoic plutonic rocks that intrude a suite of predominantly metaigneous rocks (Reference 283). The western limit of the Charlotte Terrane and Carolina Zone is the Central Piedmont shear zone, a late Paleozoic ductile thrust, located approximately 15 miles northwest of the site.

Piedmont rocks of the Carolina Zone consist of a complex series of interlayered and folded amphibolite grade metamorphic rocks (Figures 2.5.1-220, 2.5.1-224, and 2.5.1-225).

Figure 2.5.1-224 shows geology of the site area as mapped by Secor et al. (Reference 364) and Horton and Dicken (Reference 289). Figure 2.5.1-225 shows unpublished, updated mapping of the site area and portions of the site vicinity (Reference 363). Plutonic intrusions of granitic to granodioritic composition are common, as are diabase dikes of Mesozoic age. Although limited outcrops and exposures make detailed mapping difficult, the site area has been extensively studied resulting in a more comprehensive understanding of the site area within the regional context of the Piedmont.

Results of radiometric age dating analyses performed as part of detailed studies for Unit 1 indicate the following sequence of events affecting the rocks of the site area (References 240, 241, 242, 243, and 244):

1. Deposition of quartzose, argillaceous, silty, and feldspathic arenaceous rocks, and extrusion of mafic volcanic rocks in an early Paleozoic archipelago or island arc setting
2. Deep burial
3. Complex folding, faulting, and regional metamorphism of the Charlotte Belt
4. Intrusion, crystallization, and cooling of granodiorite/adamellite plutons
5. Production of joints in response to a broad regional stress field
6. Introduction of fluids, triggering precipitation of aplite and pegmatoid dike rocks along portions of the joint system
7. Minor displacement along northeast trending joint system
8. Very minor displacement along northwest trending joint system
9. Hydrothermal alteration along some joints, and alteration and recrystallization of microbreccias along all segments of shears
10. Epeirogenic uplift, weathering, and erosion

Radiometric age dates from Rb-Sr and K-Ar measurements indicate the following absolute age chronology:

1. Crystallization and cooling of Winnsboro plutonic complex granodiorite by approximately 300 Ma
2. Emplacement of aplite dikes no later than 227 Ma
3. Shearing along the joint systems
4. Hydrothermal introduction of laumontite and annealing of microbreccias within the shears no earlier than 300 and no later than 45 Ma, and probably between 300 and 150 Ma

2.5.1.2.3 Site Area Stratigraphy

The site is located within the Winnsboro plutonic complex, a granitoid plutonic complex that includes abundant xenoliths of older surrounding greenschist- and amphibolite-facies metamorphic rocks (Reference 364). The felsic Winnsboro plutonic complex intruded the metamorphic country rock, which is composed primarily of complexly interlayered and folded gneiss and amphibolite. Lithologic contacts and foliations in the metamorphic rocks exhibit a predominant northeast striking structural grain and are interpreted to represent metamorphosed rocks of igneous, volcanic, and sedimentary origin (Reference 364).

The Carboniferous plutonic rocks at the site are primarily granodiorite. Unweathered granodiorite samples obtained from the excavation for Unit 1 yield Rb-Sr and K-Ar ages of about 300 Ma (Reference 240). Borehole data from the area of Units 2 and 3 indicate that the Winnsboro plutonic complex includes a range of igneous rock compositions and textures that include granodiorite, quartz diorite, migmatite, and pegmatite dikes.

The youngest rock type in the site area is a series of steeply dipping diabase dikes emplaced during Mesozoic extension associated with rifting of the Atlantic Ocean. Individual dikes strike N15° to 30°W, are up to several miles long, and typically a few to tens of feet in thickness.

A relatively thick weathering profile is developed on the bedrock units in the site area. Outcrops of basement rock are primarily limited to roadcuts and fluvial valleys. The residual soil and saprolite predominantly consist of red to reddish-brown stiff clayey and silty soils with varying sand content. The residual soils become more yellow to reddish-brown with depth. Sand content and density of the residual soil and saprolite generally increase with depth. Saprolite is differentiated from residual soil by the presence of relict rock fabric. Alluvial deposits are present along the Broad River, Frees Creek, and in the flatter segments of smaller drainages and erosion gullies in the site area.

Borings drilled as part of the foundation investigation for Units 2 and 3 indicate that the thickness of residual soil and saprolite varies considerably across the site area. Figure 2.5.1-226 shows a surficial geologic map of the site area and B-series (*e.g.,* B-215, B-216, etc.) boring locations (see Subsection 2.5.4). Subsurface sections were constructed near Units 2 and 3 (Figure 2.5.1-227), section locations shown on Figure 2.5.1-228). These sections were constructed to illustrate the irregular distribution of rock types within the Winnsboro plutonic complex, the variability of residual soil and saprolite thicknesses, and the variability in depths to sound rock. As shown on these sections, the thicknesses of residual soil and saprolite are highly variable at the site. Maximum thickness of residual soil is about 40 feet. Maximum thickness of saprolite is about 50 feet. The combined thickness of residual soil and saprolite ranges from about 25 to 70 feet at Units 2 and 3 (Figure 2.5.1-227). The variation and irregular thickness of the weathered zone is likely due to the rock lithology, orientation of foliation or joints, and/or surface topography. Rock outcrops in limited areas indicate that residual soil and saprolite are locally absent. (Figure 2.5.1-226).

Beneath the saprolite, bedrock is classified as partially weathered rock, moderately weathered rock, and sound rock to reflect the degree of increased weathering with depth. The term “sound rock” is defined in this subsection “as generally hard, slightly discolored to fresh (bright mineral surfaces) rock with slight alteration/staining localized along joints and shears in the rock mass.” Rock quality designation typically exceeds about 70%. Zones of sound rock may be underlain by zones of rock quality designation <70% but that are composed of mostly slightly weathered to fresh rock” (Reference 317). This definition of sound rock is based on the determination of the rock quality designation and visual observations of the rock core. The definition of “sound,” “fresh,” or “hard” rock can vary depending on which geologic, geotechnical, or geophysical parameters or properties form the basis of the definition. For example, as described in Subsection 2.5.4, shear wave velocity (Vs) is used to assess the seismic wave transmission properties of foundation materials.

As shown in Figure 2.5.1-227, the combined thickness of the "partially weathered rock" (PWR) and "rock" mass overlying sound rock is variable and can range between about 0 and 20 feet in the vicinity of Units 2 and 3. The depth to sound rock reflects an irregular weathering profile in the Winnsboro plutonic complex and ranges from about 40 to 75 feet in the vicinity of Units 2 and 3 (Figure 2.5.1-227).

Outcrop areas mapped in the site area vicinity include both plutonic rocks of the Winnsboro plutonic complex and metamorphic country rock (Reference 364). These rock lithologies compare well with lithologies encountered from borings drilled as part of the foundation investigation. Evaluation of the core indicates the presence of Winnsboro Complex rocks, amphibolite-grade metamorphic country rocks, and migmatitic rocks indicative of contact margins.Figure 2.5.1-228 shows a contour map of the sound rock surface at Units 2 and 3, and also shows the rock types encountered at the top of sound rock (Reference 317).

An exposure located to the northwest of the site at the Fairfield Pump Storage Facility penstocks provides valuable insight to the crosscutting relationships and macroscale features and variations of the plutonic rocks. Figure 2.5.1-229 shows an assembled panoramic view of the exposure. Rock fabric features such as flow structures, pegmatites, and brecciated mafic inclusions are present, indicating the complex nature of the rock assemblage at the site.

Within the site area, three major rock categories are identified, each containing a further division of individual rock facies. The most prevalent category consists predominantly of granitic rocks (granodiorite and quartz diorite) associated with the Winnsboro plutonic complex. The second consists of amphibolite grade metamorphic rocks (biotite and hornblende gneiss and amphibolite schist) associated with the Carolina Zone. The third category consists of migmatitic rocks associated with margin contacts and multiphase plutonism. These three categories are described below.

Granodiorite and Quartz Diorite

Granodiorite and quartz diorite are the most commonly encountered rocks in the site area, as indicated by geologic mapping, borings, and previous geologic studies and excavation mapping programs performed for Unit 1. Detailed excavation mapping performed for Unit 1 indicates both concordant and discordant contacts between the plutonic granites and country rock consisting of more foliated gneissic and schistose rocks. Moreover, orientation data on the country rock was found to be irregularly discordant near the pluton boundary indicating the intrusive and disruptive nature of the pluton units. Rocks of the Winnsboro plutonic complex are assigned a Carboniferous age (Reference 364).

Biotite and Hornblende Gneiss and Amphibolite Schist.

Amphibolite-grade metaigneous and metasedimentary rocks of the Carolina Zone encountered within the site area include biotite and hornblende gneiss and amphibolite schist. These rocks are likely Cambrian or older in age (Reference 364).

Migmatites

Migmatites are the least commonly encountered rock type in the site area based on field reconnaissance data, geologic mapping, and core from foundation borings. The best exposure of migmatites is located near the Fairfield Pumped Storage Facility penstocks (Figure 2.5.1-229). Migmatite composition ranges from granitic to dioritic with crystal sizes ranging from aphanitic to phaneritic. Textures include flow structures that range from anastomosing to laminar resembling gneissic banding. Inclusions are often present including granitic (plutonic), gneissic (country rock) and basaltic clasts. Brecciation of the inclusions is common. Recognition of migmatites in core is problematic due the physical scale of features such as inclusions and flow structures that may be mistaken for foliation.

2.5.1.2.4 Site Area Structural Geology

Previous geologic investigations in the site area include studies conducted for the VCSNS site as well as geologic mapping completed in the surrounding area. In addition to extensive literature research of regional tectonism, specific investigations include:

- Detailed geologic mapping of excavations
- Regional geologic reconnaissance
- Trench mapping
- Radiometric dating
- X-ray diffraction analysis
- Aerial photography and ERTS imagery analysis
- Geophysical surveys including gravity and magnetics
- In situ stress measurements
- Evaluation of microseismal data related to reservoir impoundment

These studies help to establish the structural history of the site and surrounding region and synthesize the data acquired from the shear zones noted in the excavation for Unit 1.

Field reconnaissance was performed in the site region, site vicinity, site area, and site, with the level of effort progressively increasing with proximity to the site. The program was designed to augment and verify aspects of previous geologic maps from the Unit 1 FSAR, and publications by the USGS, state agencies, and other literature sources. Specific activities relative to the site area included:

- Review of geologic maps with respect to field exposures
- Reconnaissance of the VCSNS site
- Updating the site geologic map (from FSAR)
- Observation of accessible geologic exposures (outcrops, cutslopes, stream banks, and roadcuts) within the site (0.6-mile radius) and more significant exposures within the site area (5-mile radius)
- Analysis of USGS stereo aerial photography of site area taken before construction of Unit 1 and comparison to subsequent mapping and field exposures
- Field reconnaissance of all previously mapped faults and folds within site area (5-mile radius)
- Aerial reconnaissance of the site (0.6-mile radius) and site area (5-mile radius) to identify geomorphic features indicative of potential faulting or other geologic hazards

The site area investigations showed no history of landsliding, subsidence, uplift, or collapse resulting from slope failures, tectonic activity, or karstic dissolution. Additionally, review of the site physiography has identified no characteristics that would indicate the potential for these events in the future.

During construction of Unit 1, minor bedrock shears were exposed in the foundation after removal of approximately 100 feet of residual overburden (Figure 2.5.1-230). Detailed investigations were conducted to evaluate these features by both the applicant's consultant (Reference 240) and the NRC staff and its consultants (Reference 392). Based on the results of the analyses, the staff concluded that:

- The minor shears are not capable faults as defined by 10 CFR 100, Appendix A
- The impoundment of the Monticello Reservoir will not adversely affect these faults
- The seismic design bases as presented in the Safety Evaluation Report represent appropriately conservative values (Reference 392).

These minor shears and fractures are common to rocks throughout the Piedmont (References 364 and 433) and may be encountered within the foundation excavations for Units 2 and 3. During excavation for these units, detailed mapping of the foundation exposures will provide the ability to document the presence or absence of these minor bedrock shears, which typically cannot be recognized nor adequately characterized by surficial mapping or analysis of drill core.

The scope of investigation performed by Dames & Moore (Reference 240) for Unit 1 included detailed geologic mapping, sampling, excavation of trenches, drilling of an inclined boring, petrofabric analyses, structural analyses, radiometric dating, X-ray diffraction analysis, literature review, air photo and imagery analysis, gravity and magnetic data analysis, in situ stress measurements, evaluation of potential movement along shears due to the filling of the Monticello Reservoir, review of local microseismic data, correlation of Piedmont seismic activity with reservoir impoundments, and offsite geologic reconnaissance.

The Unit 1 excavation exposed near-vertical, northeast, and northwest striking sets of shears that appear to follow the joint system (Reference 240). Additional excavations for the staging area, control building, intermediate building wall, and north dam of the service water pond were mapped to document these features (References 241, 242, 243, and 244) (Figures 2.5.1-230 and 2.5.1-231). The dominant set of shears are northeast striking, oblique-slip faults with left-lateral and south-side-down normal components of slip. The dominant faults are divided into Zones 1, 2, and 3 (Figure 2.5.1-230). Zone 3 faults are the most significant and exhibit a maximum displacement of about 7 feet. Individual shear zones range in thickness from a fraction of an inch to less than 2 feet and exhibit an en echelon map pattern with several of the smaller shears terminating within the exposure. The shears do not penetrate the overlying soil profile to the ground surface. Many shears exhibit growth of a mineral assemblage indicative of hydrothermal origin. The presence of undeformed, euhedral laumontite (zeolite) crystals on many of the shear surfaces indicates that these minor faults have not slipped since the hydrothermal activity. Rb-Sr and K-Ar age dating of the hydrothermal laumonite and surrounding rock, along with other lines of evidence, constrain the hydrothermal event to some time before 45 Ma, with a likely Mesozoic age (References 240 and 392). The Mesozoic timing of last movement on the bedrock shears demonstrates that these features are not capable tectonic sources and represent neither a ground motion hazard nor a surface rupture hazard to the site.

The following discussion summarizes the sampling and analyses presented in Dames & Moore (1974) (Reference 240), as well as key observations and results that demonstrate the analyses were performed for those parts of the shear zones that experienced the last movement, and that the last movement is constrained as no younger than Mesozoic in age.

Samples for age dating were collected from the least-weathered microbreccia in each of the widest shears from shear Zones 1 and 3. Control samples were also collected from unfractured and unweathered rock, approximately 5 to 15 feet on either side of the primary sample locations. Based

on crosscutting field relationships, the microbreccia and hydrothermal mineral growth along shear zones post-date formation of the younger rock units (granodiorite and aplite dikes), and thus were the focus of additional sampling. From shear Zone 3, specimens were collected for X-ray diffraction to identify minerals and fracture-filling material related to hydrothermal activity. Hand picking of individual crystals using needle and tweezers isolated a pure mineral concentrate for X-ray diffraction analysis. This analysis identified the predominant hydrothermal mineral as laumonite, occurring as both vein filling in the microbreccias and as euhedral and subhedral crystals in vugs along shears. Euhedral crystals of laumontite were also sampled in this same manner for K-Ar age dating. X-ray diffraction identified lesser amounts of alpha quartz and kaolin within the microbreccias.

Both mesoscopically and microsopically, the microbreccias appear to be produced by brittle failure, exhibiting angular rock and crystal fragments suspended in a matrix of compositionally similar, but finer, material. Under 200x and 400x magnification, the matrix has a distinct interlocking crystal mosaic and there is no evidence of un-recrystallized rock powder. The microbreccias, which typically exhibit a thickness of one to two inches but locally widen to a maximum width of less than two feet, are thoroughly permeated by hydrothermal laumontite, which occurs as both vein filling and crystals and crystal groups in microbreccia. The following mesoscopic and microscopic observations indicate the hydrothermal activity post-dates brittle displacement along the Unit 1 foundation shears and that no additional displacement has occurred since the hydrothermal activity:

- Crosscutting relationships in the Unit 1 excavation reveal the latest movement occurred on the northwest-striking set of shears (maximum slip of 4 inches) as opposed to the more common northeast-striking shears (maximum slip of 7 feet). Hydrothermal mineralization appears along both sets of shears and also, to a lesser extent, other joint surfaces that exhibit no displacement within the Unit 1 excavation. This demonstrates that the hydrothermal event post-dates the formation of joints and shears.

- "Vugs up to about 18 inches long lined with euhedral pink laumontite crystals up to about 10 mm long (Photographs #10 and 11) were observed in all shear orientations. At least two points (Plate 14) along a principal shear in shear zone 3, and elsewhere, laumontite crystals completely fill the shear, having grown inward from both walls." The lack of deformation of these crystals indicates that no displacement has occurred on these minor shears following crystal growth.

- In thin-section, "delicate microscopic overgrowths on microcline crystals project into laumontite vein filling or micorbreccia and have not been disturbed by shearing or crushing."

Given that unsheared hydrothermal mineralization occurs in both sets of shears (northwest- and northeast-striking), no movement has occurred along these surfaces since the hydrothermal event. Radiometric dating of rock and mineral specimens from the VC Summer Unit 1 excavation (Dames & Moore 1974) (Reference 240) constrain the timing of slip on the shears to have occurred: (1) after the cooling of the granodiorite approximately 300 Ma and emplacement of aplite dikes no later than 227 Ma; and (2) before the hydrothermal mineralization prior to 45 Ma, based on the K-Ar age of the laumontite crystals. The 45 Ma age for the formation of laumontite is considered a minimum, and since there are no known occurrences of hydrothermal activity within the stability field of laumontite in the Piedmont since Triassic and Jurassic time, the likely age of the laumontite is late Paleozoic to Mesozoic (300-150 Ma) (Dames & Moore 1974) (Reference 240). Therefore, the minor shears exposed in the VC Summer Unit 1 excavation are assessed to be Mesozoic or older in age.

Faults and shear zones within the site area include the Wateree Creek fault (References 363 and 364), the Chappells shear zone (Reference 284), and a postulated unnamed fault of Dames & Moore (Reference 239). These features are described briefly below, and in more detail in Subsections 2.5.1.1.2.4 and 2.5.3.2.

Secor et al. (Reference 364) map the more than 8-mile-long Wateree Creek fault as an approximately north striking, unsilicified fault zone. At its nearest point, the Wateree Creek fault is located approximately 2 miles south of the VCSNS site (Figure 2.5.1-225). Based on crosscutting relationships with Triassic or Jurassic diabase dikes, Secor et al. (Reference 364) estimate a minimum age of Triassic for the Wateree Creek fault.

The Chappells shear zone is a broad, ductile shear zone with probable dextral offset (References 267 and 266). The Chappells shear zone strikes east-northeast roughly parallel to the regional structural grain and extends from near Lake Wateree to Lake Thurmond and into Georgia (Figure 2.5.1-212) (References 267, 266, 284, 363). At its nearest point, the Chappells shear zone is located approximately 2 miles south of the VCSNS site. The unmetamorphosed Winnsboro plutonic complex intrudes the shear zone (References 267, 266, 284, 363). Based on crosscutting relationships with the Carboniferous Winnsboro plutonic complex, the Chappells shear zone is Paleozoic in age; there is no evidence to suggest post-Paleozoic motion on the Chappells shear zone.

As part of an investigation performed for the Parr Hydroelectric Project, Dames & Moore (Reference 239) describes a postulated fault 3 miles south-southwest of the VCSNS site (Figure 2.5.1-224). Evidence for this fault includes shear fabrics recognized in a single roadcut exposure. Recent field reconnaissance did not recognize evidence for faulting in the vicinity of Dames & Moore’s (Reference 239) postulated fault near Parr, South Carolina (Reference 263). The unnamed fault near Parr, South Carolina, if it exists, is assigned a Paleozoic age.

2.5.1.2.5 Site Area Engineering Geology

From an engineering geology perspective, the VCSNS site provides favorable geologic conditions for the construction of Units 2 and 3. The site is underlain by hard, crystalline rock of the Winnsboro plutonic complex. In situ measurements of shear wave velocities (Vs) demonstrate that the sound rock underlying the site exhibits average Vs values in excess of the 8,000 feet/second required by the AP1000 DCD for a hard rock site (Subsection 2.5.4). The majority of Vs values also exceed 9,200 feet/second, thereby classifying the site as a hard rock site for development of ground motions (Figure 2.5.4-226).

Subsection 2.5.4 presents a more detailed description of Vs and other static and dynamic properties of foundation materials. Subsection 2.5.4 also presents discussion of engineering soil properties, including index properties, static and dynamic strength, and compressibility. Variability and distribution of properties for the foundation-bearing layer will be evaluated and mapped as the excavation is completed. Settlement monitoring will be required during and after construction for structures founded on engineered backfill.

Based on previous studies for Unit 1, bedrock at the site contains joints, fractures, and minor bedrock shears. These features are common throughout the crystalline bedrock of the Piedmont and may be encountered within the foundation excavations for Units 2 and 3. During excavation for these units, detailed mapping of the foundation exposures will provide the ability to document and evaluate the presence or absence of minor shears. Excavations for Unit 1 and associated structures exposed northeast and northwest striking sets of near-vertical shears that appear to follow the joint system (References 240, 241, 242, 243, and 244) (Figures 2.5.1-230 and 2.5.1-231). Subsections 2.5.1.2.4 and 2.5.3.1.1 present more detailed discussion of these minor bedrock features. These minor bedrock shears are not capable tectonic sources and do not represent either a ground motion hazard or a surface rupture hazard to the site.

A relatively thick weathering profile is developed on the bedrock units in the site area. Borehole data for Units 2 and 3 reveal that the thicknesses of residual soil and saprolite range from several feet to tens of feet. As shown on Figure 2.5.1-227, the thickness of the weathering profile is highly variable

and the elevation of the top of sound rock is variable beneath Units 2 and 3. The variation and irregular thickness of the weathered zone is likely due to the rock lithology, orientation of foliation or joints, surface topography, and/or a combination of these factors.

No mining operations (other than borrow of surficial soils) or excessive extraction and/or injection of groundwater occur or have occurred within the site area that could affect site area geologic conditions. The Mineral Resources Map of the state of South Carolina (Reference 326) indicates that there are no oil and gas fields or coal mines within the state. Within 25 miles of the site, there are numerous active and abandoned mines and quarries, but these do not present a hazard to the VCSNS site. The nearest mining operation to the site is a quarry for dimension stone, located approximately 5 miles northeast of the VCSNS site, east of the Monticello Reservoir. The crystalline bedrock of the Winnsboro plutonic complex at the VCSNS site is not susceptible to subsidence due to groundwater withdrawal.

2.5.1.2.6 Site Area Seismicity and Paleoseismology

Neither the EPRI seismicity catalog (Reference 250) nor the updated EPRI earthquake catalog (discussed in Subsection 2.5.2) includes any earthquakes of $m_b \geq 3.0$ in the site area (5-mile radius). Only three recorded earthquakes of $m_b \geq 3.0$ have occurred within the site vicinity (25-mile radius), the largest of which was m_b 4.3.

Impoundment of water within the Monticello Reservoir resulted in minor reservoir-induced seismicity (References 364, 410, and 225). This reservoir-induced seismicity is discussed in Subsection 2.5.2. The reservoir-induced seismicity includes small, shallow earthquakes associated with the filling of the Monticello Reservoir in 1977 and 1978. Most of this seismicity at the Monticello Reservoir occurred at depths less than about 1.5 miles and was limited to within the reservoir area. The largest recorded event was m_b 2.8. (Reference 225). The reservoir-induced seismicity began decreasing after 1978 (Reference 225). This type of phenomenon has been observed at other reservoir sites in the Appalachian region.

The highest recorded shaking intensities estimated for the VCSNS site resulted from earthquakes located outside of the site area. The August 31, 1886, Charleston, South Carolina, earthquake is one of the largest historical earthquakes in the eastern United States. The event produced MMI X shaking in the epicentral area (Reference 214). Maximum MMI shaking intensity at the VCSNS site is estimated at approximately VII or VIII (Reference 214). The Charleston earthquake is discussed in greater detail in Subsection 2.5.1.1.3.2.1 and 2.5.2.

The January 1, 1913 m_b 4.8 Union County, South Carolina earthquake (Reference 250) was likely located 30 to 50 miles from the VCSNS site, although this earthquake is poorly located and the fault on which this earthquake occurred has not been identified. The Union County earthquake was felt over an area of approximately 43,000 square miles, with an estimated MMI of VI to VII. MMI at the site was approximately IV. Taber (Reference 381, as reported in Reference 397) estimated Rossi-Forel shaking intensity III at the VCSNS site from the Union County earthquake.

There are no published reports of paleoseismologic studies within the site area. Geologic reconnaissance studies of outcrops and exposures performed for the VCSNS Units 2 and 3 COL application reveal a general lack of liquefaction-susceptible deposits within the site area and, therefore no paleoliquefaction features were found within the site area.

2.5.1.2.7 Site Groundwater Conditions

A detailed discussion of groundwater conditions is provided in Subsection 2.4.12.

2.5.1.3 References

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Table 2.5-1
Limits of Acceptable Settlement Without Additional Evaluation

Differential Across Nuclear Island Foundation Mat	Total for Nuclear Island Foundation Mat	Differential Between Nuclear Island and Turbine Building[1]	Differential Between Nuclear Island and Other Buildings[1]
1/2 inch 50 ft	6 inches	3 inches	3 inches

Note:

1. Differential settlement is measured at the center of the nuclear island and the center of the adjacent structures.

Table 2.5.1-201
Definitions of Classes Used in the Compilation of Quaternary Faults, Liquefaction Features, and Deformation in the Central and Eastern United States

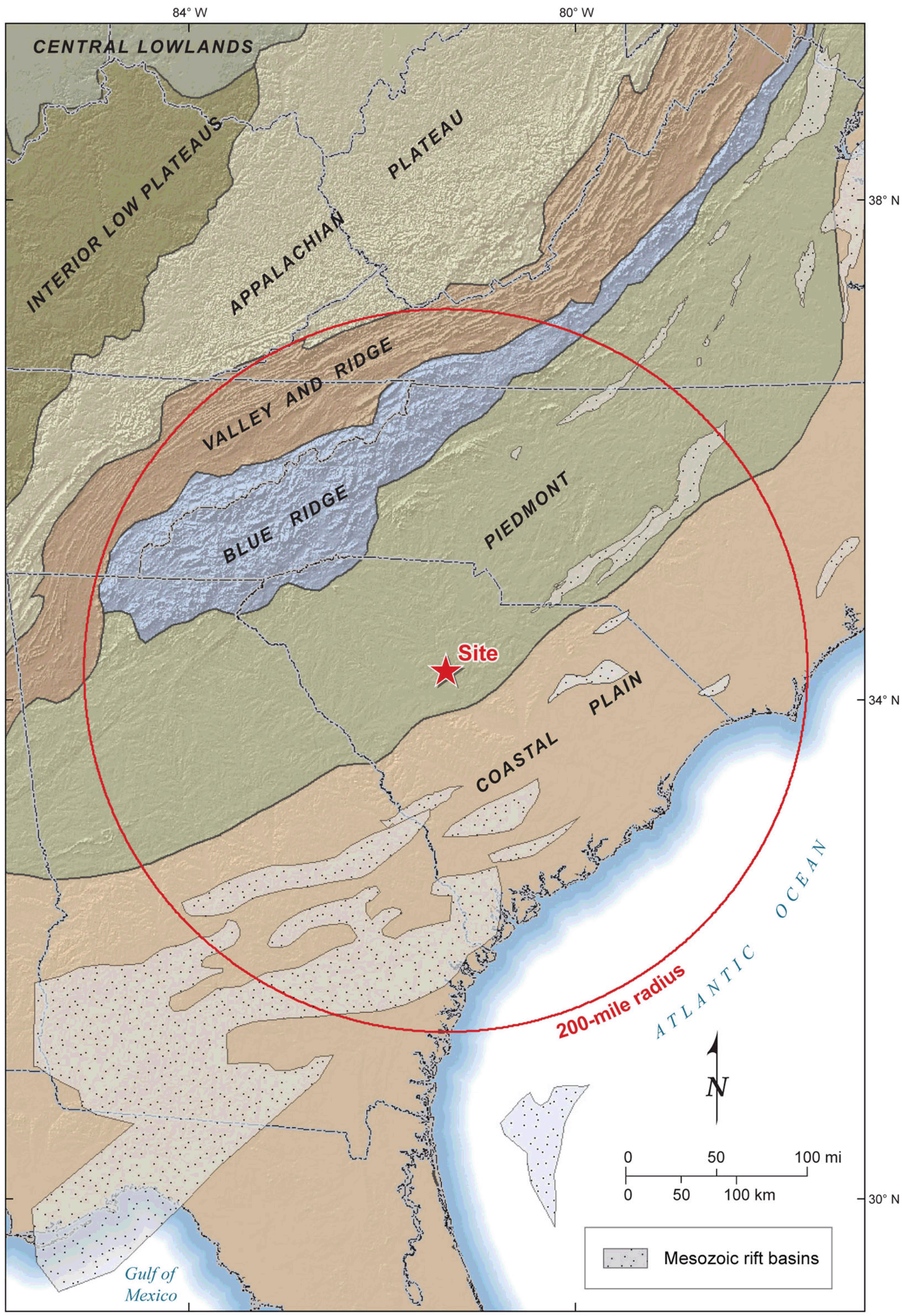
Class Category	Definition
Class A	Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed for mapping or inferred from liquefaction to other deformational features.
Class B	Geologic evidence demonstrates the existence of a fault or suggests Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.
Class C	Geologic evidence is insufficient to demonstrate (1) the existence of tectonic fault, or (2) Quaternary slip or deformation associated with the feature.
Class D	Geologic evidence demonstrates that the feature is not a tectonic fault or feature; this category includes features such as demonstrated joints or joint zones, landslides, erosional or fluvial scarps, or landforms resembling fault scarps, but of demonstrable non-tectonic origin.

Source: References 232 and 406

Table 2.5.1-202
Summary of Proposed Quaternary Features Within the Site Region

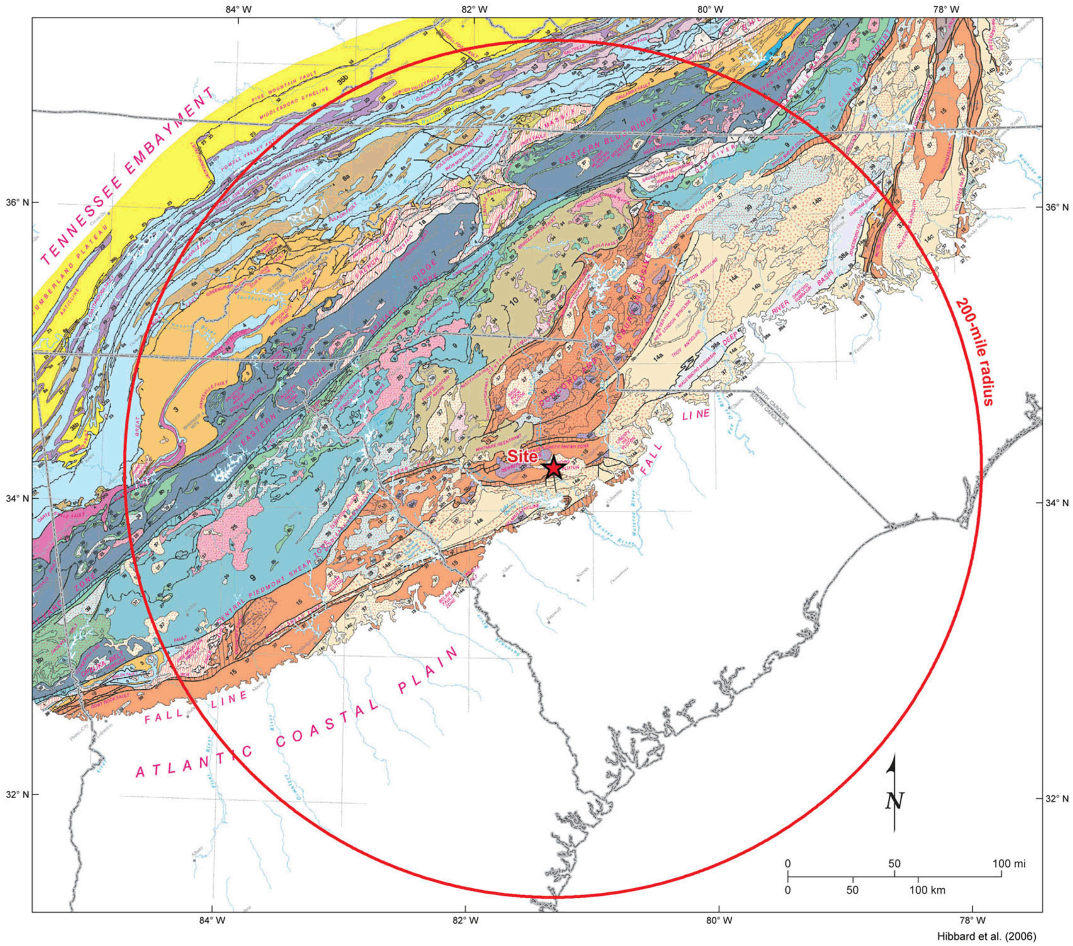
Feature Name	Orientation	Length	Reference(s)[(1)]	Class[(2)]
1. Fall Lines of Weems	NE	450 mi	Weems (1998) (Reference 398)	C
2. Belair fault	NE	15+ mi	Dennis et al. (2004) (Reference 246)	C
3. Pen Branch fault	NE	20+ mi	Snipes et al. (1993) (Reference 374)	C
4. Cooke fault	ENE	6 mi	Behrendt et al. (1981) (Reference 210) Hamilton et al. (1983) (Reference 268)	C
5. East Coast Fault Zone/ southern segment	NE/N35°E	375 mi/ 125 mi	Marple and Talwani (2000) (Reference 325)	C
6. Eastern Tennessee Seismic Zone	NE	185 mi	Powell et al. (1994) (Reference 345)	C
7. Stanleytown-Villa Heights faults	NNE	600 ft each	Conley and Toewe (1968) (Reference 431)	C
8. Pembroke faults	ENE	330+ ft	Law et al. (2000) (Reference 313)	B
9. Bluffton liquefaction features	n/a (3)	n/a (3)	Talwani and Schaeffer (2001) (Reference 386)	A
10. Helena Banks fault	ENE	75 mi	Behrendt and Yuan (1987) (Reference 209) Behrendt et al. (1983) (Reference 211)	C
11. Charleston liquefaction features	(3)	(3)	Talwani and Schaeffer (2001) (Reference 386)	A
12. Georgetown liquefaction features	(3)	(3)	Talwani and Schaeffer (2001) (Reference 386)	A
13. Cape Fear Arch	NW	100+ mi	Crone and Wheeler (2000) (Reference 323)	C
14. Hares Crossroads fault	(4)	(4)	Prowell (1983) (Reference 346)	C

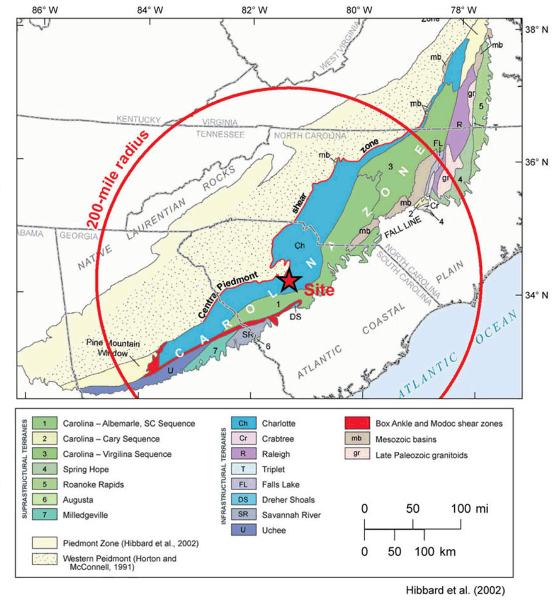
Notes:
(1) Source reference for feature orientation and/or length.
(2) Feature class from Crone and Wheeler (2000) (Reference 232) and Wheeler (2005) (Reference 406).
(3) Orientation and length data for individual liquefaction and paleoliquefaction features are not applicable. Taken together, however, the distribution of Bluffton, Charleston, and Georgetown features indicates a NE orientation, parallel to the South Carolina coast.
(4) The proposed Hares Crossroads fault was recognized in a single, two-dimensional roadcut exposure. As such, orientation and length information are not available.



Modified from Fenneman and Johnson (1946)

Figure 2.5.1-201 Map of Physiographic Provinces and Mesozoic Rift Basins





See Sheet 2 of 2 for explanation

Figure 2.5.1-202 Tectonic Map of the Piedmont—Terranes within the Carolina Zone (Sheet 1 of 2)

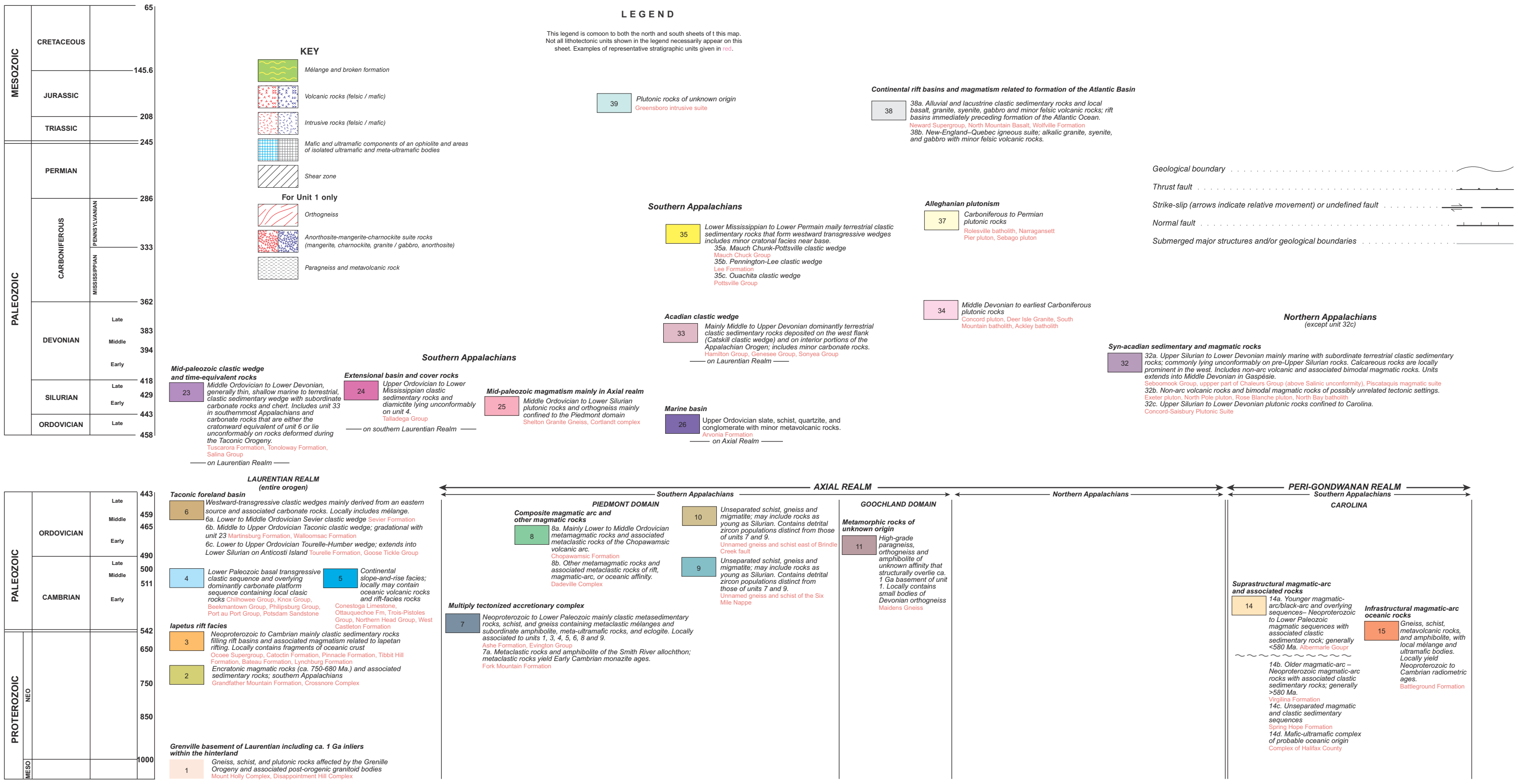
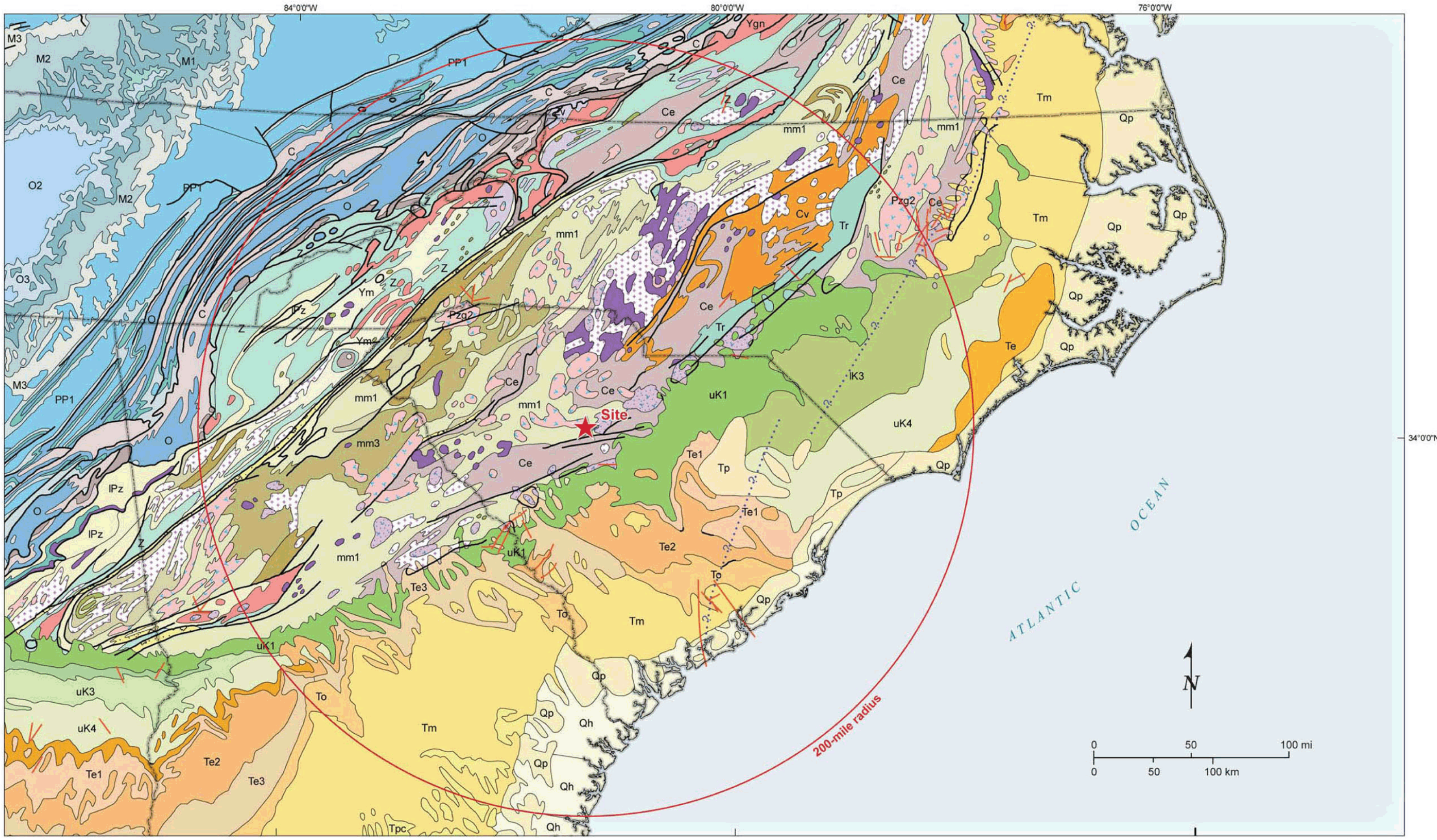


Figure 2.5.1-202 Tectonic Map of the Piedmont—Western Piedmont (Sheet 2 of 2)



Modified from King and Biekman (1974) as digitized by Schruben et al. (1994)

Figure 2.5.1-203 Site Region Geologic Map (Sheet 1 of 2)

Explanation

Faults

- Paleozoic faults
- Mesozoic faults
- Cenozoic faults
- Postlated East Coast Fault System

Geologic Units

QUATERNARY	Qh	Holocene
QUATERNARY	Qp	Pleistocene glacial deposits
TERTIARY	Tp	Pliocene
TERTIARY	Tm	Miocene
TERTIARY	To	Oligocene
TERTIARY	Te3	Eocene, Jackson Group
TERTIARY	Te2	Eocene, Claiborne Group
TERTIARY	Te1	Eocene, Wilcox Group
TERTIARY	Te	Eocene
UPPER CRETACEOUS	uK4	Navarro Group
UPPER CRETACEOUS	uK3	Taylor Group
UPPER CRETACEOUS	uK2	Austin and Eagle Ford Groups
UPPER CRETACEOUS	uK1	Woodbine and Tuscaloosa Groups
LOWER CRETACEOUS	IK3	Washita Group
TRIASSIC	Tr	Triassic
PERMIAN	PP1	Wolfcampian
PERMIAN	PP2	Leonardian
PENNSYL-VANIAN	IPz	Paleozoic
MISSISSIPPIAN	M3	Upper Mississippian, Chesterian series
MISSISSIPPIAN	M2	Upper Mississippian, Meramecian series
MISSISSIPPIAN	M1	Lower Mississippian, Osagean and Kinderhookian series
MISSISSIPPIAN	mm4	Metamorphic complex, felsic orthogneiss
MISSISSIPPIAN	mm1	Metamorphic complex, felsic and paragneissic schist
MISSISSIPPIAN	M	Mississippian
DEVONIAN	D	Devonian
DEVONIAN	Pzg2	Middle Paleozoic granitic rocks
ORDOVICIAN	O	Ordovician
ORDOVICIAN	O3	Upper Ordovician
ORDOVICIAN	O2	Middle Ordovician
CAMBRIAN	C	Cambrian
CAMBRIAN	Ce	Eugeosynclinal
CAMBRIAN	Cv	Volcanic rocks
PRECAMBRIAN	Z	Sedimentary
PRECAMBRIAN	Zv	Volcanic rocks
PRECAMBRIAN	Ygn	Orthogneiss
PRECAMBRIAN	Ym	Paragneiss and schist

Modified from King and Biekman (1974) as
digitized by Schruben et al. (1994)

Figure 2.5.1-203 Explanation of Site Region Geologic Map (Sheet 2 of 2)

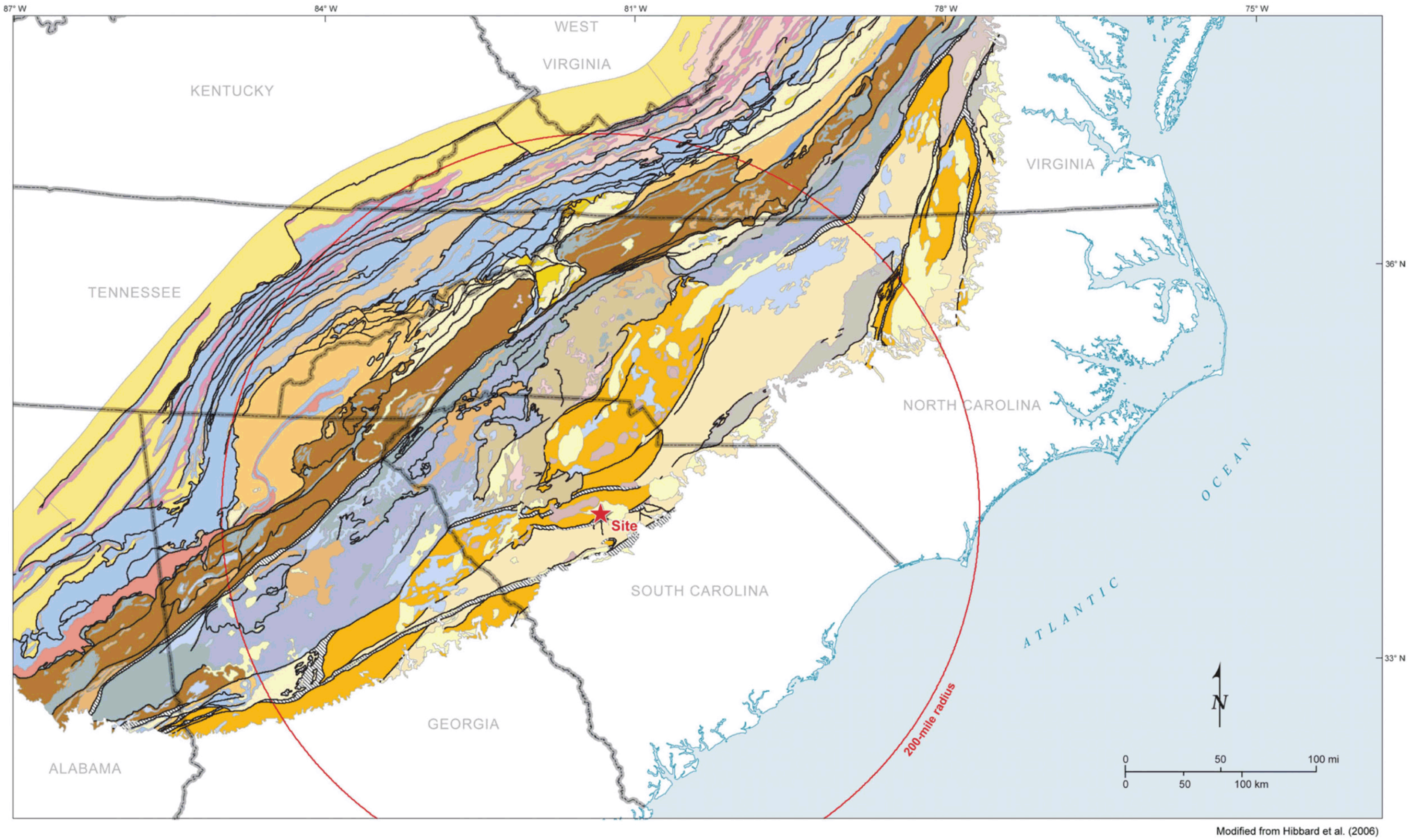


Figure 2.5.1-204 Lithotectonic Map of the Appalachian Orogen (Sheet 1 of 2)

Explanation

Faults

- Paleozoic faults
- Mesozoic faults
- Cenozoic faults, includes postulated East Coast Fault System
- Shear zones

Lithotectonic Units

JURASSIC

- Plutonic rocks of unknown origin
- Continental rift basins and magmatism related to formation of the Atlantic Basin

CARBONIFEROUS

- Carboniferous to Permian plutonic rocks
- Lower Mississippian to Lower Permain maily terrestrial clastic sedimentary rocks that form westward transgressive wedges includes minor cratonal facies near base.

DEVONIAN

- Middle Devonian to earliest Carboniferous plutonic rocks
- Mainly Middle to Upper Devonian dominantly terrestrial clastic sedimentary rocks deposited on the west flank (Catskill clastic wedge) and on interior portions of the Appalachian Orogen; includes minor carbonate rocks.

SILURIAN

- Syn-acadian sedimentary and magmatic rocks
- Extensional basin and cover rocks; Upper Ordovician to Lower Mississippian clastic sedimentary rocks and diamictite lying unconformably on unit 4.
- Mid-paleozoic clastic wedge and time-equivalent rocks; Middle Ordovician to Lower Devonian, generally thin, shallow marine to terrestrial, clastic sedimentary wedge with subordinate carbonate rocks and chert. Includes unit 33 in southernmost Appalachians and carbonate rocks that are either the cratonward equivalent of unit 6 or lie unconformably on rocks deformed during the Taconic Orogeny.

ORDOVICIAN

- Mid-paleozoic magmatism mainly in Axial realm; Middle Ordovician to Lower Silurian plutonic rocks and orthogneiss mainly confined to the Piedmont domain
- Marine basin; Upper Ordovician slate, schist, quartzite, and conglomerate with minor metavolcanic rocks.
- Tactonic foreland basin; Westward-transgressive clastic wedges mainly derived from an eastern source and associated carbonate rocks. Locally includes mélange
- Unseparated schist, gneiss and migmatite; may include rocks as young as Silurian. Contains detrital zircon populations distinct from those of units 7 and 9.
- Unseparated schist, gneiss and migmatite; may include rocks as young as Silurian. Contains detrital zircon populations distinct from those of units 7 and 9.
- Composite magmatic arc and other magmatic rocks

- Metamorphic rocks of unknown origin; high-grade paragneiss, orthogneiss and amphibolite of unknown affinity that structurally overlie ca. 1 Ga basement of unit 1. Locally contains small bodies of Devonian orthogneiss

CAMBRIAN

- Lower Paleozoic basal transgressive clastic sequence and overlying dominantly carbonate platform sequence containing local clasic rocks
- Continental slope-and-rise facies; locally may contain oceanic volcanic rocks and rift-facies rocks
- Multiply tectonized accretionary complex; Neoproterozoic to Lower Paleozoic mainly clastic metasedimentary rocks, schist, and gneiss containing metaclastic mélanges and subordinate amphibolite, meta-ultramafic rocks, and eclogite. Locally associated to units 1, 3, 4, 5, 6, 8 and 9.
- Infrastructural magmatic-arc/oceanic rocks; gneiss, schist, metavolcanic rocks, and amphibolite, with local mélange and ultramafic bodies. Locally yield Neoproterozoic to Cambrian radiometric ages.
- Suprastructural magmatic-arc and associated rocks

PRECAMBRIAN

- Lapetus rft facies; Meoproterozoic to Cambrian mainly clastic sedimentary rocks filling rift basins and associated magmatism related to lapetan rifting. Locally contains fragments of oceanic crust
- Lapetus rft facies; encratonic magmatic rocks (ca. 750-680 Ma.) and associated sedimentary rocks; southern Appalachians
- Grenville basement of Laurentian including ca. 1 Ga inliers within the hinterland; gneiss, schist, and plutonic rocks affected by the Grenille Orogeny and associated post-orogenic granitoid bodies.

Modified from Hibbard et al. (2006)

Figure 2.5.1-204 Lithotectonic Map of the Appalachian Orogen (Sheet 2 of 2)

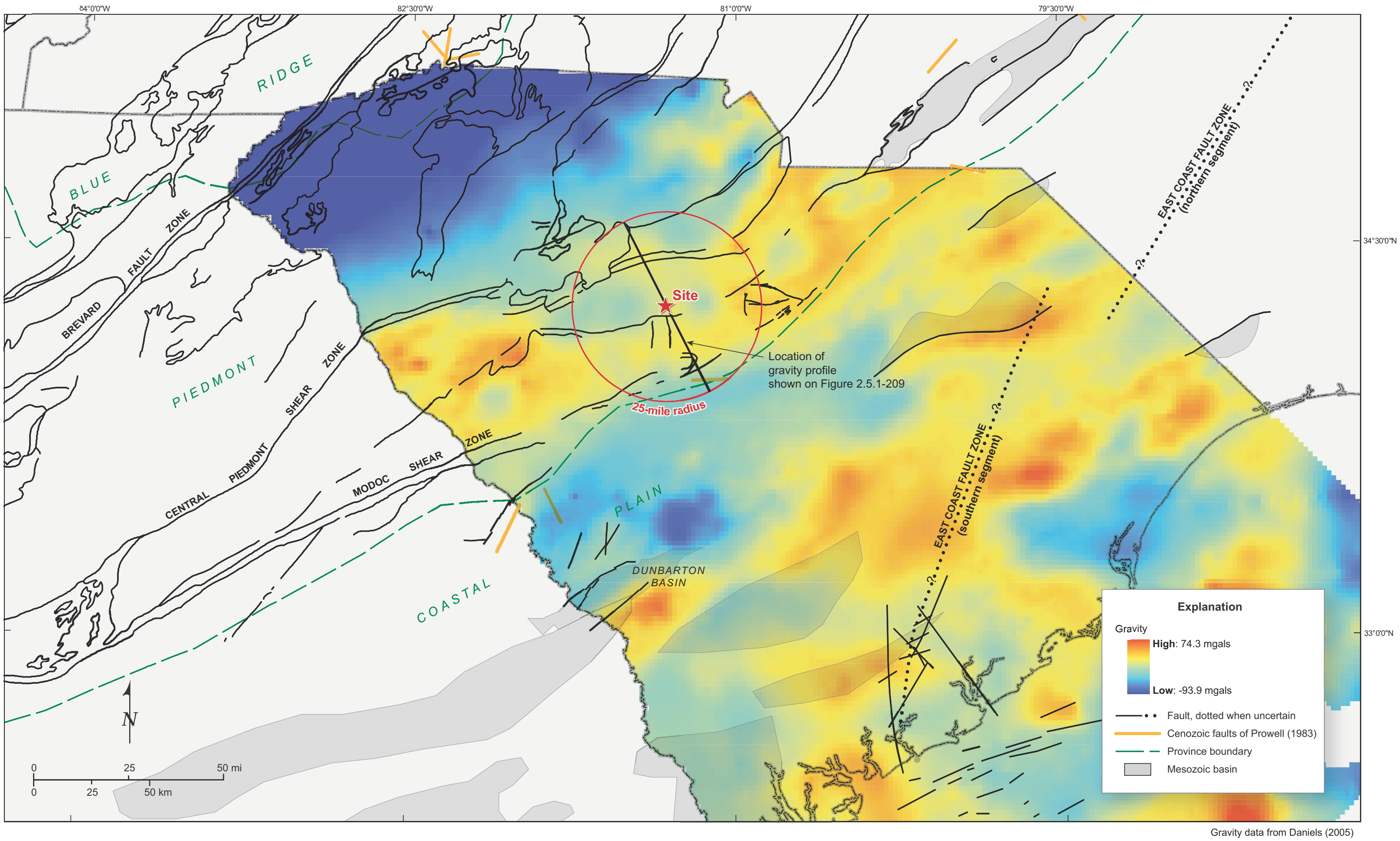


Figure 2.5.1-205 Regional Gravity Data

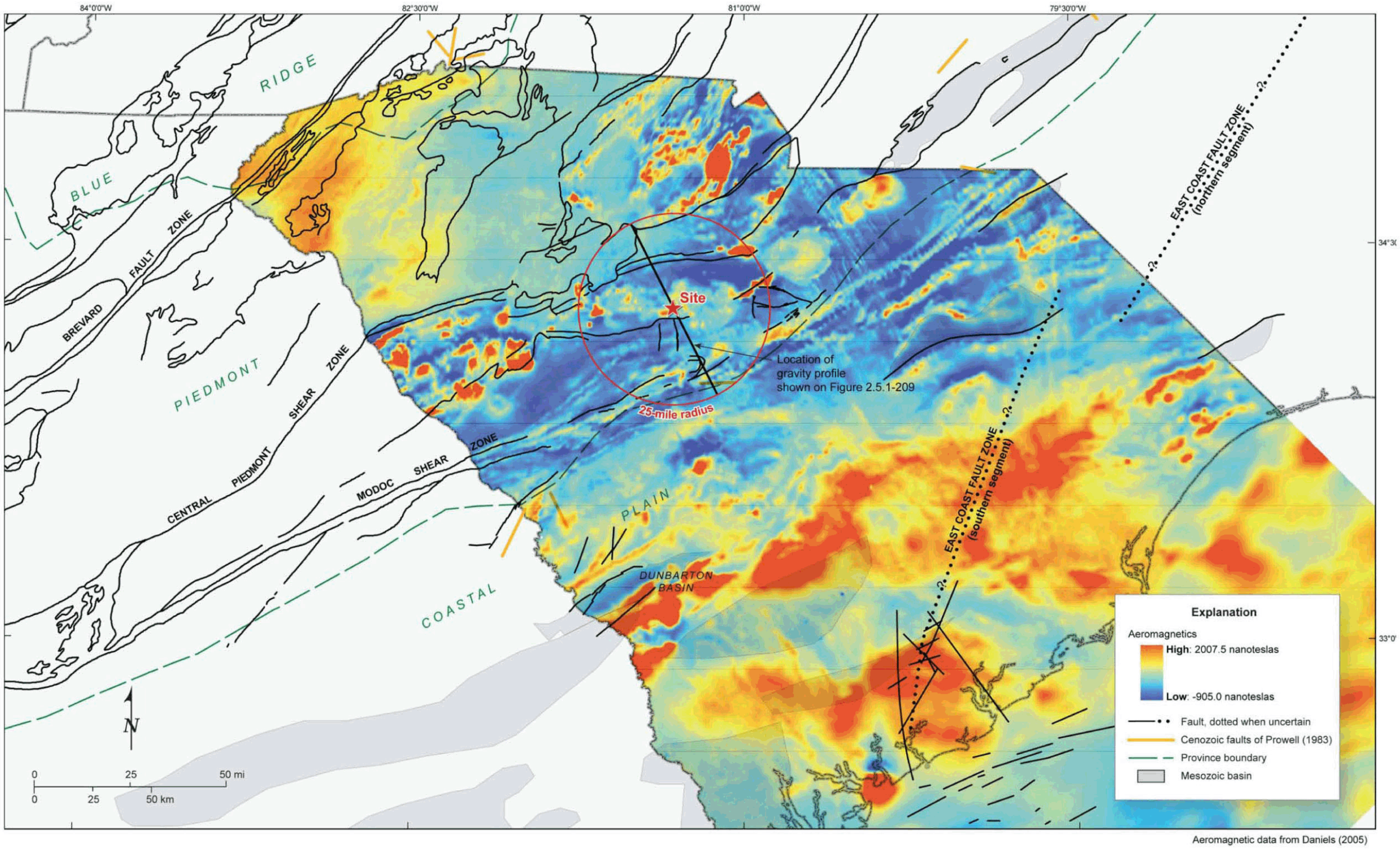


Figure 2.5.1-206 Regional Magnetic Data

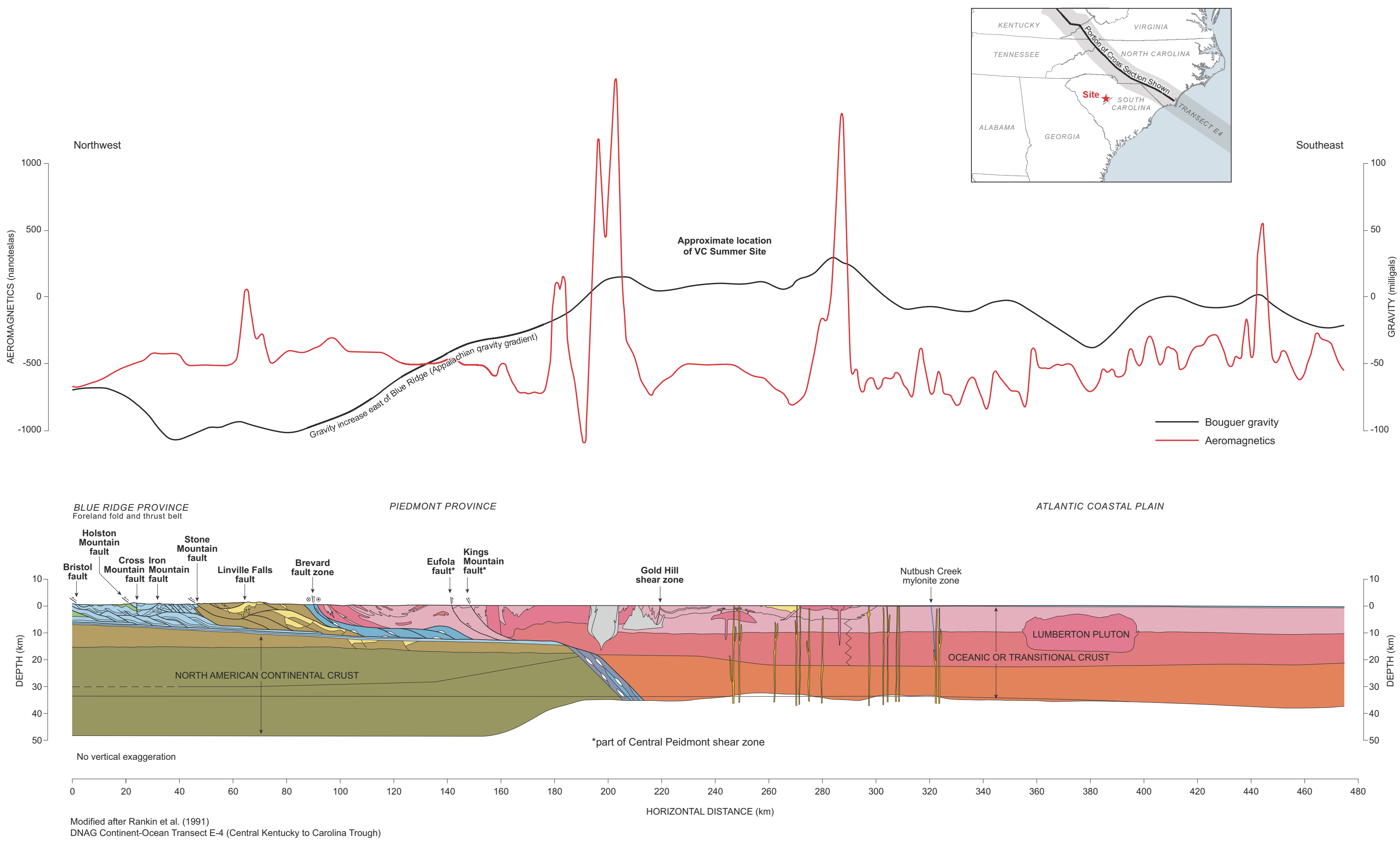
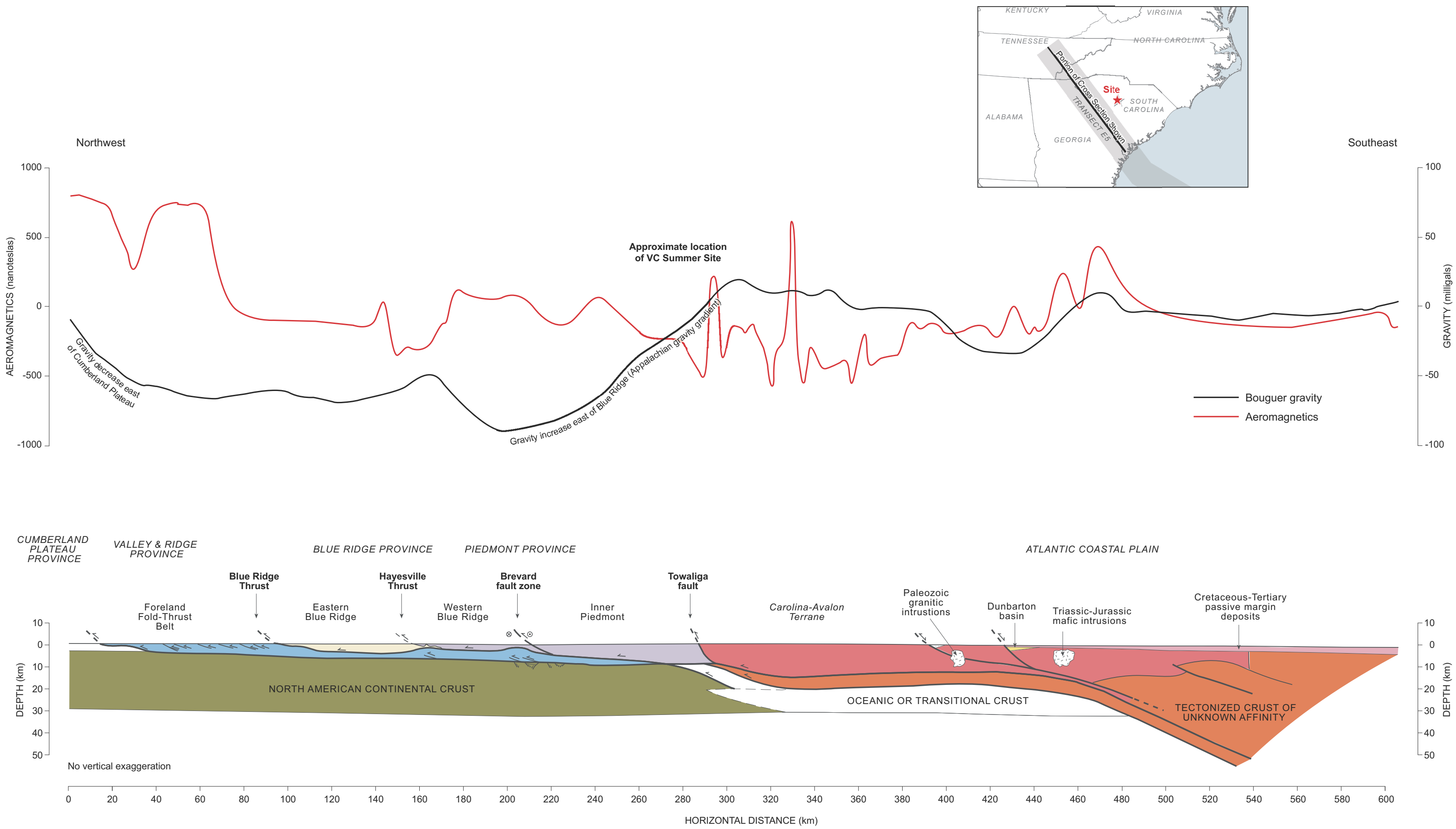


Figure 2.5.1-207 Regional Cross-Section E4



Modified after Hatcher et al. (1994)
DNAG Continent-Ocean Transect E-5 (Cumberland Plateau to Blake Plateau)

Figure 2.5.1-208 Regional Cross-Section E5

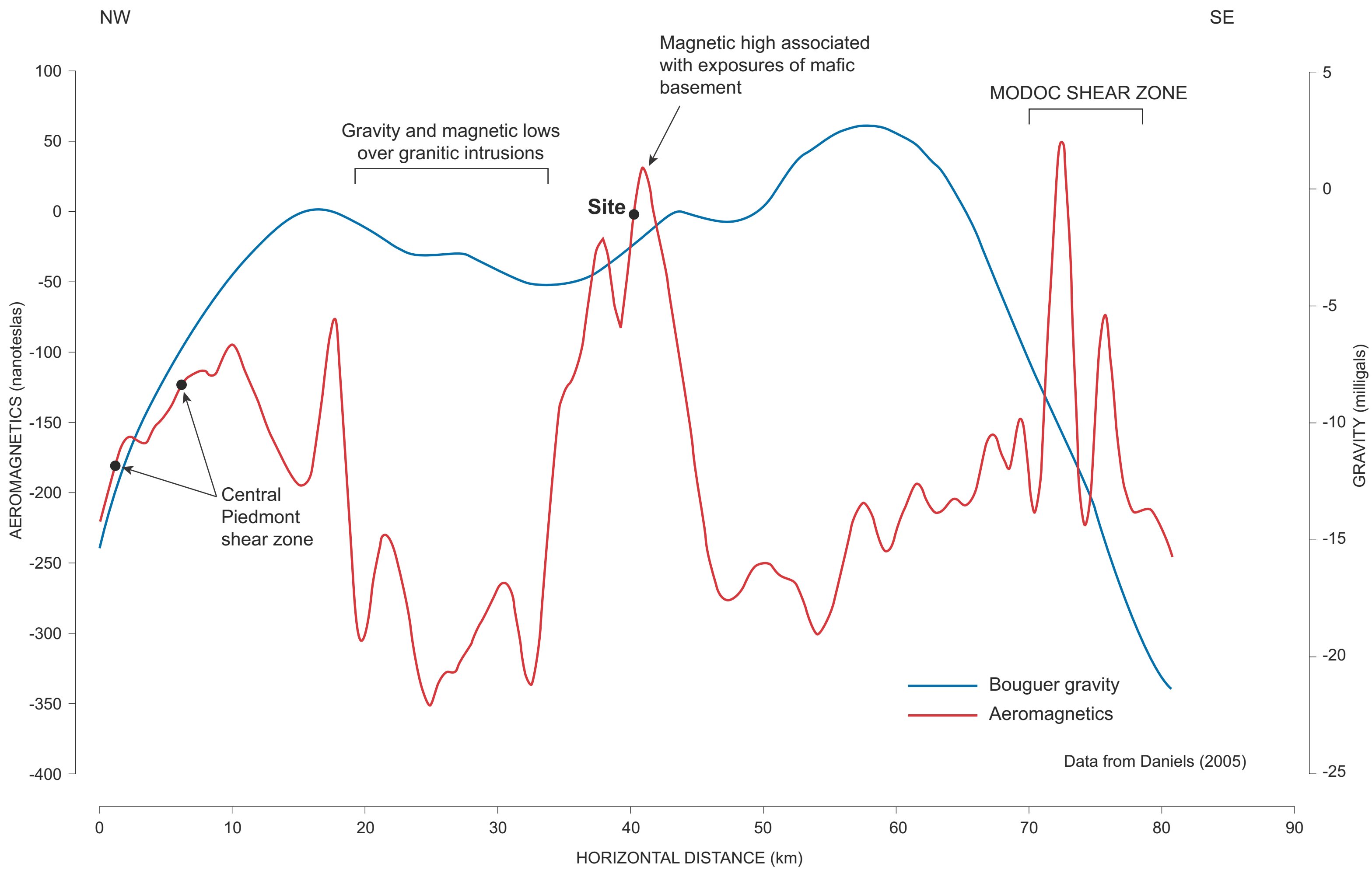
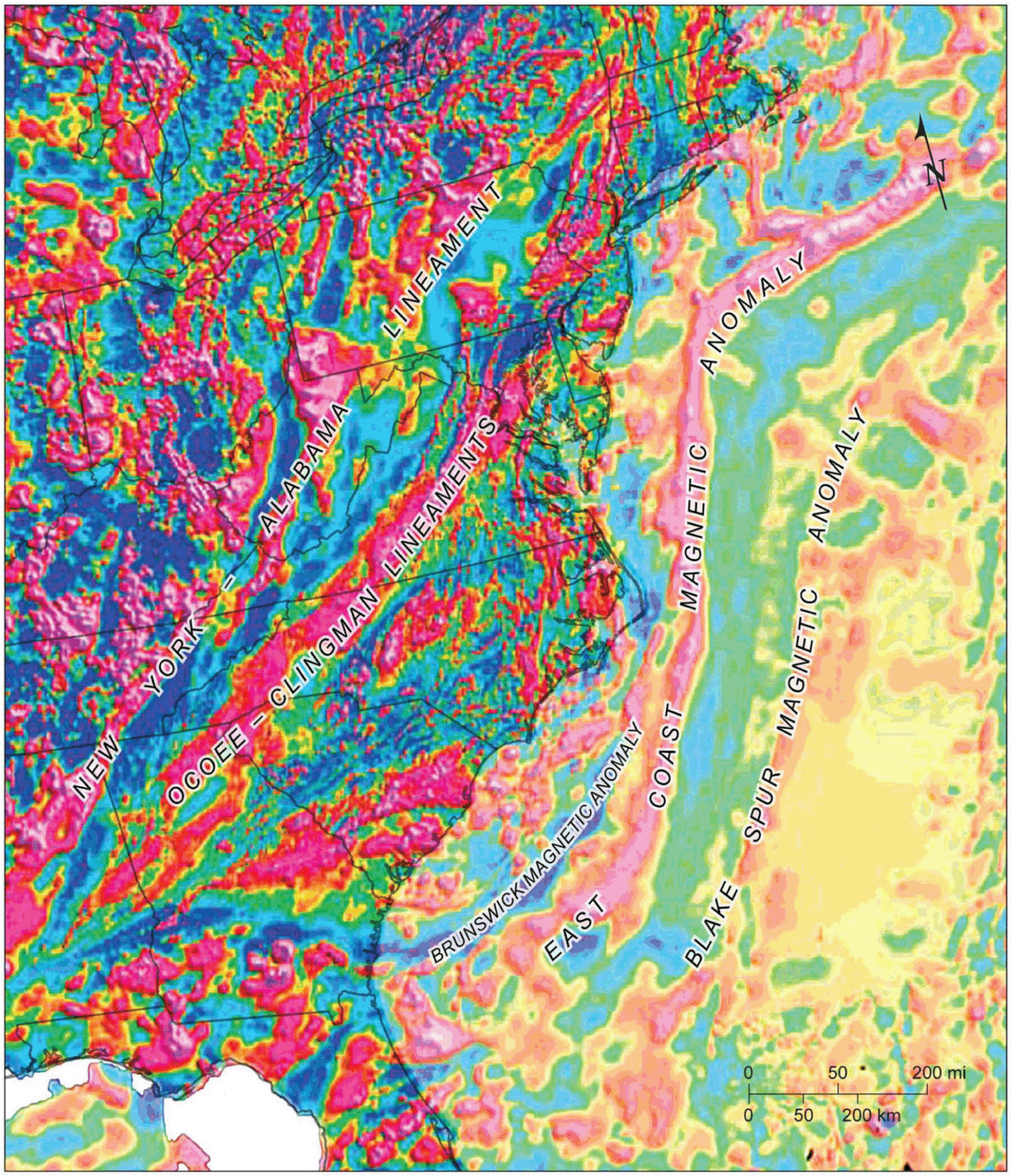


Figure 2.5.1-209 Site Vicinity Gravity and Magnetic Profiles



Modified after NAMAG 2002

Figure 2.5.1-210 Major Eastern U.S. Aeromagnetic Anomalies

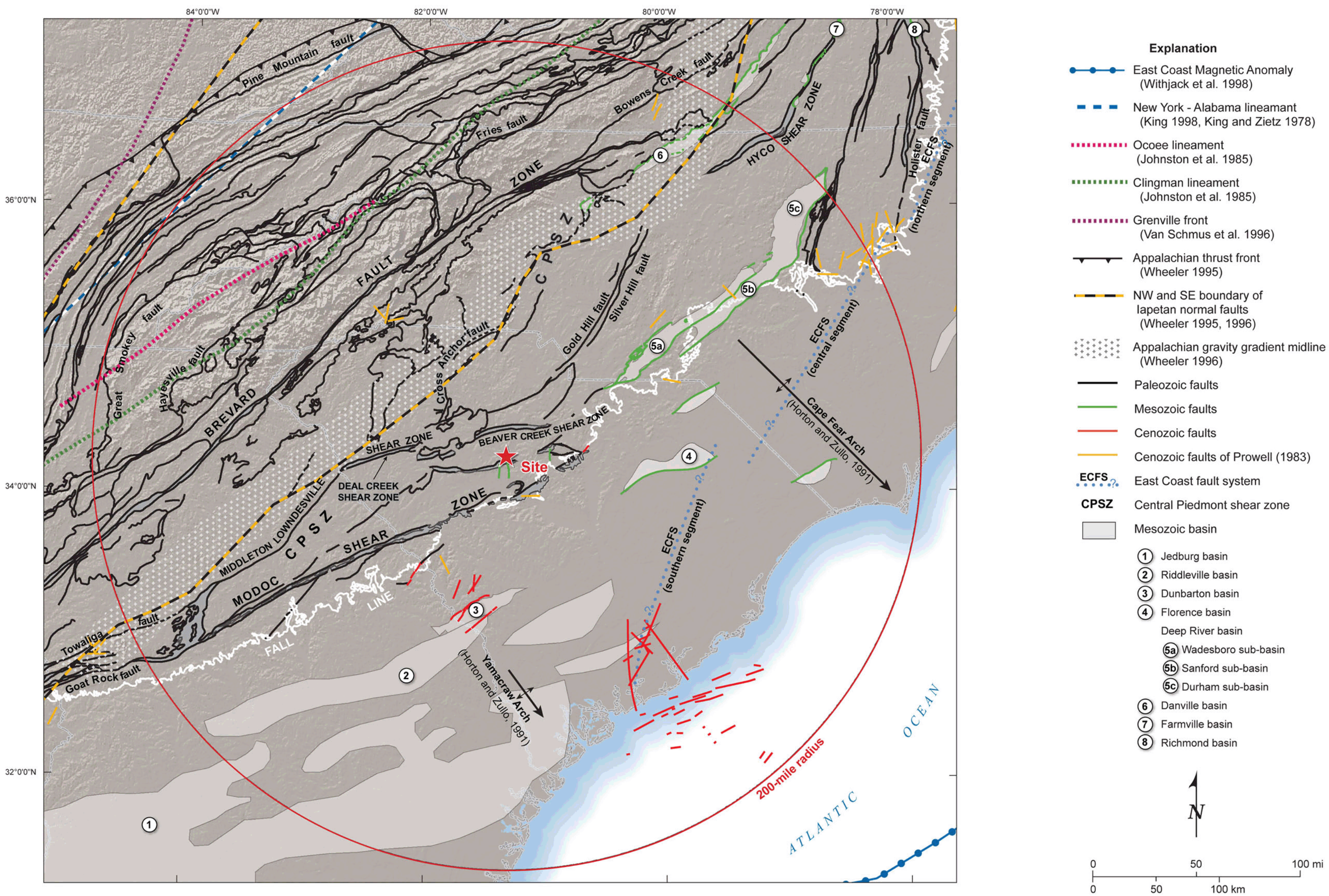


Figure 2.5.1-211 Site Region Tectonic Features

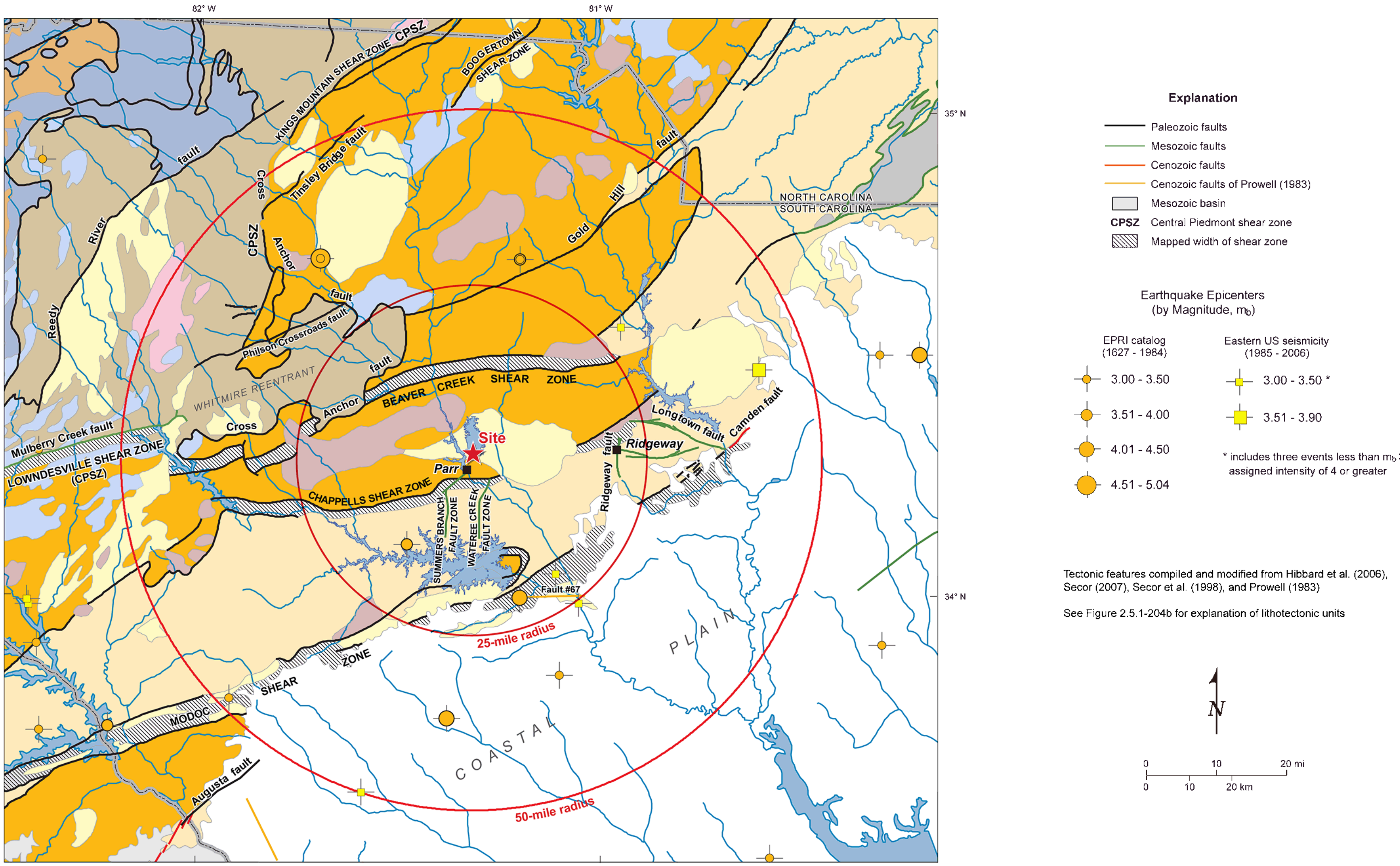


Figure 2.5.1-212 50-Mile Tectonic Features Map

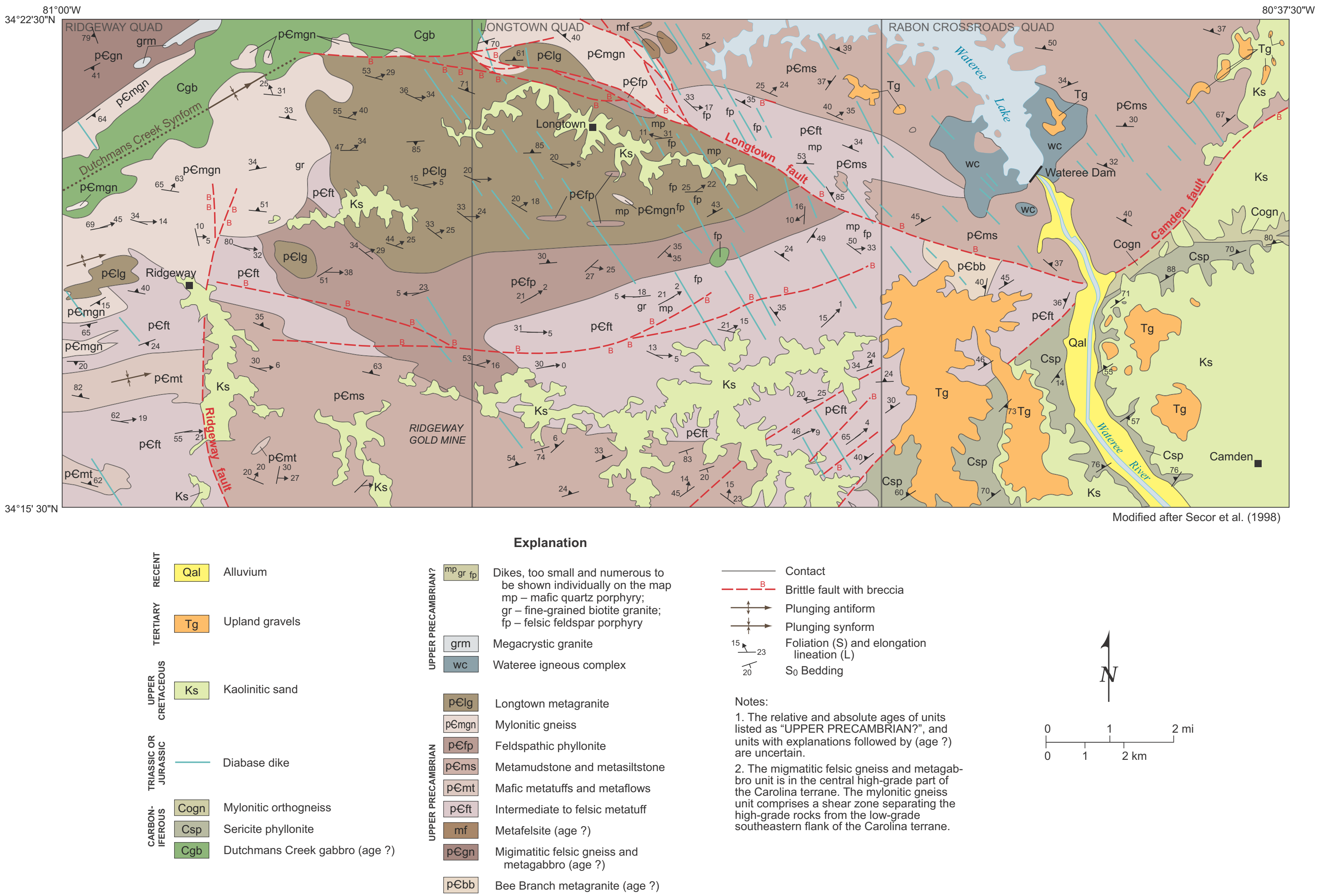


Figure 2.5.1-213 Geologic Map of the Ridgeway-Camden Area

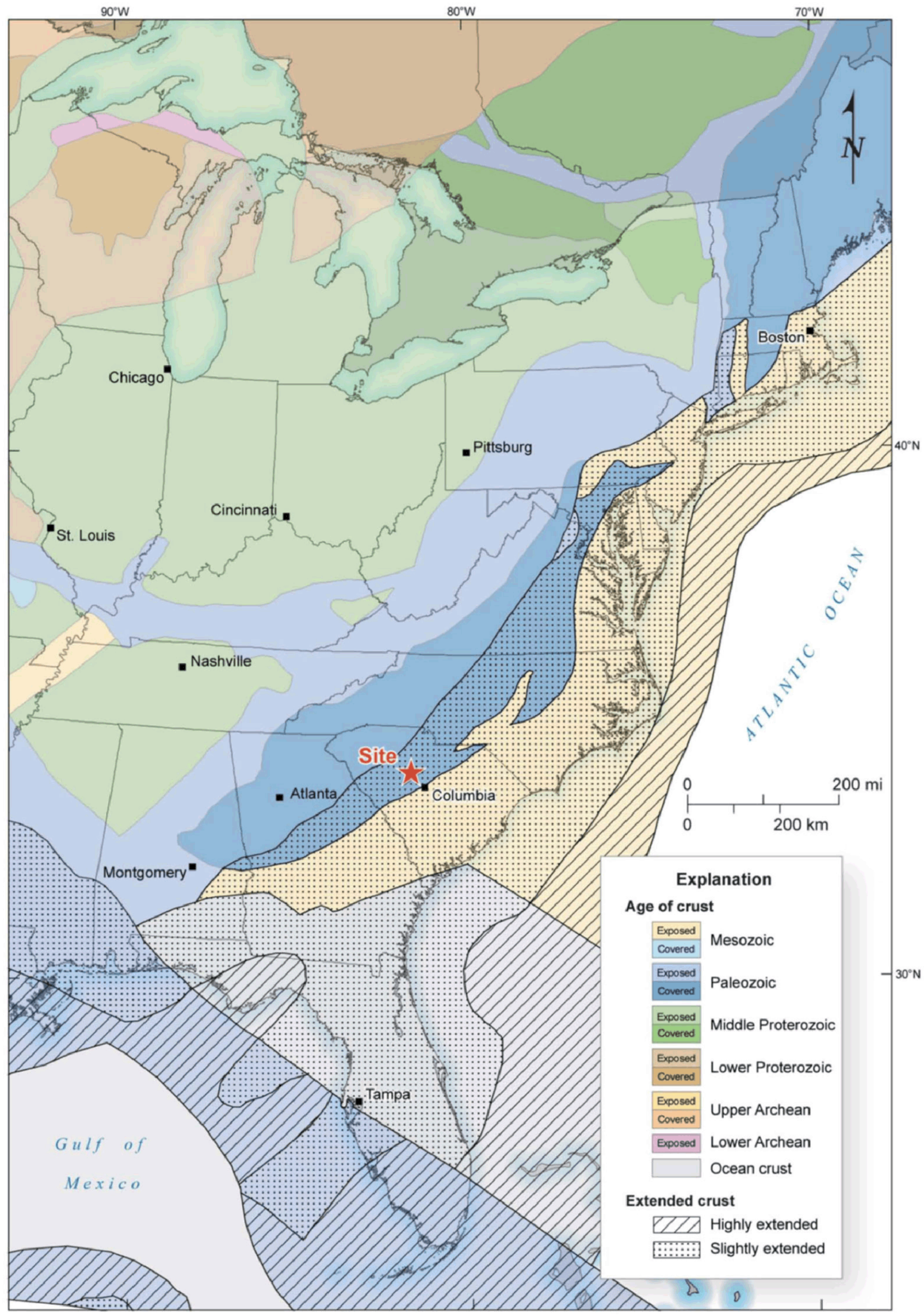


Figure 2.5.1-214 Crustal Ages from Johnston et al. (1994)

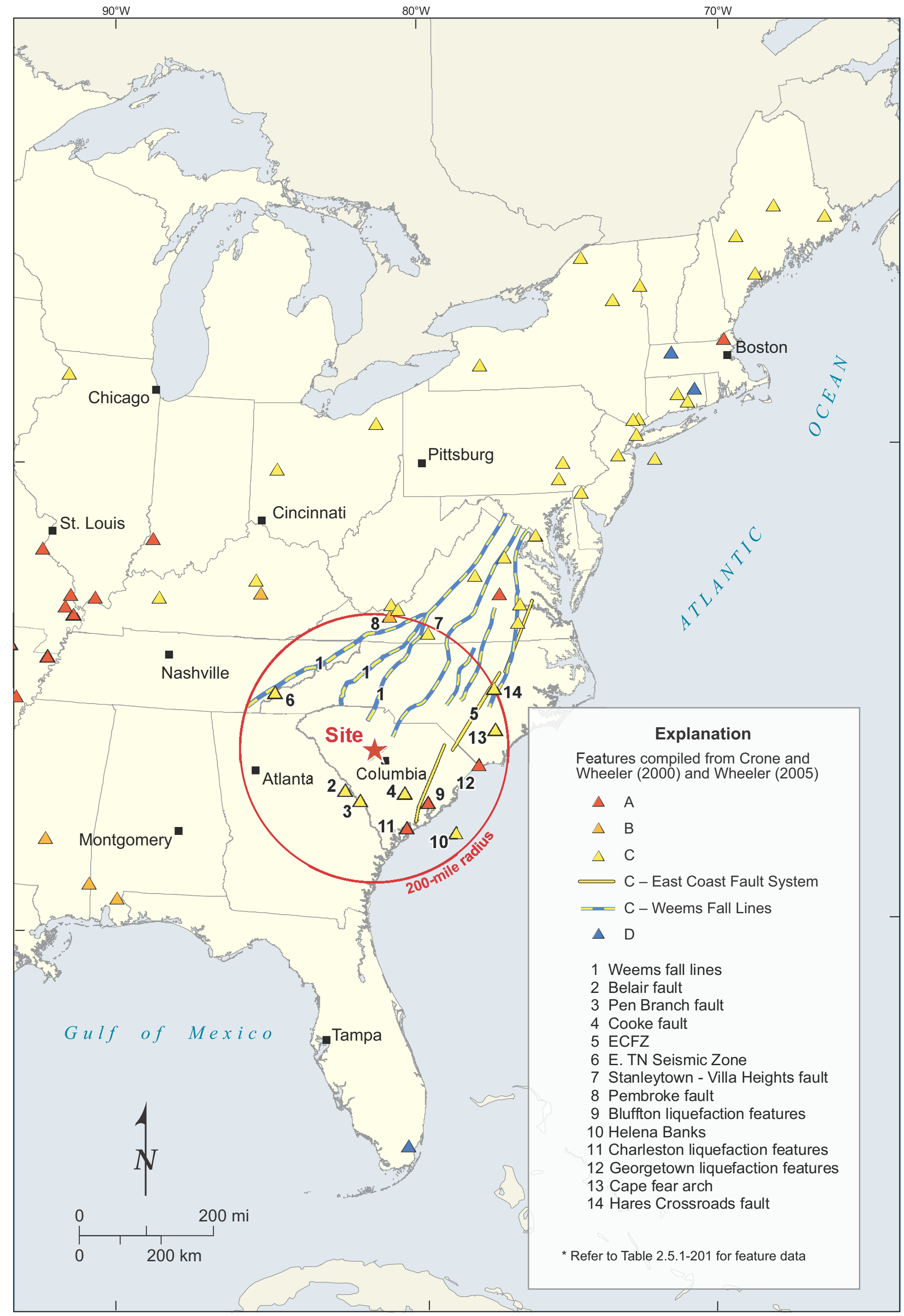


Figure 2.5.1-215 Potential Quaternary Features in the Site Region

Figure 2.5.1-216 Seismic Zones and Seismicity in CEUS

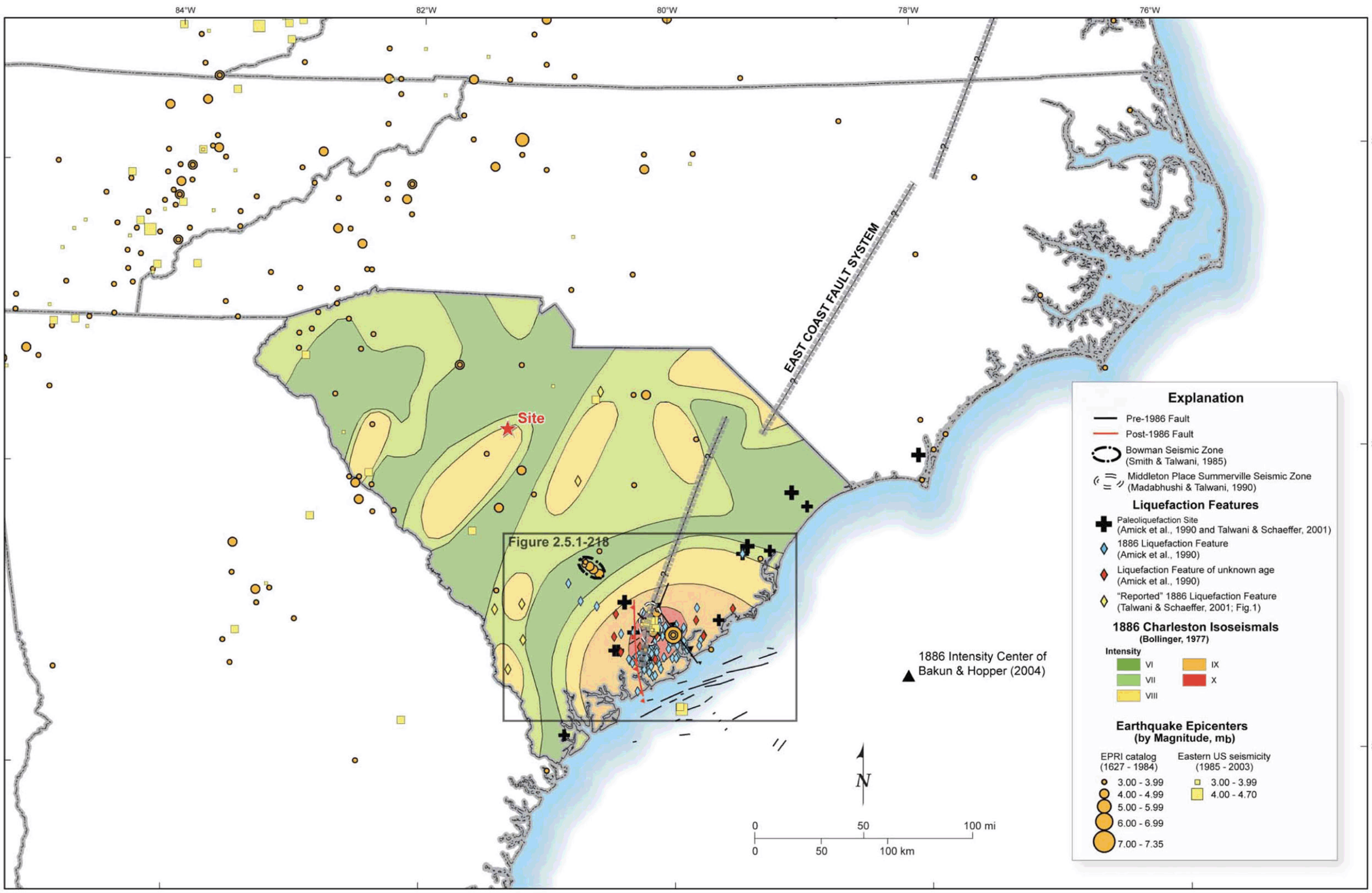


Figure 2.5.1-217 Regional Charleston Tectonic Features

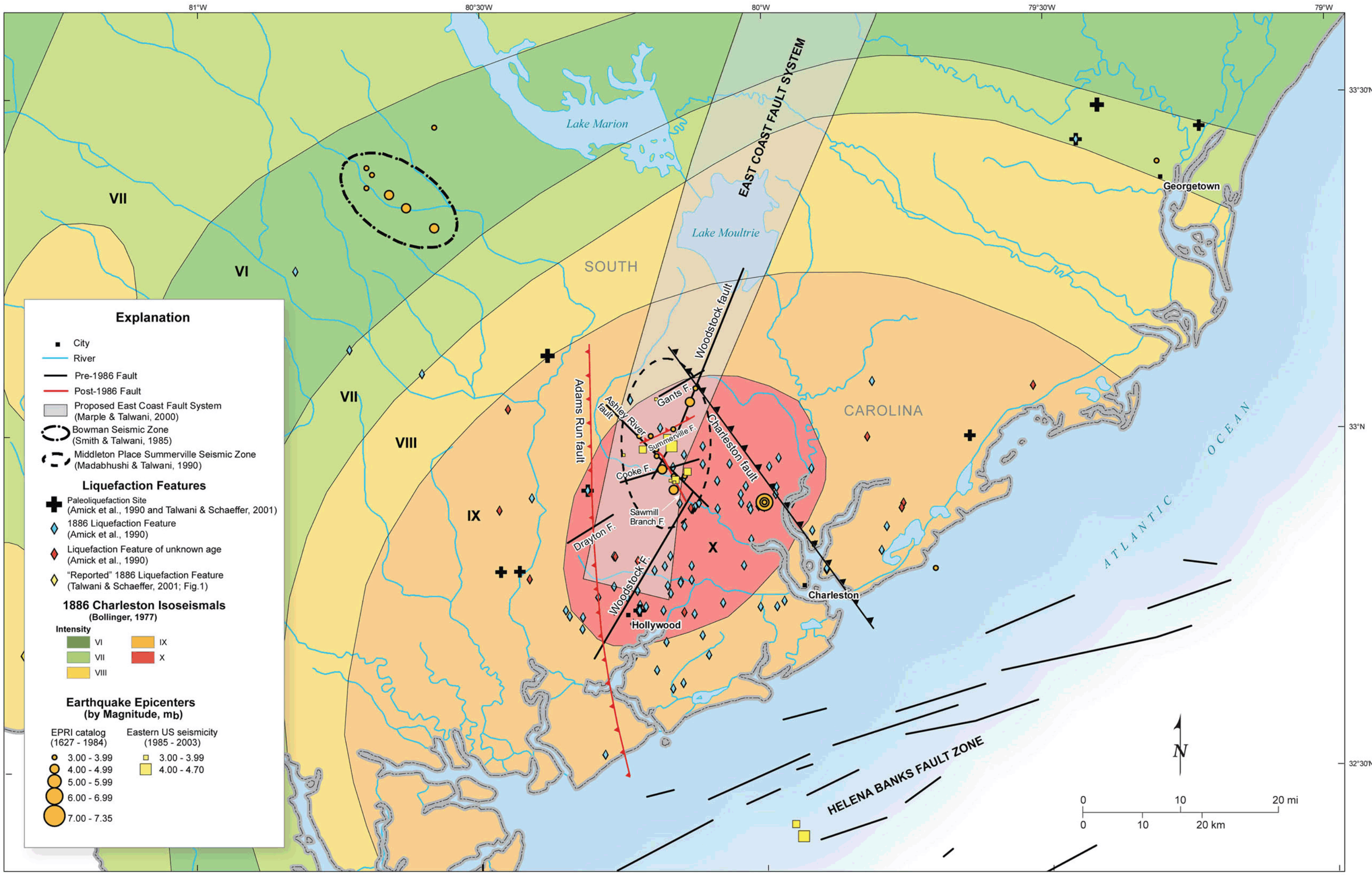


Figure 2.5.1-218 Local Charleston Tectonic Features

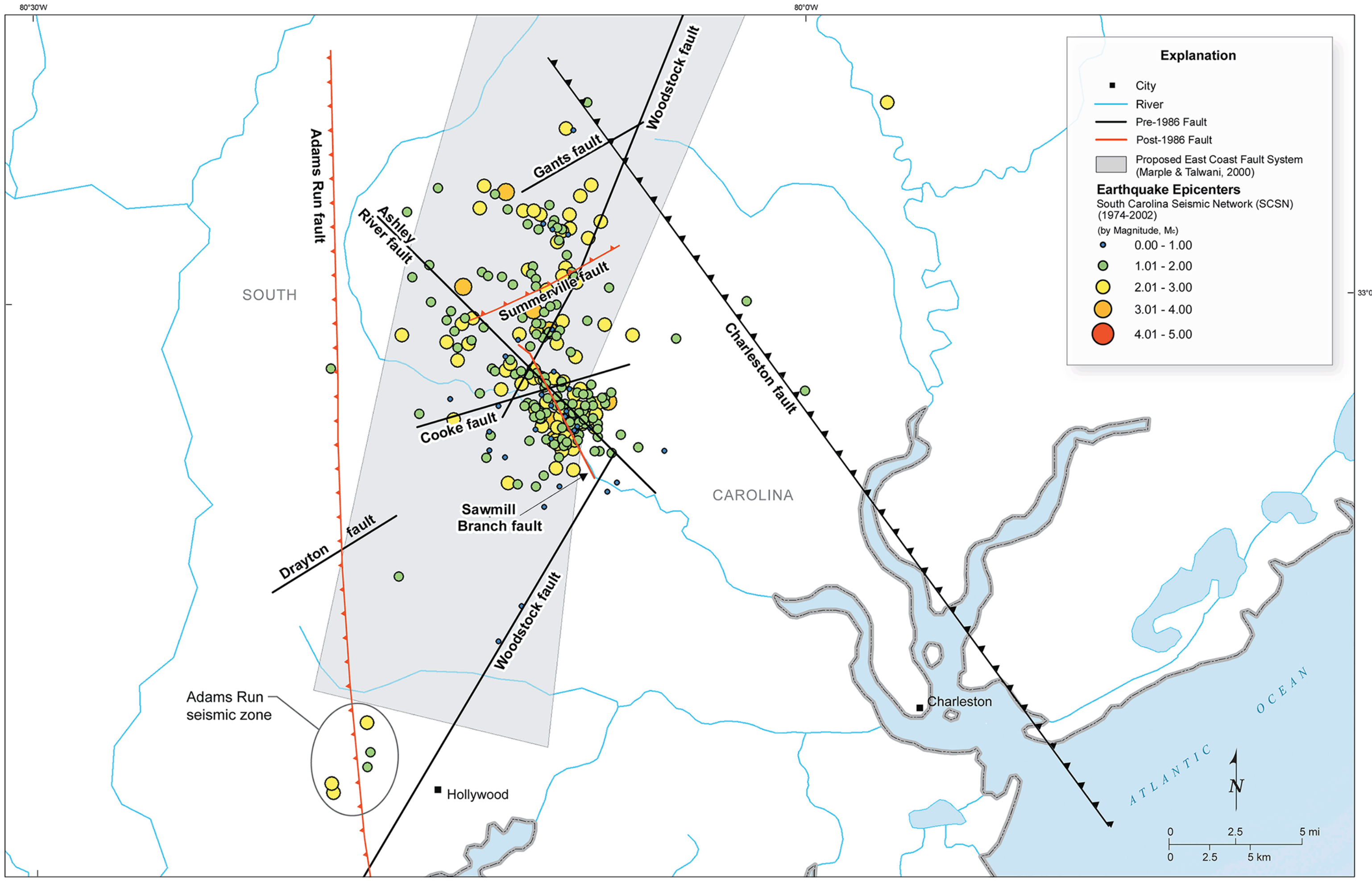


Figure 2.5.1-219 Charleston Area Seismicity

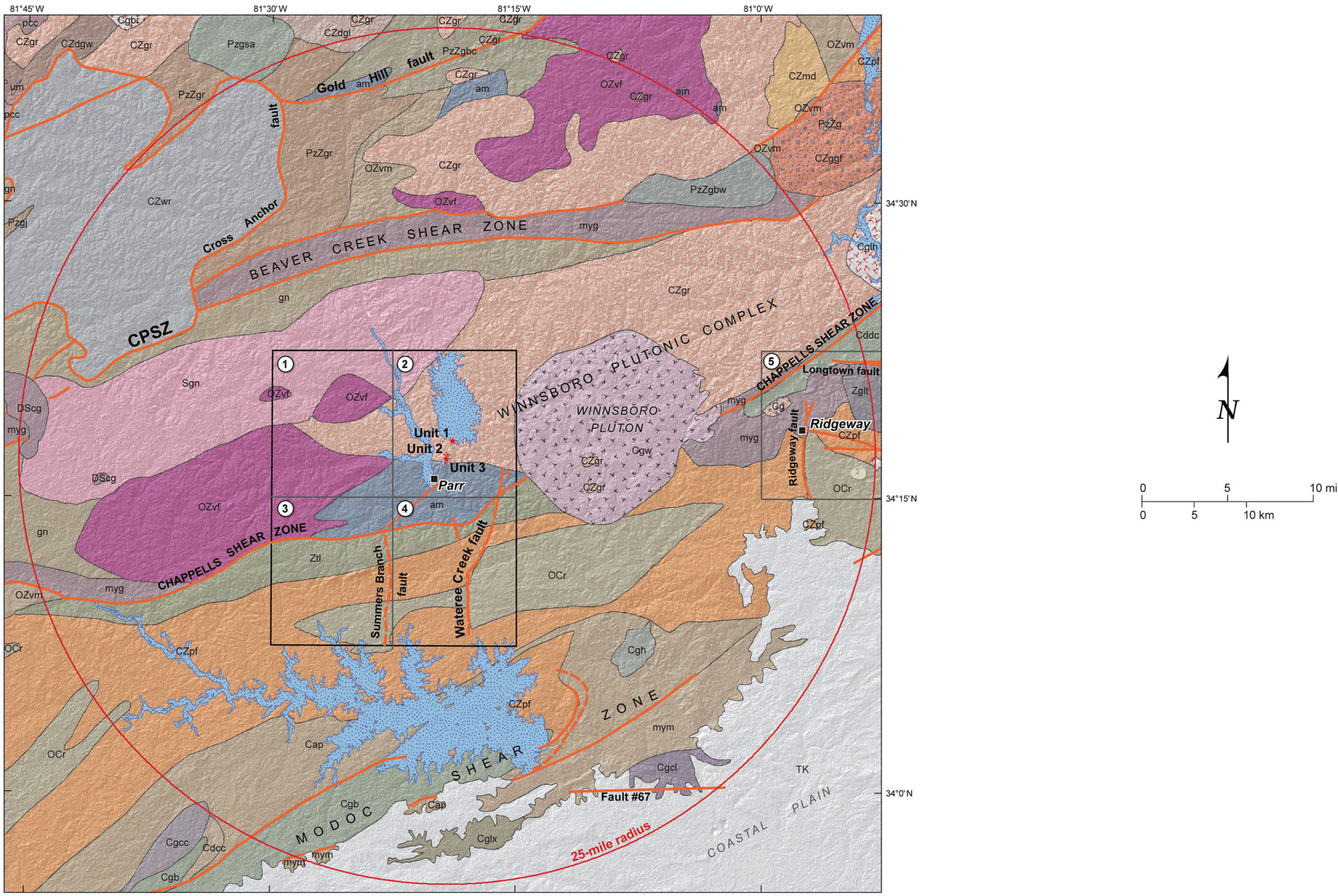


Figure 2.5.1-220 Site Vicinity Geologic Map (Sheet 1 of 2)

Explanation

Horton and Dicken (2001)

LATE PALEOZOIC
- myg — Mylonitic gneiss
- mym — Mylonitic rocks of Modoc fault zone

CARBONIFEROUS TO PERMIAN
- Cgb — Granite, Batesman pluton
- Cgbr — Granite, Bald Rock pluton
- Cgcc — Granite, Clouds Creek pluton
- Cgcl — Granite, Columbia pluton
- Cgh — Granite, Harbison pluton
- Cglh — Granite, Liberty Hill pluton
- Cgw — Granite, Winnsboro pluton
- Cglx — Granite, Lexington pluton

CARBONIFEROUS
- Cdcc — Gabbro and diorite, Clouds Creek pluton
- Cddc — Gabbro and diorite, Dutchmans Creek pluton

DEVONIAN TO SILURIAN
- DScg — Gabbro

SILURIAN
- Sgn — Newberry granite and similar, possilby related granites

ORDOVICIAN TO MIDDLE CAMBRIAN
- OCr — Richtex Formation - metamudstone

MIDDLE CAMBRIAN
- Cap — Asbill Pond Formation - metamorphosed siltstone and sandstone with interbedded metavolcanic rocks

PALEOZOIC
- Pzgj — Granite sheets near Joanna
- Pzgsa — Santuck granite

MIDDLE PALEOZOIC TO NEOPROTEROZOIC
- PzZg — Metagabbro and minor metadiorite
- PzZgbc — Metagabbro and minor metadiorite - Chester
- PzZgbw — Metagabbro and minor metadiorite - Big Wateree Creek

ORDOVICIAN TO NEOPROTEROZOIC
- OZvf — Felsic metavolcanic rocks and layered felsic gneiss
- OZvm — Mafic to intermediate metavolcanic rocks including hornblende gneiss and amphibolite

PALEOZOIC TO NEOPROTEROZOIC
- PzZgr — Metamorphosed granitoids
- am — Amphibolite and amphibole gneiss
- gn — Biotite-quartz-plagioclase gneiss
- um — Ultramafic rock - metamorphosed

EARLY PALEOZOIC-NEOPROTEROZOIC
- CZdgl — Metadiorite and minor metagabbro - Lockhart metadiorite
- CZdgw — Metadiorite and minor metagabbro - Wildcat Branch complex

CAMBRIAN OR NEOPROTEROZOIC
- CZggf — Great Falls metagranite - metamorphosed muscovite-biotite granite
- CZgr — Metamorphosed granite to granodiorite
- CZmd — Metadiorite
- CZpf — Persimmon Fork Formation - mainly metatuff
- CZwr — Biotite-quartz-feldspar gneiss of Whitmire reentrant

NEO-PROTEROZOIC
- Ztl — Metatolanlite

UNDETERMINED
- pcc — Philson Crossroads complex - biotite-quartz-fledspar gneiss having layers of amphibolite and metagranite

Other Mapped Quandrangles, not shown

1. Pomaria 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
2. Jenkinsville 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
3. Little Mountain 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
4. Chapin 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
5. Ridgeway 7.5-minute quandrangle, Secor et al. (1998); See Figure 2.5.1-213

Faults modified from Hibbard et al. (2006) and Secor (2007); dashed where postulated and likely non-existent

Figure 2.5.1-220 Explanation of Site Vicinity Geologic Map (Sheet 2 of 2)

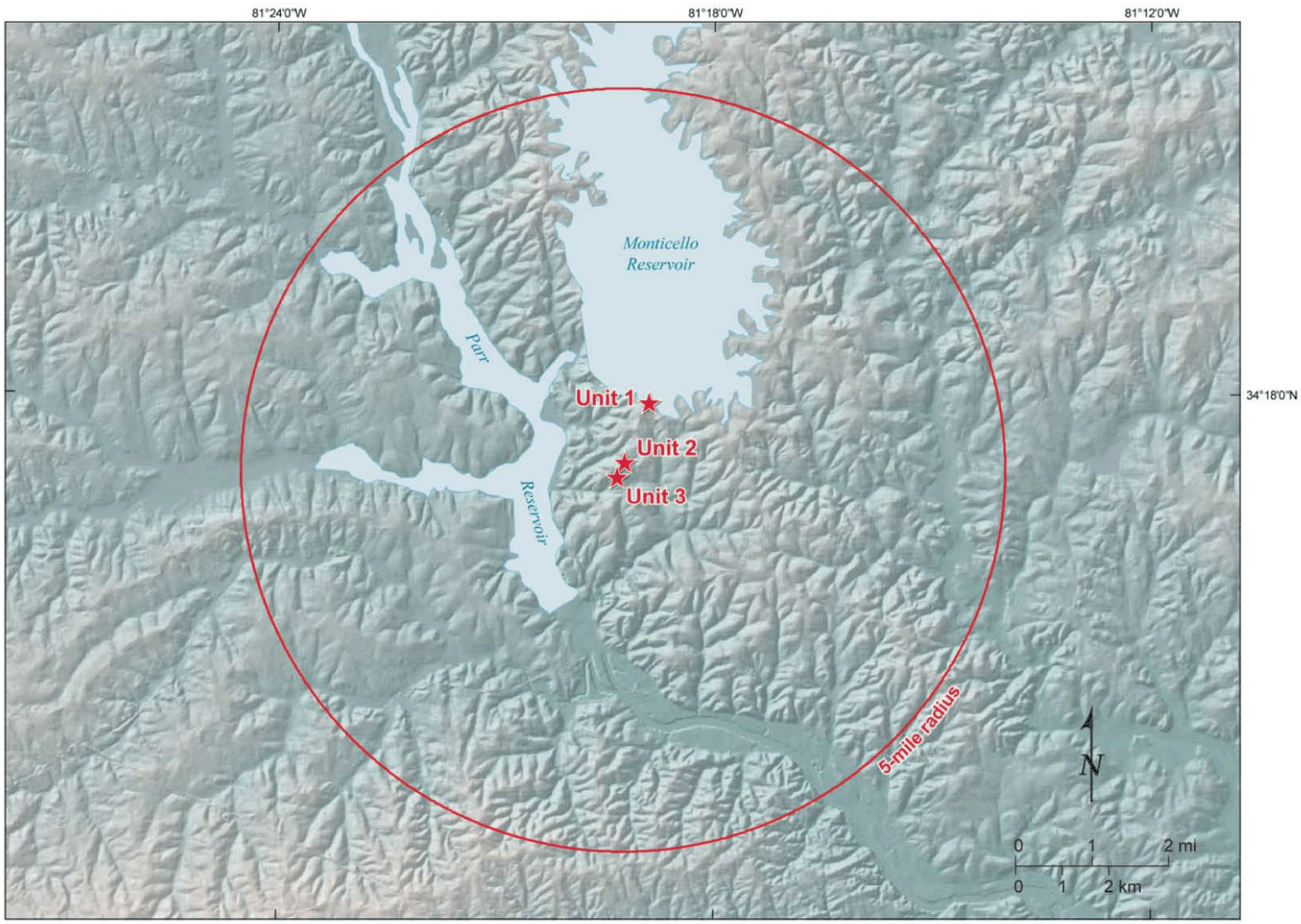


Figure 2.5.1-221 Site Area Relief Map

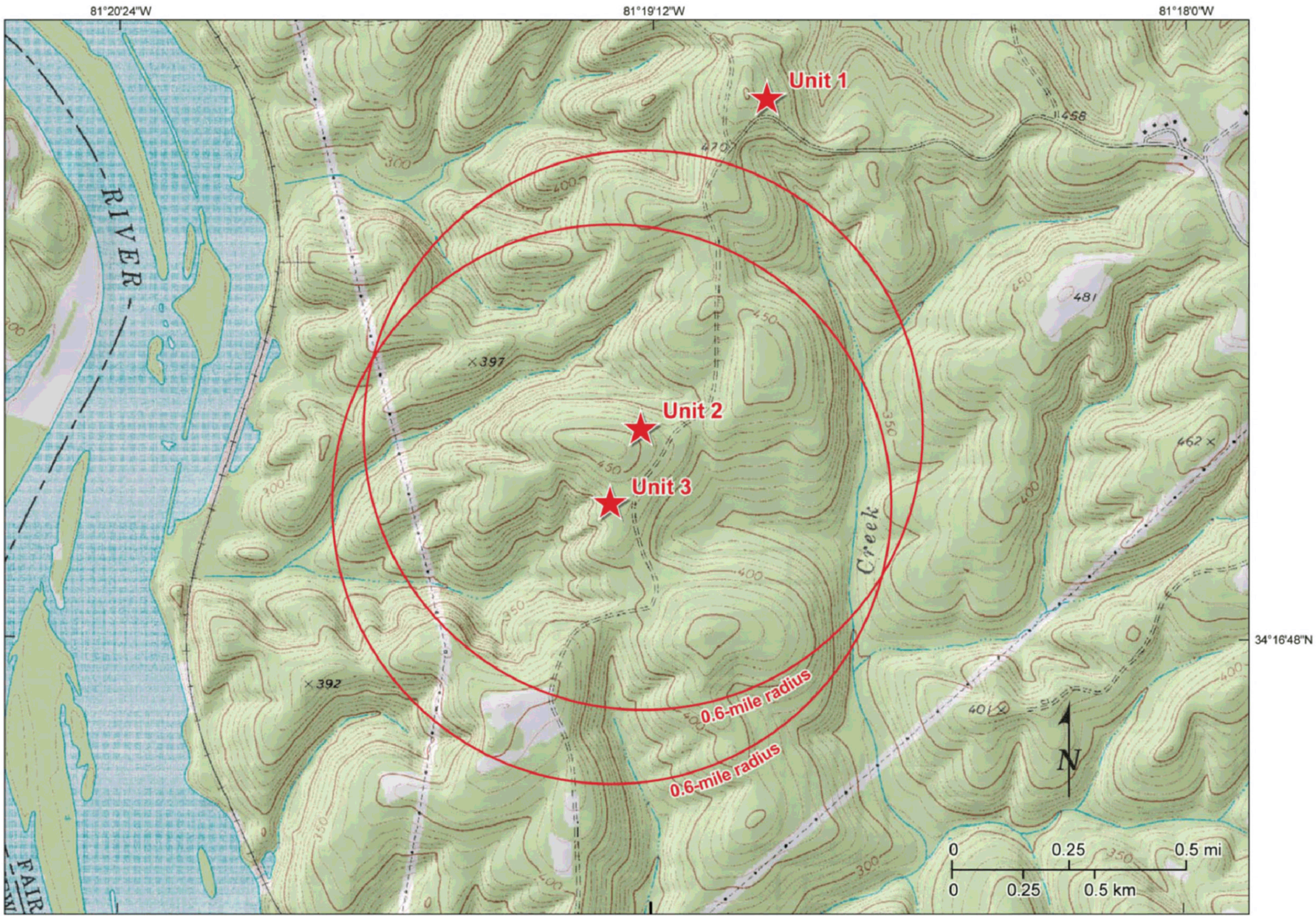
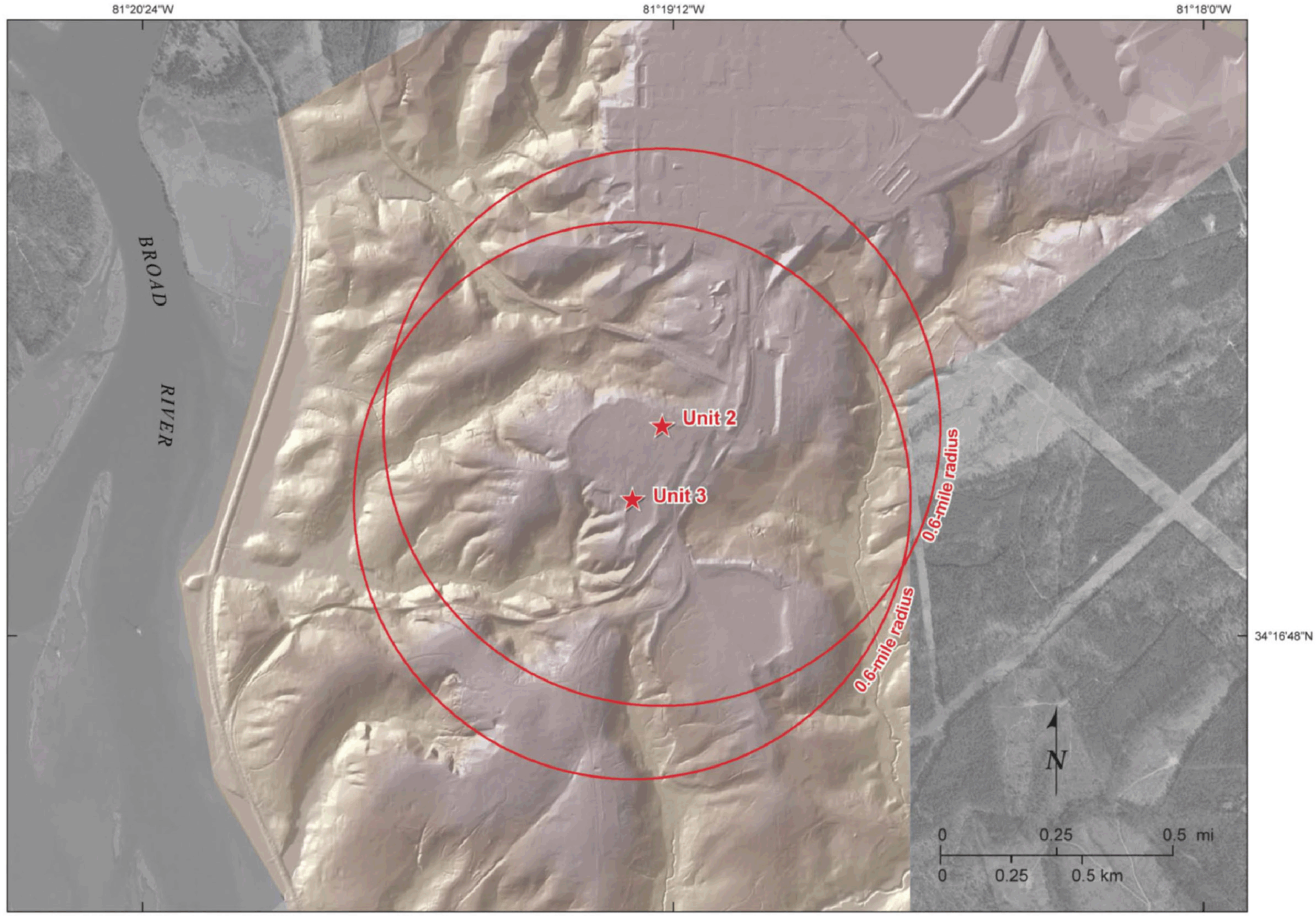


Figure 2.5.1-222 Site Topographic Map



Source: DEM (Digital Elevation Model) Hillshade generated from the contours of 2006 Glenn Associates Surveying, Inc. AutoCAD DWG Digital Data File.

Figure 2.5.1-223 Site Shaded Relief Map

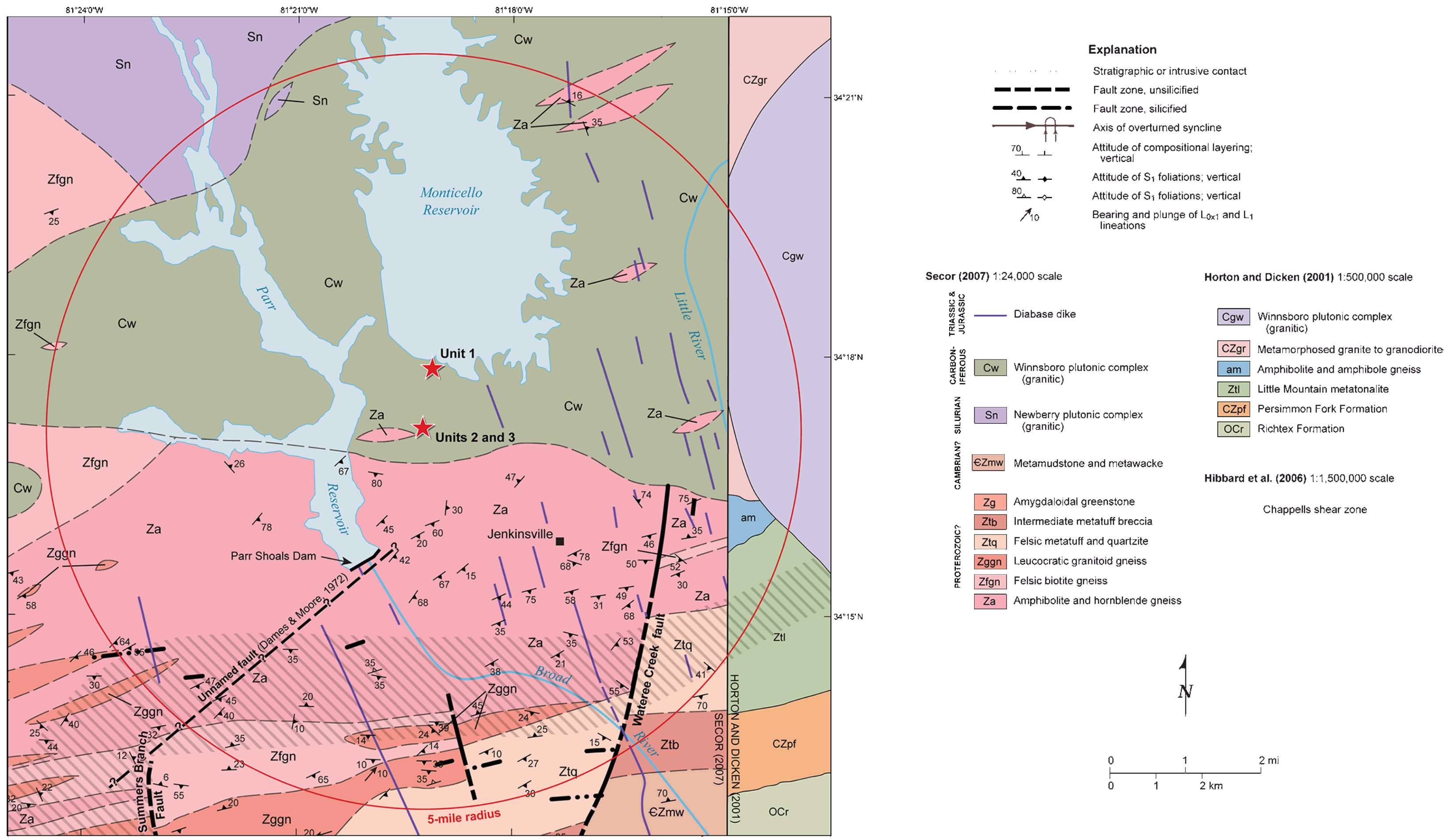


Figure 2.5.1-224 Site Area Geologic Map

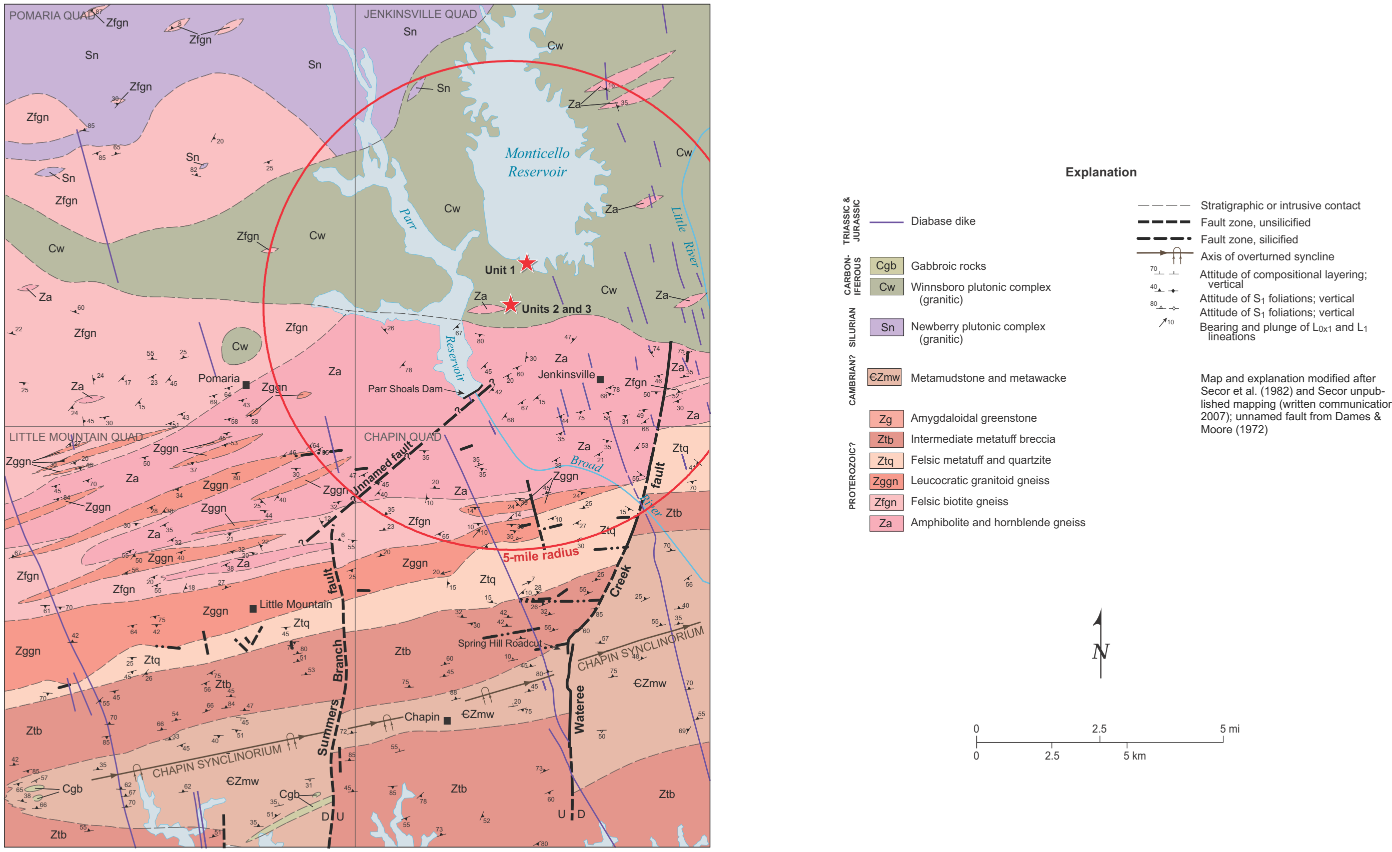


Figure 2.5.1-225 Geologic Map of the Jenkensville, Pomaria, Little Mountain and Chapin 7.5-Minute Quadrangles

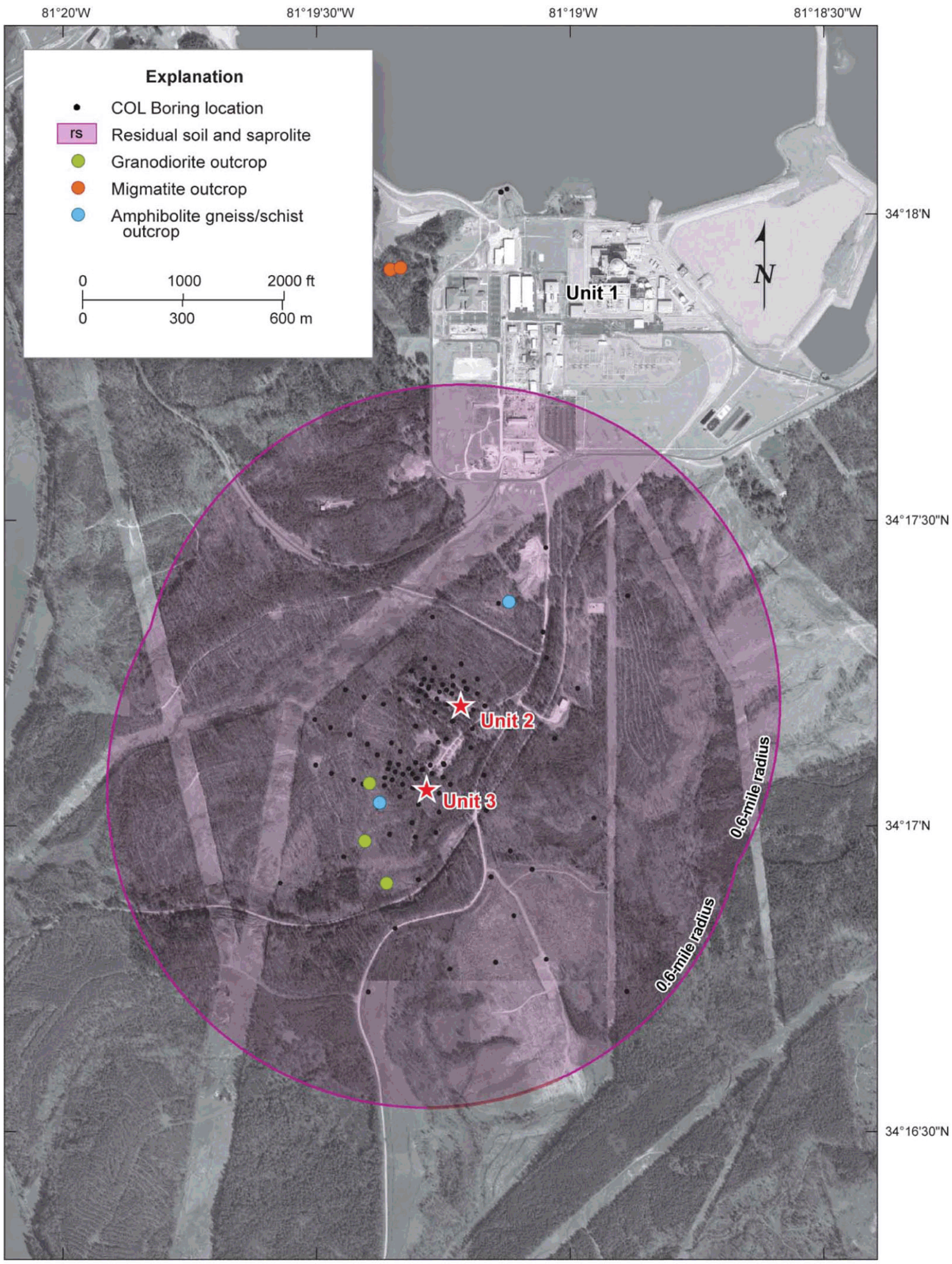


Figure 2.5.1-226 Map of Surficial Geology, Plant Layout and Borehole Locations for the Site Area

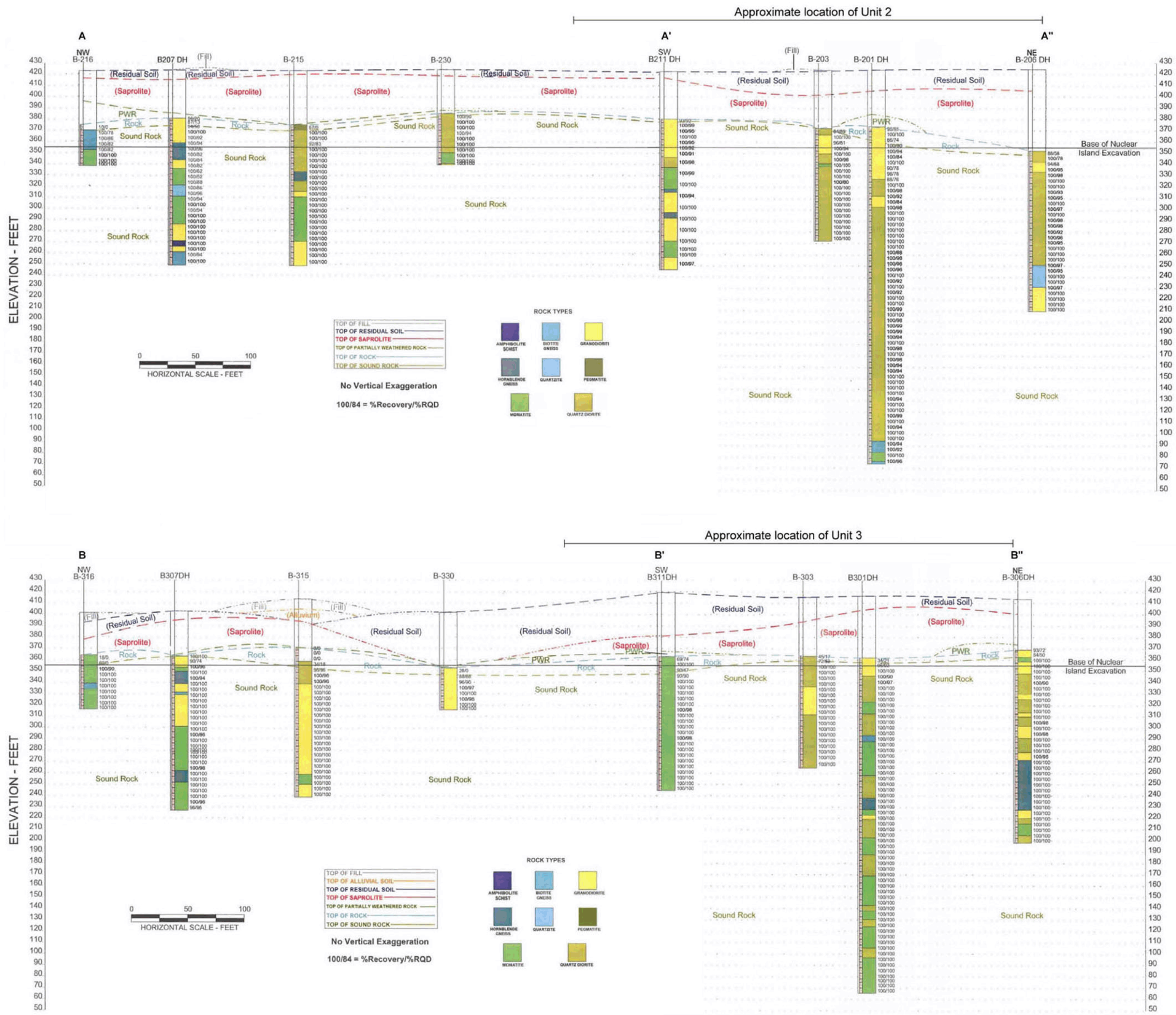


Figure 2.5.1-227 Geologic Cross Sections A-A" and B-B"

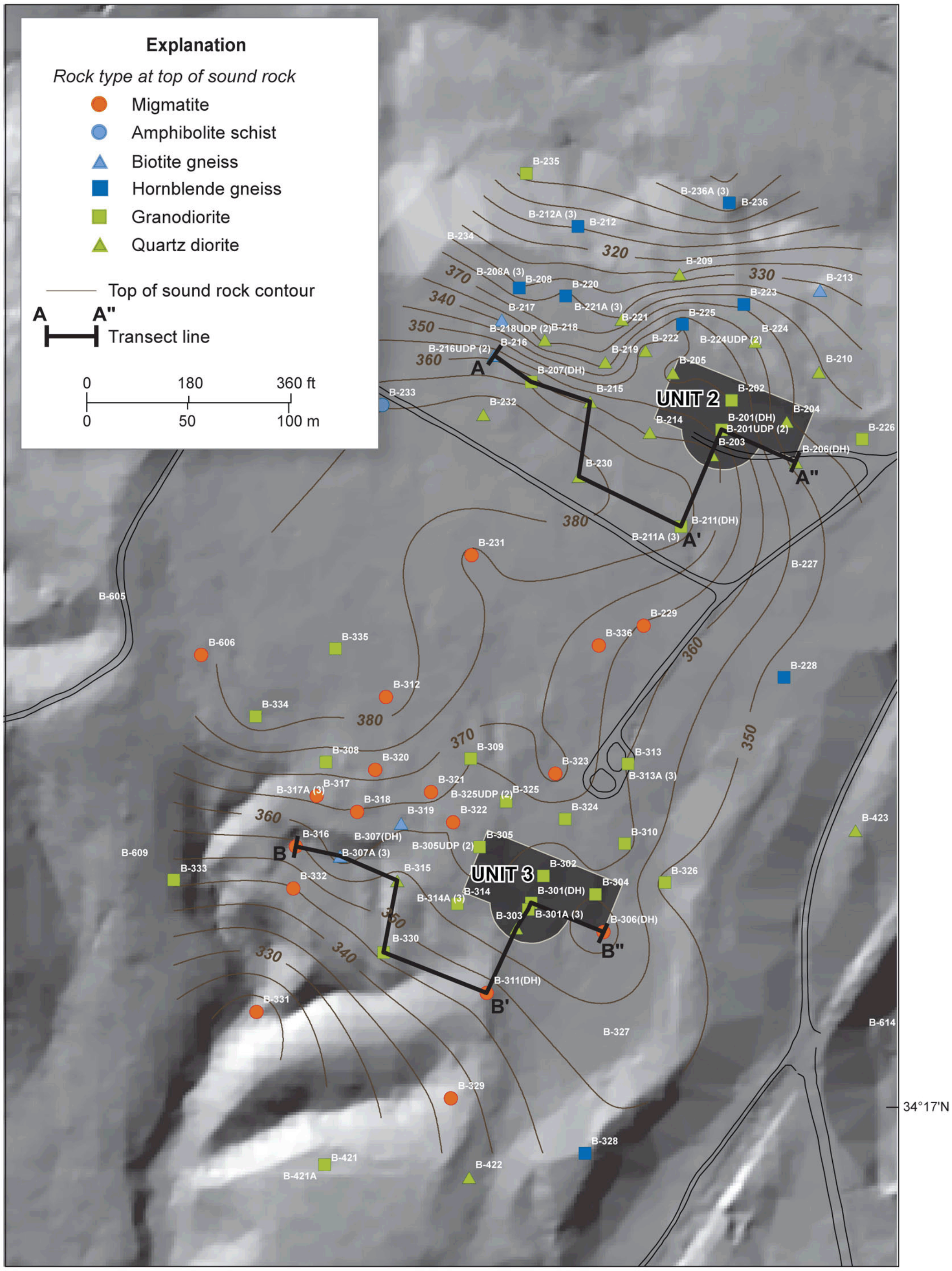


Figure 2.5.1-228 Contour Map of Sound Rock Surface at Units 2 and 3

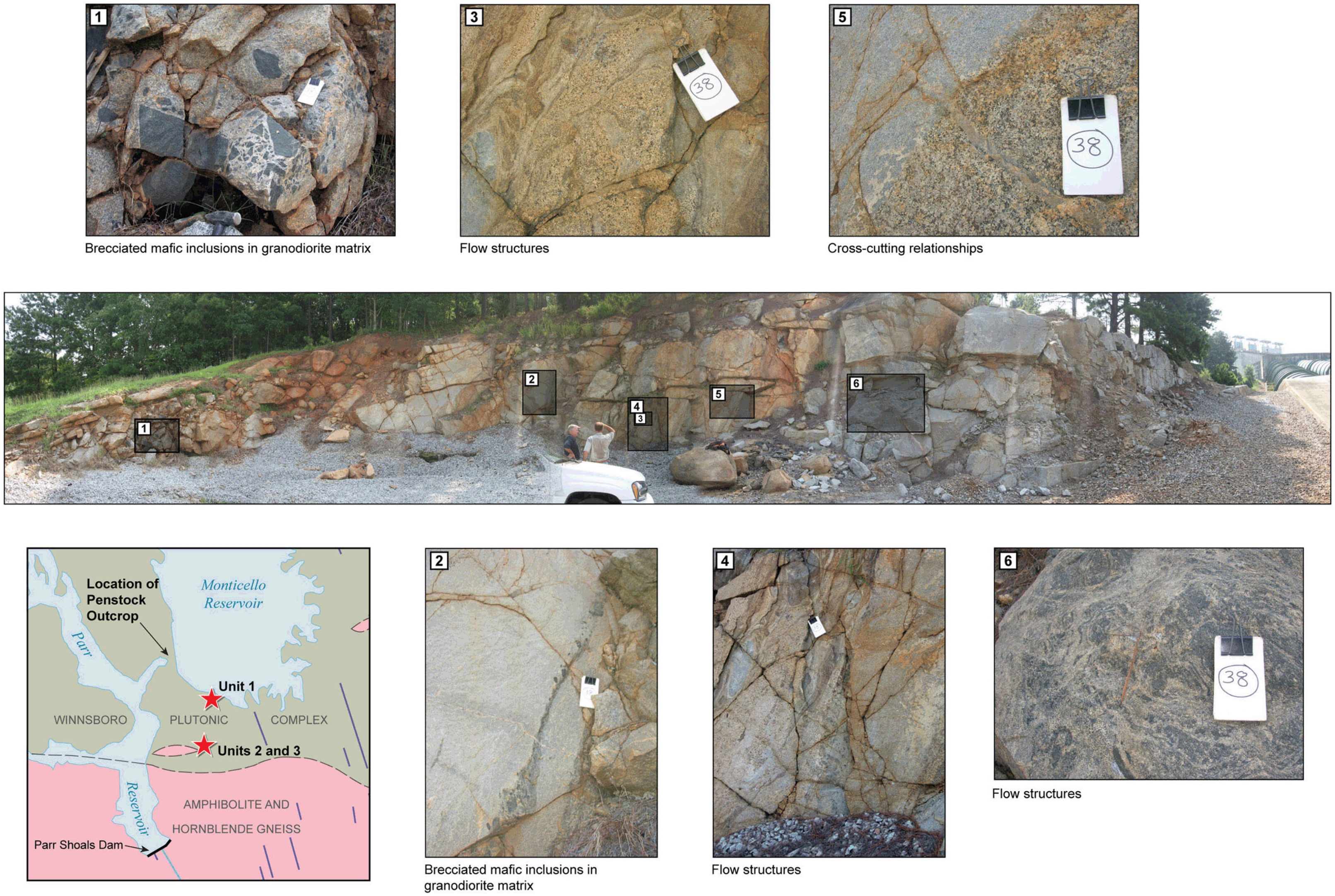


Figure 2.5.1-229 Photographs of Fairfield Pumped Storage Facility Penstock Outcrop

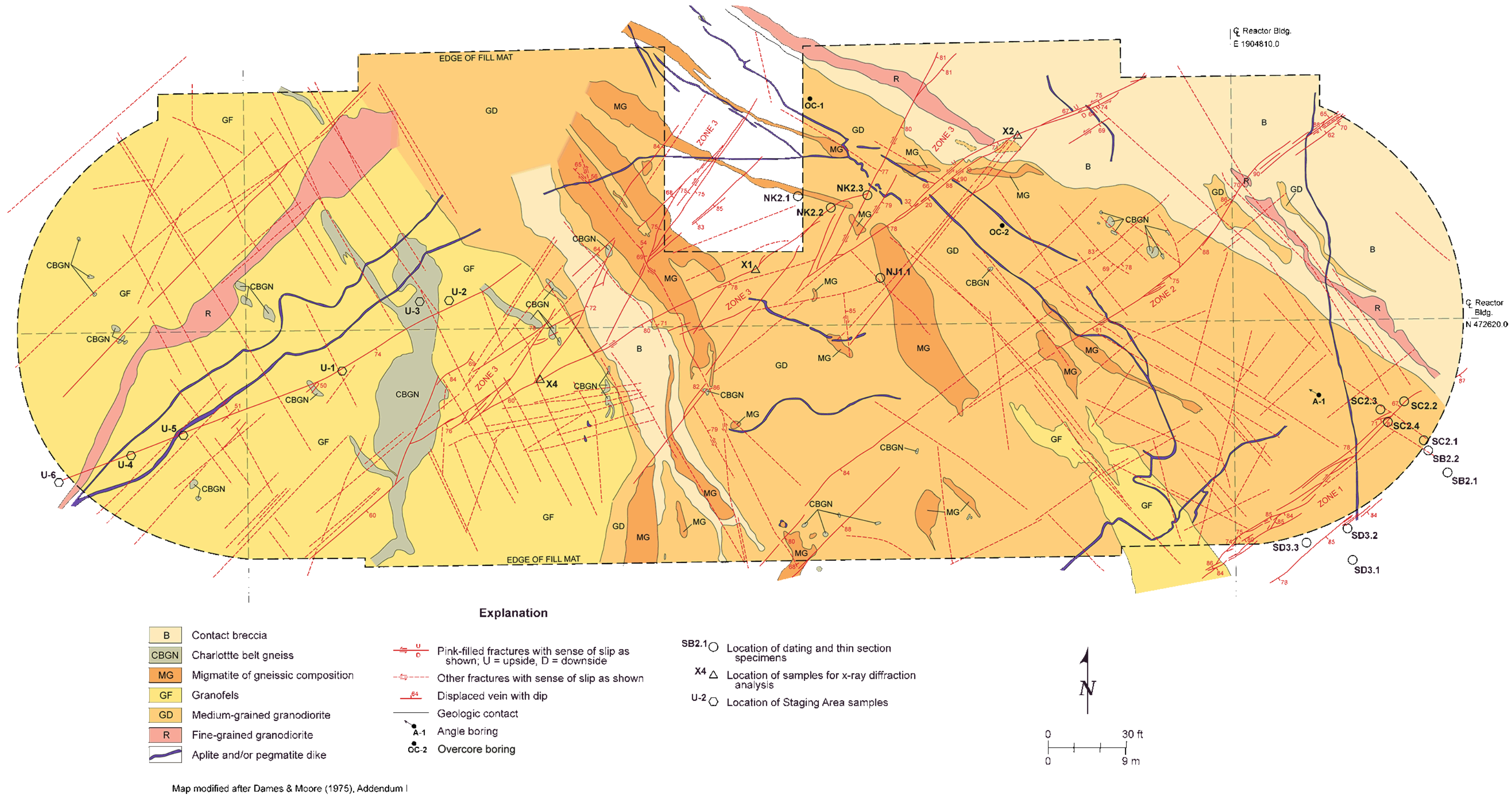


Figure 2.5.1-230 Structure Map of Unit 1 Excavation

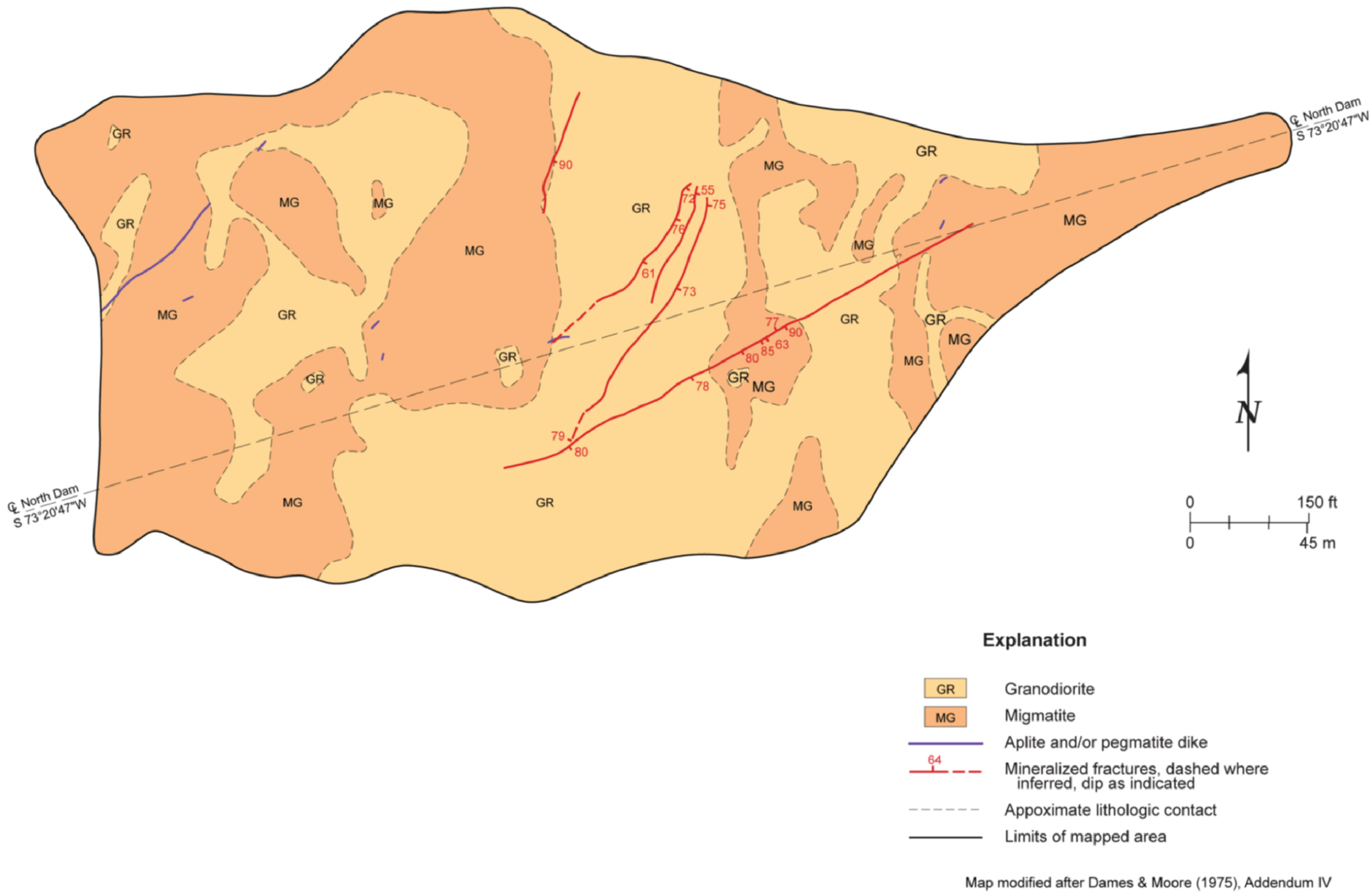


Figure 2.5.1-231 Structure Map of the Unit 1 Service Water Pond North Dam Site

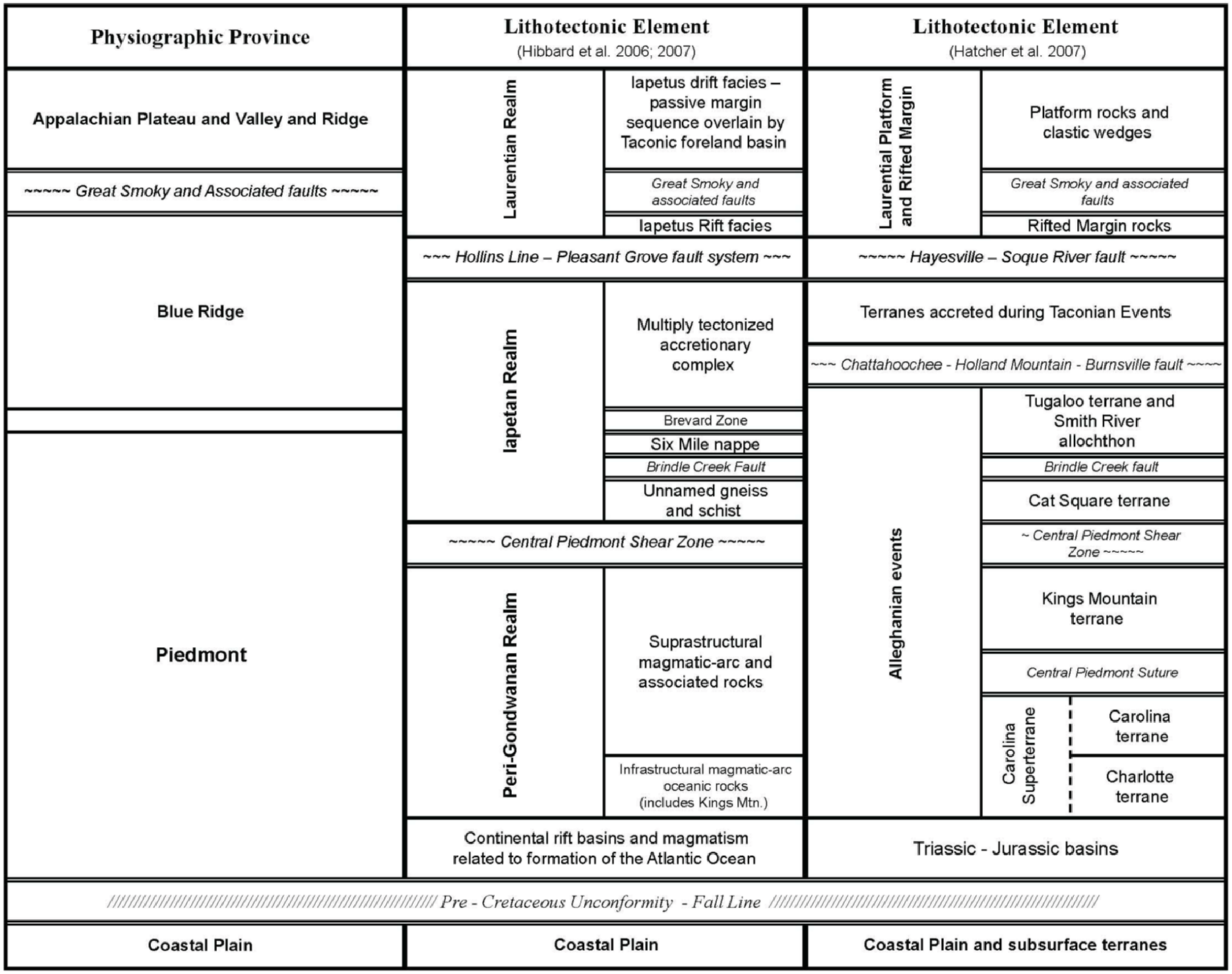


Figure 2.5.1-232 Correlations Between Physiographic Provinces and Recent Lithotectonic Classifications